HSR
HOCHSCHULE FÜR TECHNIK
RAPPERSWIL SWITZERLAND

UNIVERSITY OF APPLIED SCIENCES

Environment Mapping Self-Sustainable Robot

Bachelor Thesis

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emss
environment mapping
self-sustainable robot

Abstract

The aim of the emss *project is to tackle the problems of a self-sustainable, environment mapping robot in a bottom up approach. The major challenges imposed by such a mobile robot include the assembly of hardware, and more importantly the necessary software algorithms for localization, navigation, and discovery. Using ready-made hardware, much of the time-consuming electrical engineering problems have been avoided, allowing a strong focus on software. However, many hardware modifications have been undertaken to better suit the needs of the project. Building upon previous work achieved in our Semester Project, where a part of the necessary hardware and software was developed, the goal of this Bachelor Thesis is to create a basic environment map of obstacles and floor plan to the most accurate degree possible with the given hardware and data-sources, all while safely navigating and exploring the area. In addition, third-party applications, such as a Wireless Positioning System, must be able to connect to the* emss *framework and make use of the positioning data for their own purposes. The* emss *framework, consisting of a set of "hot-swappable" modules written in* C++, *provides an extensible design, which allows a wide array of functionality and supports different strategies for the same problem. The framework features a full blown multi-threaded software stack which allows the autonomous controlling and interfacing of the robot. The Hardware Abstraction Layer allows for the complete emulation of the underlying hardware, achieved largely by reverse engineering the behavior of the proprietary hardware. Safe navigation has been achieved by intelligently avoiding drops, obstacles, and walls. Furthermore, small areas can be autonomously navigated and mapped using different space-filling algorithms and map structures. Collaboration with third-party software has been realized with the Wireless Positioning System* PointZero *by automatically collecting necessary signal reference points. Other routine tasks, such as docking the robot on its docking station, have been implemented. In this paper we present an accurate description how these tasks have been realized, our assessment of the results, and insights into future improvements.*

Management Summary

Background

A household name for several decades now, the robot is a well studied creature. The field of robotics has been keenly researched and applied in the areas of engineering, mathematics, and even distant practices such as philosophy. However, most of the researched topics related to robotics still remain widely unresolved. After forty years of dedicated efforts on a global scale, robots still can just barely walk (Webb, 2001). The community is still trying to get off its feet to reach the breakthroughs needed to launch the new century as the *Century of Robotics*.

The *iRobot Create* is a special version of the popular vacuum cleaner robot called "*Roomba*". The *Create* is specifically designed for hobbyists and robot enthusiasts who wish to build on an existing platform instead of starting from scratch. Therefore it no longer contains a vacuum cleaner, but rather a cargo bay with an interface to the internal hardware. In our former Semester Project, a robotics framework was successfully realized based on the hardware provided by *iRobot*. The goal of the project was to create a self-sustaining robot which manages to navigate and explore its environment by itself without remote influence. This way it is able to return to a charging station if necessary in order to "to keep alive". The project focused on the development of software which reads data from the *iRobot*'s built-in sensors as well as from additional sensors, plans the robot's path based on the sensor data, and controls the robot's movement along this path. The software foundation required for these tasks was realized along with an in-depth look at theoretical solutions for the given problems. In addition, a large part of the theory was implemented and tested in both a partially-simulated environment as well as a physical hardware environment.

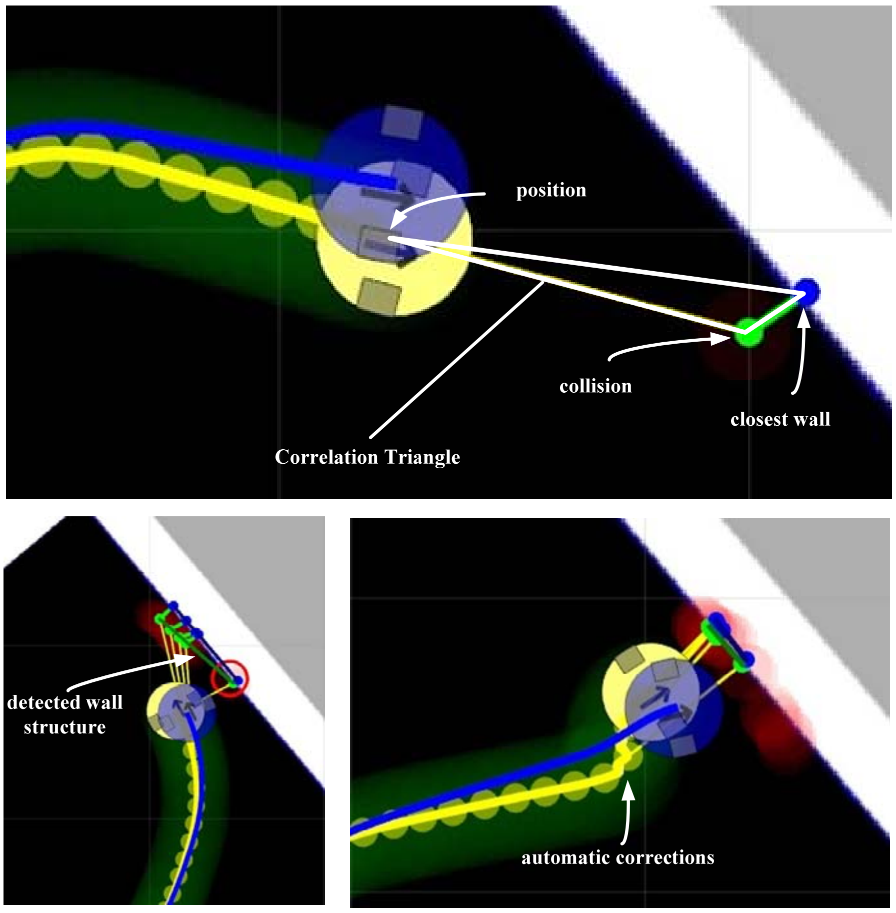
Along with the hardware, the resulting software proved stable and very functional. However, it lacked in functionality and refinement in the following areas: navigation, tracking, simulation, and diagnostics. The continued most serious hurdle throughout the project was the localization technique. This was tackled from a software perspective by first trying to make the robot move in a predictable fashion (such as along a curve), and then to track its position using the sensory data from the hardware controller. This proved to be a problem, as the localization over time became very inaccurate.

Assembled Robots

Approach

Before attacking the new hurdles presented by the project, the previous work was studied, assessed, and improved where appropriate. This included the refactoring and cleaning up of code in the software. In addition, modifications to the hardware were undertaken to make improvements to the overall design. Most notably, the original docking station was redesigned. The new docking station was fitted with small incisions in the casing to allow for secondary contact pieces to stick out and make contact with both the internal batteries and the onboard computer batteries. Next a simulated environment was realized which enables the emulation of the complete hardware. This was achieved largely by reverse engineering the behavior of the proprietary hardware. This functionality is essential for rapid development and testing, as it allows a quick and easy environment for seeing the results of an algorithm or task. In order to enable third-party applications to make use of the *emss* framework, a protocol was defined and implemented. This was realized using *UDP over IP* technology, and enabled messages to be remotely sent to and from the framework.

In addition, a new navigation module was implemented to allow an easier environment for which different tasks can be created in the system. This new module was based on previous work of the *emss* project called „System of Weights“ (Krüsi & Grob, 2008). The new navigation module is completely dynamic and reacts solely on the current perception on the state of the environment at that moment of time. Finally, an advanced tracker was implemented which is able to make small corrections in the localization error when deemed appropriate. To do this, the tracker makes use of a pre-loaded floor-plan in order to make correlations between its perceived virtual world and the physical world.

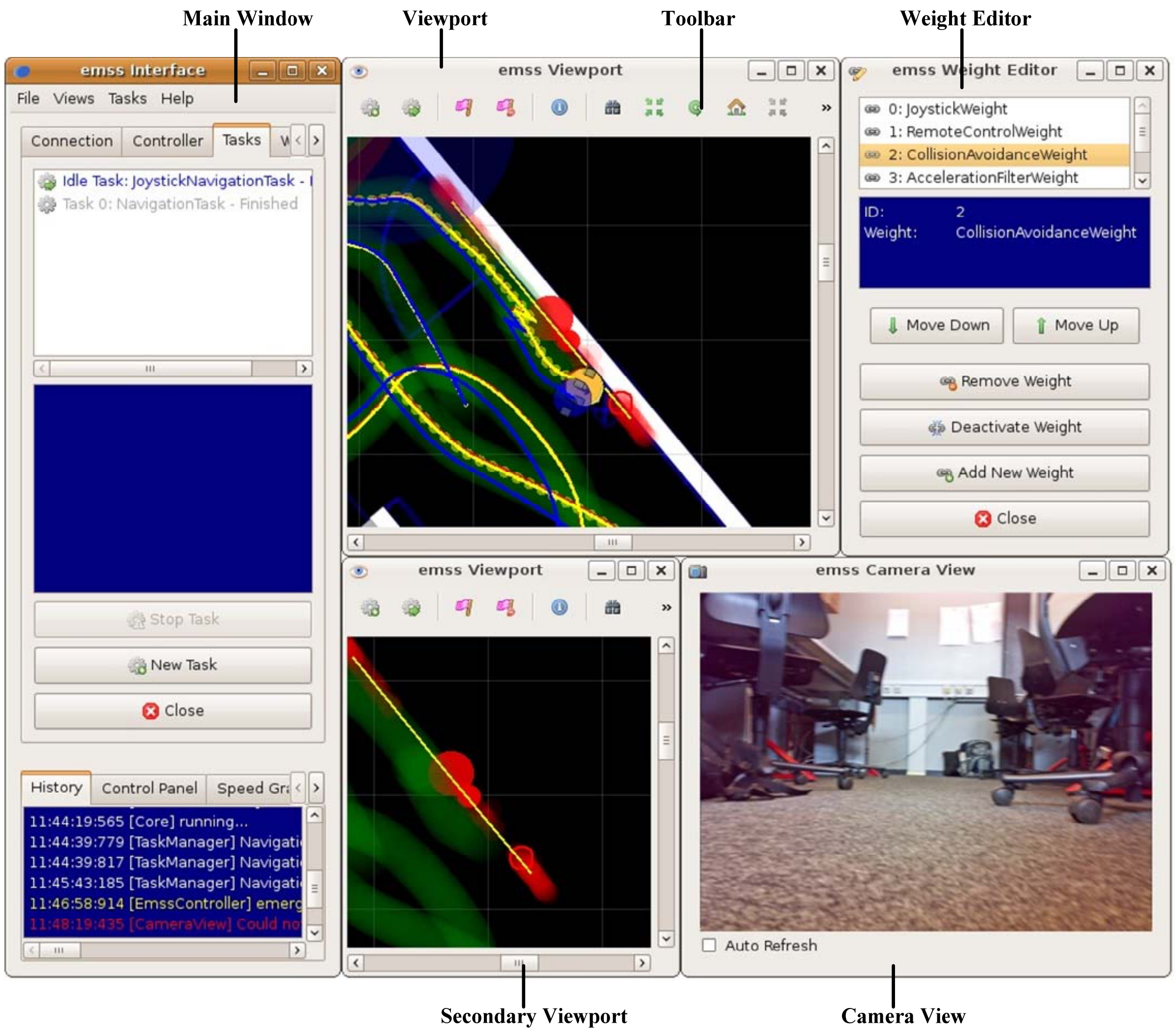


Tracker Performing Automatic Corrections

Results

The resulting *emss* framework, consisting of a set of "hot-swappable" modules written in *C++*, provides an extensible design, which allows a wide array of functionality and supports different strategies for the same problem. The framework features a full blown multi-threaded software stack which allows the autonomous controlling and interfacing of the robot. All important modules required for the navigation, maneuvering, and safe controlling of the robot have been implemented. In addition, the simulated environment yields an accurate, feature-complete, and flexible workspace for testing the software.

Safe navigation has been achieved by intelligently avoiding drops, obstacles, and walls by constantly generating and updating the various supporting data structures. Furthermore, small areas can be autonomously navigated and mapped using different space-filling algorithms and map structures. Other routine tasks, such as docking the robot on its docking station, have been implemented and tested. Collaboration with third-party software has been realized with the Wireless Positioning System *PointZero* by automatically collecting the necessary signal reference points, called fingerprints. A rich graphical user interface is provided by the framework, allowing user interaction with all the different modules within.



Idle Task: JoystickNavigationTask - I
Task 0: NavigationTask - Finished

```
11:44:19:565 [Core] running...
11:44:39:779 [TaskManager] Navigati
11:44:39:817 [TaskManager] Navigati
11:45:43:185 [TaskManager] Navigati
11:46:58:914 [EmssController] emerg
11:48:19:435 [CameraView] Could no
```

0: JoystickWeight
1: RemoteControlWeight
2: CollisionAvoidanceWeight
3: AccelerationFilterWeight

ID:	2
Weight:	CollisionAvoidanceWeight

Interface Application with Multiple Viewports and Views

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1 Introduction

What happened to the robotic revolution? Looking back at old technology and mechanics magazines from the 1950's, one cannot help but muse at the wild expectations people had regarding the future of robots. Often portrayed was a bizarre mix of people and machines, living together in a society with the robot as man's new best friend. Some went to the extent to predict a new race of slaves which would serve mankind by the 1960's – as did the 1957 *Mechanix Illustrated* article *You'll own Slaves by 1965* (Binder, 1957). The predictions from last century are far from reality. Not only has the progression of the robot been much slower than expected, traversing a very subtle path, but also its role in society has been completely redefined from the original conceptions. Instead of serving us breakfast in the morning, cleaning our living space during the day, and taking our hat and coat from us when we return in the evening, as depicted in the 1940 film *Leave It To Roll-Oh* (Handy, 1940), robots have found their birthplace in the factory. There they toil away all day, and sometimes night, performing mundane routine tasks over and over. Looking at such a machine, with its precise movements and repetitive activities, its hard edges and vacuous appearance; it has little resemblance of ourselves. Is not the robot supposed to be mankind's birth-child?

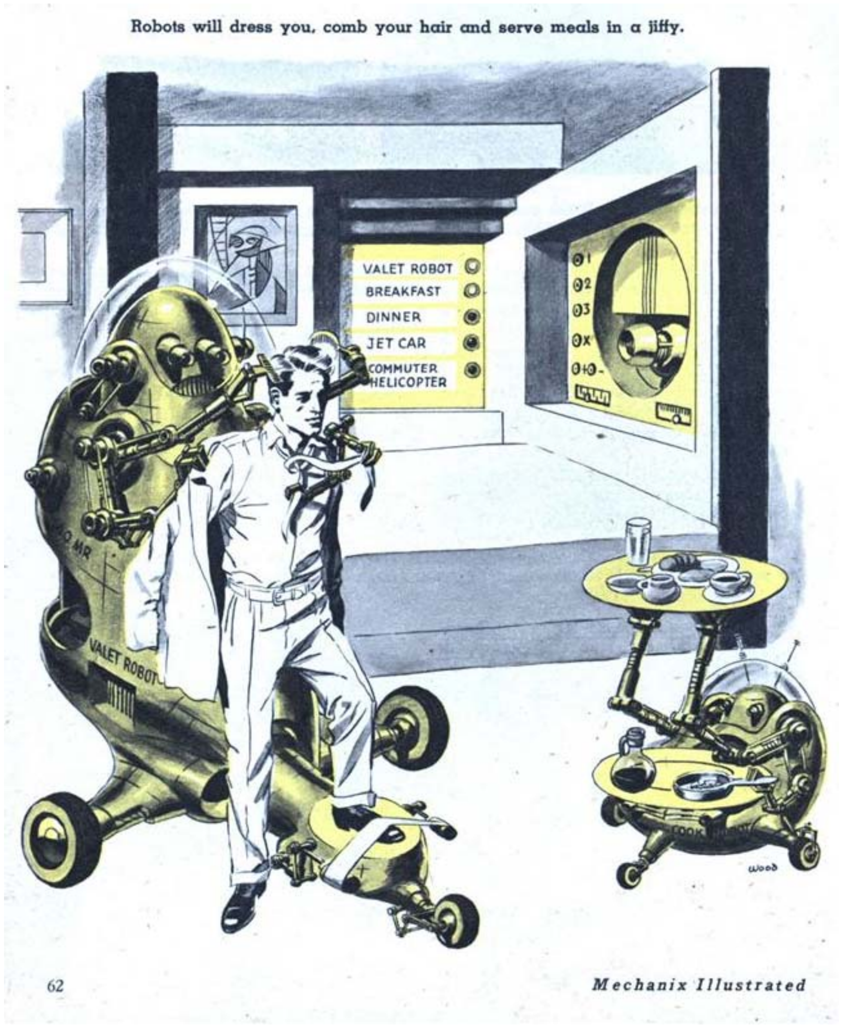

Figure 1-1: Illustration in "You'll own Slaves by 1965", Mechanix Illustrated, 1957

The robotic revolution has not yet undergone in the scale and realm so many thought it would. What then has kept it? Does the robot just need more time to develop and grow, or is our concept of the robot fundamentally flawed? A long standing problem in the field of robotics is the perception of the environment. To us humans, this is a trivial task. We see, hear, and touch our environment around us, combining these senses to form a somewhat indescribable organic perception of the world (Thorpe, Clatz, Duggins, Gowdy, MacLachlan, & Ryan, 2001). It is here, at one of the most essential parts of our defining quality, where the robot has stumbled. The ability to perceive the environment and comprehend its implications is the first step in actively being a part of it. Only then can a robot take it's prematurely crowned role of being mankind's helper. For thousands of years we have tried to understand our perceptions, starting with primitive cave drawings and slowly mastering perception with realistic paintings. However, teaching robots to understand perception has proven very difficult, even though a robot can easily imitate its environment through the form of radar, sonar, lidar, or visual images.

After forty years of dedicated efforts on a global scale, robots still have trouble recognizing our face, they move carefully through our world with a slow pace, and are shy to interact. They just barely have learned how to walk (Webb, 2001). In many ways, the robot is still a toddler – unable but eager to explore the world. However, they are growing faster and faster. Each year we are introduced to new robots that are superior in perception and mobility. Each year new robots join our daily lives in some fashion or another. Our question remains; when will we be able to christen this century as the *Century of Robotics*?

2 Project Definition

2.1 Task

The concrete goal is to create a basic environment map of obstacles and floor plan to the most accurate degree possible with the given hardware and data-sources while safely navigating and exploring the area, allowing third-party applications (such as a WPS) to use the localization data for their own purposes. Data Sources for localization are include feedback from wheel servos, emulated movement through space, infra-red sensor and a pre-rendered floor plan of room structures without obstacles (hallways, rooms, doors, stairs).

The following subtasks are defined:

1. Safe-navigation within a simple room
2. Basic environment mapping skills
3. Basic localization using different data-sources and hardware
4. Protocol for third-party application tasks
5. Assembly of additional units

Delivery documents:

1. Installation Guide, if relevant.
2. Complete compiler-ready source code, including program documentation as well as download-ready zip file with executable binaries.
3. Technical Report and Software-Engineering Documentation, including High-Level Programmer Documentation.
4. Additional documents according to requirements of the Department of Computer Science.

2.2 Details

1. Pre-requisites:
   a. The physical environment must contain only static obstacles. Moving objects will not be distinguished from still obstacles on the environment map, however the robot will attempt to avoid such collisions if possible.
   b. Obstacles within the physical environment must portray a certain degree of simplicity in structure. Complex and intricate structures, such as many chair-legs, cables and wiring, et cetera should not be present or blocked off.
   c. The physical environment must be a closed off region. Doors to other areas must be closed.
   d. The test environment consists of the second-floor of building 6 at HSR including hallways, stair-drops, doorways, corners, and some large obstacles. A live demonstration will be given of the robot's functionality in such a test environment.
2. Agile development will be practiced, and where appropriate with Unit-Tests. Value is placed on well-tested software with easy installation.
3. A User-Manual is only required in justified cases.

4. For a successful project completion, 12 ECTS points, requiring at least 360 work hours-per-person, will be awarded.

2.3 Conditions, Infrastructure, Deadlines und Assessment

1. Conditions Hardware/OS:
    a. *iRobot Create* Hardware
    b. x86 Computer
    c. OS: *Windows* / *Linux*
2. Software:
    a. *GNU C / C++*
    b. *Qt* 4.5
    c. *Eclipse* IDE
    d. *GNU GDB*
3. Deadlines und Assessment: According to requirements at `www.i.hsr.ch`.

3 Current Situation

3.1 Robotics Field

A household name for several decades now, the robot is a well studied creature. The field of robotics has been keenly researched and applied in the areas of engineering, mathematics, and even distant practices such as philosophy. Mobile robots, those which are movable and disjoint from their environment, have been especially studied by both the research community and hobbyists. There remain few untouched topics revolving around the problematics of such robots. However, most of the researched topics related to robotics still remain widely unresolved. The community is still trying to get off its feet to reach the breakthroughs needed to launch the next generation of robots and artificial beings.

The *iRobot Create* is a special version of the popular vacuum cleaner robot called *Roomba*. The *Create* is specifically designed for hobbyists and robot enthusiasts who wish to build on an existing platform instead of starting from scratch. Therefore it no longer contains a vacuum cleaner, but rather a cargo bay with an interface to the internal hardware. A small niche of *iRobot Create* hobbyists have strapped a full-blown laptop computer to the *Create* (Jonathan, Jonathan, Arvind, Omair, & Sukhatme, 2008), however, not many of these projects have been developed to a mature state. Because of the relatively young age of the *Create* product, there is little code available to kick start interested enthusiasts, hobbyists, or researchers with their project. The same applies for design concepts, where the literature revolving around *iRobot Create* projects widely varies in their opinions of design advantages and disadvantages (Kostandov, et al., Robot Gaming and Learning using Augmented Reality, 2007) (Martinez, Haverinen, & Roning, 2008) and does not provide clearly extractable strategies.

3.2 Previous Development

In our former Semester Project, a robotics framework was successfully realized. Based on the above mentioned ready-made platform provided by *iRobot,* the goal of the project was to create a self-sustaining robot which manages to navigate and explore its environment by itself without remote influence. This way it is able to return to a charging station if necessary in order to "keep alive". The project focused on the development of software which reads data from the *iRobot*'s built-in sensors as well as from additional sensors, plans the robot's path based on the sensor data, and controls the robot's movement along this path. The software foundation required for these tasks was realized along with an in-depth look at theoretical solutions for the given problems. In addition, a large part of the theory was implemented and tested in both a partially-simulated environment as well as a physical hardware environment.

3.2.1 Hardware

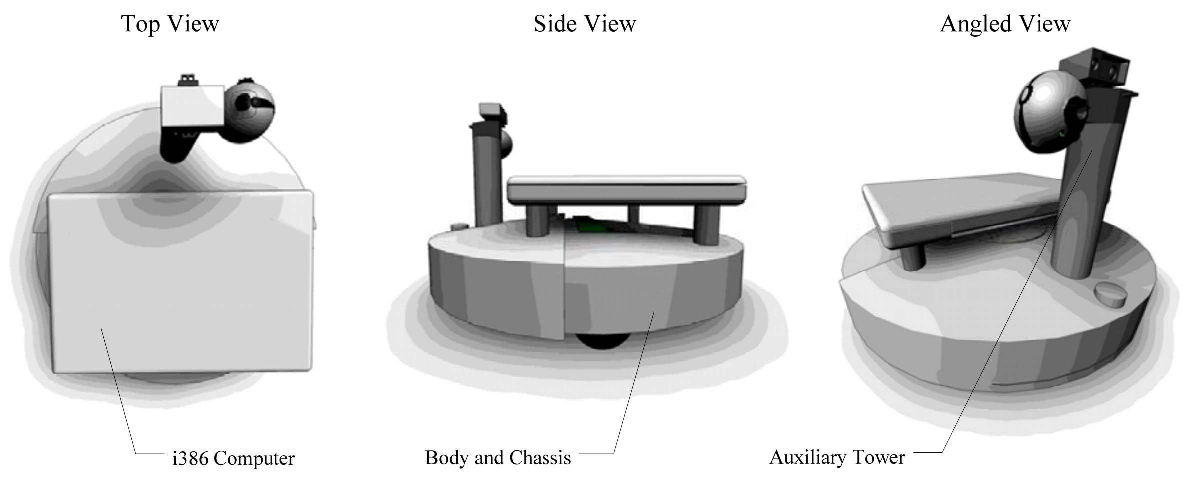

Figure 3-1: Original Design Concept

Based on a concept designed with a CAD program, the different components necessary were purchased and assembled. The final assembly almost realized the original design except for the auxiliary tower which was omitted. The mobile hardware of *emss* robot consisted of the ready-made *iRobot Create* platform and a 12-inch i386 laptop computer. The immobile hardware consisted of a modified docking station which allows for the charging of both the wheel drive batteries as well as the laptop batteries.

3.2.2 Software

The underlying groundwork for the *emss* framework was implemented. This included a multi-threaded system in which different modules[1] interacted with each other to perform navigational tasks. A large effort was put in developing theoretical solutions which could be applied to problems, or hurdles, within the framework, such as navigation by splines. A cache of utility classes, such as different mathematical structures, was implemented into the form of a powerful robotics library. This library extended to provide a set of GUI widgets which provided a useful interface to the software.

3.2.3 Results and Problems

Throughout the project the assembled robot proved robust and very functional. Complex movement through space was realized using the onboard controller. In addition to the robot itself, a charging station was modified to allow the charging of both the drive batteries and the laptop computer. However, the construction presented some problems. The charging station is quite a steep climb to dock[2], which caused trouble for the robot to dock at full payload. Additionally, the added contact points for the computer power lines were not very sturdy, and after several docks they tended to loosen and the contact quality was degraded.

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[1] At that time, modules where actually called components.
[2] About 10%.

The resulting software proved stable and very functional. However, it lacked in functionality and refinement in the following areas: navigation, tracking, simulation, and diagnostics. The continued most serious hurdle throughout the project was the localization technique. This was tackled from a software perspective by first trying to make the robot move in a predictable fashion (such as along a curve), and then to track its position using the sensory data from the hardware controller. This proved to be a problem, as the localization over time become very inaccurate due to the vague information the hardware provided.

4 Strategy

4.1 Objective

4.1.1 Concrete Goal

The concrete goal of the *emss* project is for the robot to perform a simple mapping of the environment and its contained obstacles and floor plan to the most accurate degree possible. This must be accomplished with the given hardware and data-sources. The robot should be able to navigate safely, exploring its unknown environment. In addition, third-party applications, such as a Wireless Position System, must be able to use the localization data for their own purposes.

To realize such a goal, the maneuvering and localization (tracking) of the robot must be realized in a fashion which suites the needs of both the internal processes of the robot, but also those of the external third-party applications. This means an implementation must consider the effects it has on other aspects of the project, so that in the end they can all come together to perform the specific task.

4.1.2 Pre-Requisites

In order to reduce the complexity implied by the above stated goal, some pre-requisites and restrictions have been defined.

First, the physical environment must not contain any dynamic obstacles, such as moving people. This restriction exists because of the additional complexity required to distinguish between static obstacles and dynamic obstacles. Thus Moving objects will not be distinguished from static obstacles on the environment map, however the robot will attempt to avoid such collisions if possible. Furthermore, Obstacles within the physical environment must portray a certain degree of simplicity in structure. Complex and intricate structures, such as many chair-legs, cables and wiring, et cetera, should not be present or be blocked off.

Finally, the physical environment must be a closed off region. Doors to other areas must be closed. Environments that feature entrances to further regions are undesirable because they not only significantly increase the complexity of the room structure, but also create a tangible risk of trapping the robot in one of these sub-rooms.

4.1.3 Test Environment

The test environment consists of, but not exclusively, the second-floor of building 6 at the *University of Applied Sciences Rapperswil*. This room provides hallways, stair-drops, doorways, corners, and some large obstacles. Another test environment is the use of cardboard-boxes to form different simple-shaped rooms which have a smaller scale.

4.2 Requirements Specification

4.2.1 Requirements

The following requirements have been carefully evaluated and chosen to accompany the *emss* project. They are based on previous experience with the hardware and the needs presented by the project goal.

4.2.1.1 Safe-Navigation within a Simple Room

First-things-first, it is important to consider the robots safety throughout its operation. It must be able to navigate in a simple room safely, meaning that it typically avoids obstacles it can see and almost certainly avoids from causing any serious damage, such as driving down stairs or a drop. When the robot detects such an obstacle, it should be able to assess the situation and appropriately react to it.

4.2.1.2 Basic Environment Mapping Skills

When the robot is placed in an unknown environment, it should be able to navigate and build up the basic structure of the room based on the sensory data. When the entire structure has been determined, the robot should then cover the rest of the unknown room to create a map of the environment and the obstacles contained within.

4.2.1.3 Basic Localization using Different Data-Sources and Hardware

Based on the different data sources (feedback from servos, infra-red sensors, and possible the floor-plan of the environment), the software should be able to determine its current position relative to the starting position at any time.

4.2.1.4 Protocol for Third-Party Application Tasks

Third-Party software should be able to utilize the *emss* framework for it's own purposes. For this reason a protocol must be defined for which positioning data can be retrieved remotely.

4.2.1.5 Assembly of Additional Units

A second-generation robot shall be constructed based on the design of the original hardware. This includes the modifications required on both the hardware chassis as well as the docking station, along with the mounting of the laptop unit.

4.2.1.6 Additional and Optional Features

The following requirements are optional and may be implemented if feasable.

Self-Charging Algorithm

The robot shall be able to detect the docking station and autonomously dock itself on it. This must be achieved using the built-in infra-red signals provided by the docking station.

Self-Healing Tracker

Where the localization has become corrupt or inaccurate, the self-healing tracker shall detect these errors and correct them, providing more accurate information about the robots whereabouts.

Publishing of the Project to the Robotics Community

The *emss* project is to be published as an open source project. People who wish to use the software, make modifications, and redistribute it, must be supported in doing so. To enable this, the appropriate license must be applied to the source code and made available on the internet.

4.2.2 Use Case

The following use cases have been defined to accompany the requirements.

UC1: Safe Navigation

Goal	Robot must safely navigate through an unknown environment without touching the wall or falling down a sudden drop.
Preconditions	Batteries are fully charged.
Annotation	This use case takes effect with all other use cases.
Standard Procedure	1. User places robot in an unknown environment. 2. User starts robot, it will drive randomly around. 3. Robot avoids collisions and drops. 4. Task is finished when user stops it.

Table 4-1: UC1 Safe Navigation

UC2: WallFollower

Goal	Robot searches wall and follows it until it reaches the starting point again.
Preconditions	*UC1: Safe Navigation* is implemented. Room is closed (no open doors). Room features flat and smooth wall surfaces.
Standard Procedure	1. User places robot in an unknown environment. 2. User starts robot with the wall follower command. 3. Robot searches for a wall. 4. Task is finished when the whole structure of the room is known and the robot reaches its start position.

Table 4-2: UC2 WallFollower

UC3: Exploration

Goal	Robot explores an unknown environment, fully covering the unexplored surface.
Preconditions	*UC1: Safe Navigation* is implemented. *UC2: WallFollower* is implemented.
Standard Procedure	1. User places robot in an unknown environment. 2. User starts robot. 3. Robot maps the structure of the room. 4. Robot explores the whole room, until each area has been covered. 5. Task finishes when the entire environment is known.

Table 4-3: UC3 Exploration

UC4: Fingerprinting

Goal	Automatically collect wireless signal fingerprints with current positioning data.
Preconditions	*UC1: Safe Navigation* is implemented. *UC2: WallFollower* is implemented. *UC3: Exploration* is implemented. Wireless Positioning Software (*PointZero*) is running.
Standard Procedure	Standard procedure if a map of the actual room is available: 1. User starts GUI and loads actual Map and positions the robot on the map. 2. User sets path (navigation points) for which the robot must drive. 3. Third-party software connects to *emss* and starts the fingerprinting task with the desired settings. 4. Robot drives along the navigation points and stops at each defined interval to gather a fingerprint. 5. Task is finished when robot reaches the last point on his path.
Alternate Procedure	If no actual map of the current room is available, this alternate procedure will be processed: 1. User starts GUI manually enters the actual GPS coordinates of the robot. 6. Third-party software connects to *emss* and starts the fingerprinting task with the desired settings. 2. Robot explores the unknown environment and stops after each defined interval to gather a fingerprint. 3. Task is finished when the whole area is explored.

Table 4-4: UC4 Fingerprinting

4.3 Approach

Before attacking the new hurdles presented by the project, first the previous work is to be studied and improved where appropriate. This includes the refactoring and cleaning up of code in the software. In addition, modifications to the hardware will be undertaken to make improvements. The next most important step is to fully implement a simulated environment for which testing can be done in. This will greatly reduce the testing time required when developing new algorithms.

Next the navigation module in the software will be extended to allow an easier environment for which different tasks can be created in the system. This new module will be based on previous work of the *emss* project called „System of Weights“ (Krüsi & Grob, 2008) where the implementation will follow the described theory.

To be able to let third-party software make use of the *emss* framework, a protocol will be defined and implemented. This will be realized either with *UDP* or *TCP* technology, and will enable messages to be remotely sent to and from the robot, as well as locally between the framework and other software.

In order to safely navigate through a room, the implemented System of Weights will be used. This system will have the advantage of allowing different weights to be flexibly defined and configured which best suite the task or environment. Furthermore, the individual weights will be implemented in such a fashion that they are most disjoint from each other, providing a flexible system.

An important part of the framework is the localization of the robot. It will be attempted to implement improved trackers which perform localization based on different input sources. Some might even combine the different sources for the best judgment. In addition, if the information about the environment is available, such as the floor-plan, it will be attempted to implement a tracker that can detect features it sees with its bare sensors (infra-red) and map them to the features described by the floor-plan. The difference can then be used to calculate the error and perform better localization.

4.3.1 Milestones

Our approach has lead us to many different tasks and goals. These are defined by the following milestones:

4.3.1.1 Milestone 1: Week 3

1. Preliminary work
2. Implementation of simulated environment
3. Implementation of System of Weights
4. Realization of the Remote Protocol

4.3.1.2 Milestone 2: Week 6

1. Completion of Prototype I
2. Safe navigation within a closed, simple room
3. Implementation of basic environment mapping functions
4. Release of *emss* framework v1.1

4.3.1.3 Milestone 3: Week 9

1. Completion of Prototype II
2. Realization of localization using different data sources
3. Release of *emss* framework v1.2

4.3.1.4 Milestone 4: Week 12

1. Successful completion of test scenario

4.3.1.5 Milestone 5: Week 14

1. Code-freeze

4.3.1.6 Milestone 6: Week 16

1. Completion of the project and documentation
2. Delivery of all related work, writing, code and hardware
3. Release of *emss* framework v1.3

5 Hardware

The *emss* hardware is a simple set of ready-made components, deliberately chosen to avoid many of the tedious electrical engineering problems presented in the field of robotics. All the components are plug-and-play and off-the-shelf available as consumer electronics. This chapter gives a short overview of the hardware schematics which make up the *emss* robot. A deeper, more detailed look at the hardware can be found in our previous writings (Krüsi & Grob, 2008).

5.1 iRobot Create

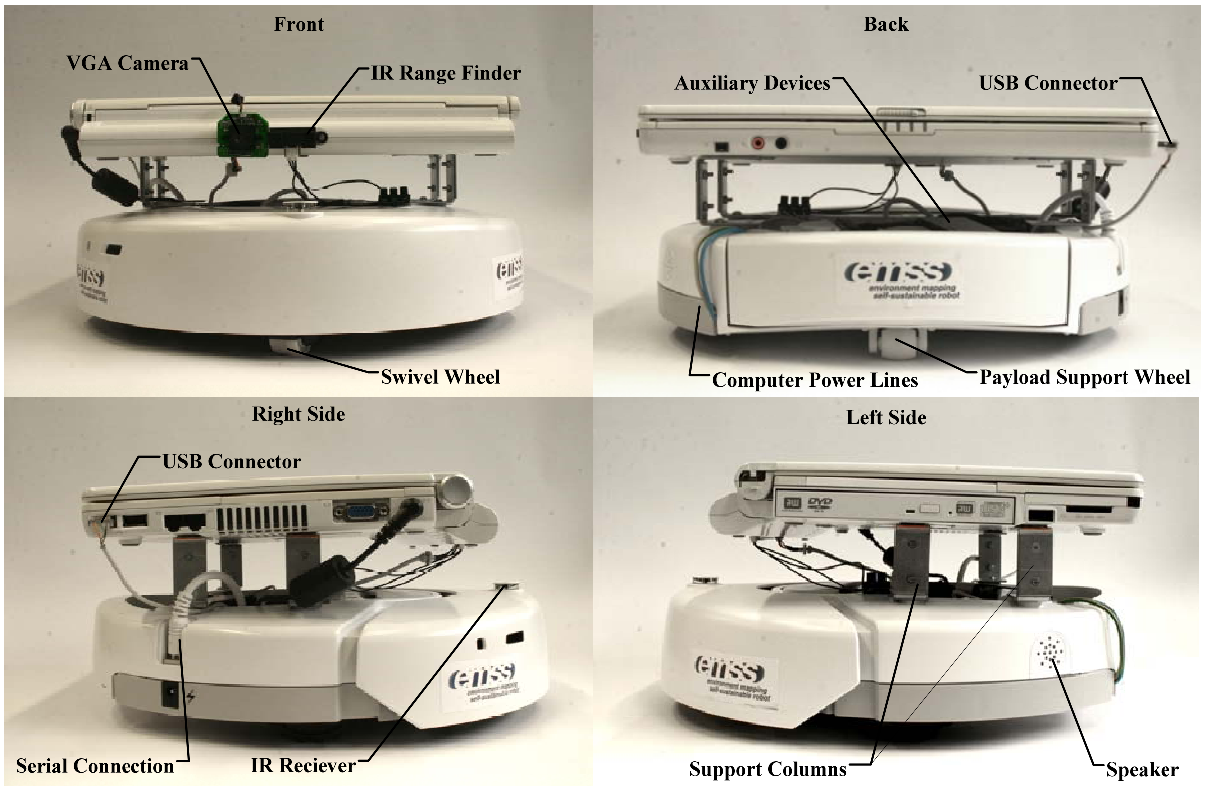


Figure 5-1: Assembled Robot

The original decision to use the *iRobot Create* platform as the basis for our robot was natural. Many hobbyists and enthusiasts had already used the *Create* for various projects. Its robust form and easy assembly proves it to be very attractive. Furthermore, the size and shape of the platform suits our need to mount a computer and other peripheries very well. Finally, the affordable total cost of ownership of the *iRobot Create* platform allows us to build a full blown robot with a small budget.

5.2 Vision

In short, the *emss* robot is very blind. Because of the limited budget, expensive laser range sensors or lidars could not be purchased. For navigation, the robot uses a single infra-red sensor (80cm range) which is pointed forwards. In some cases, such as when the robot is following a wall, a short range infra-red sensor (10cm) can be used which is pointed directly to the right. Figure 5-2 illustrates these two sensors. The VGA camera which is mounted to the laptop is not used for navigational purposes as it is outside the scope of our project.

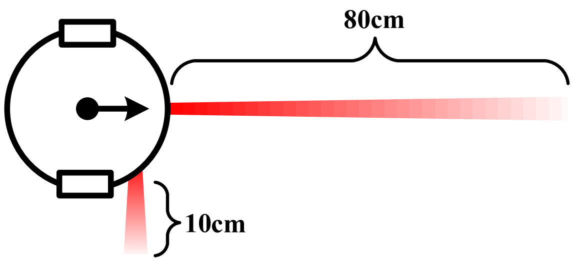


Figure 5-2: Robot Infra-Red Sensors

5.3 Interface

The controlling computer connects to the *iRobot Create* over a serial connection using the *iRobot Create Open Interface* protocol. The *emss* software is responsible for translating all controller data into the appropriate bit-level packets for the *Open Interface*. What happens after the Open Interface receives the packet is largely a black box and unknown.

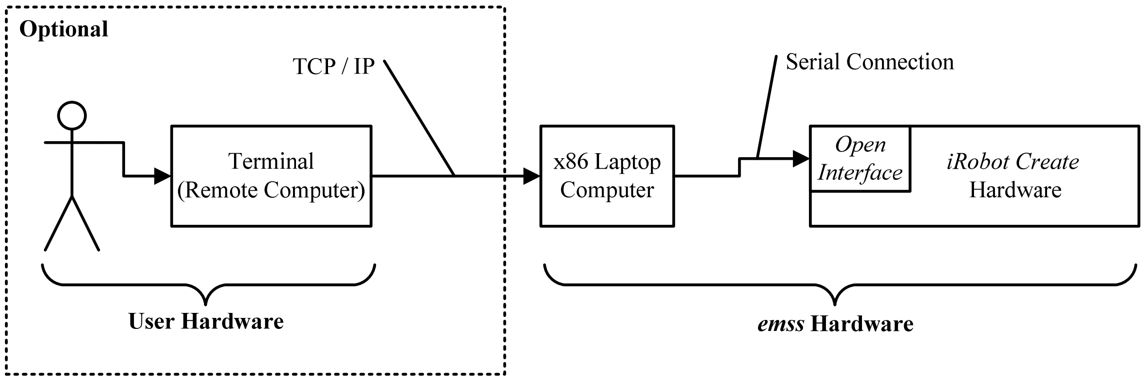


Figure 5-3: Controlling of the Robot

5.4 Modifications

The most important modifications to the *iRobot Create* hardware are the computer contact points for the docking station[3] along with the necessary cabling (shown in Figure 5-5). These are used in addition to the built-in contact points for charging of the *iRobot Create* batteries along with the computer batteries. Both sets of contact points expose 12V power supply lines which can connect by physical contact to their peers located at the base station (also shown in Figure 5-5). This mechanism allows the *emss* robot to find the docking station using the top-mounted infra-red receiver (described in detail in Section 6.3.6.3.7) and mount itself on top of the charging station, creating connections between all sets of contact points, and ultimately recharging its batteries.

5.5 Improvements

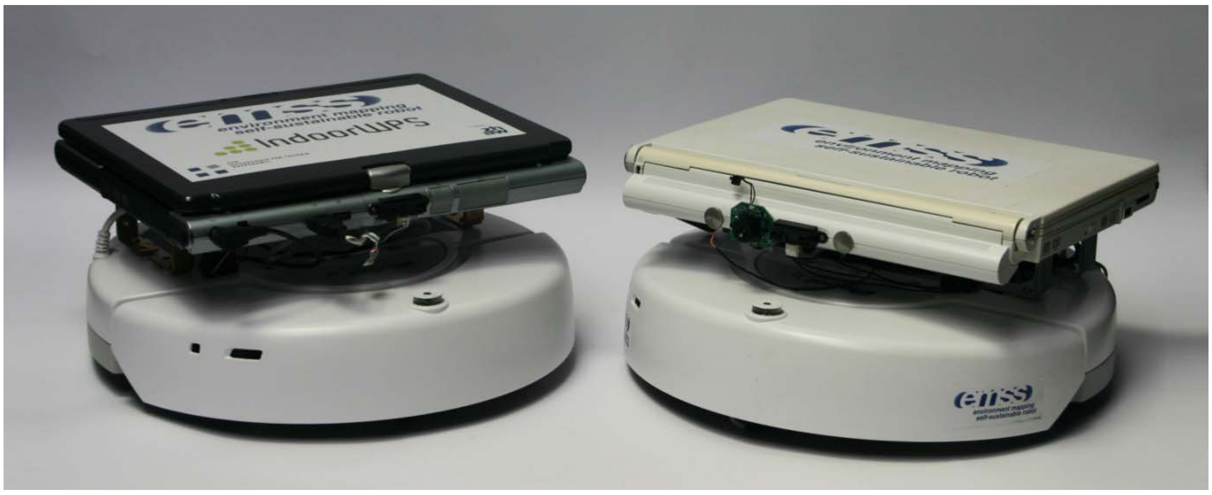


Figure 5-4: Assembled Robots

Most of the hardware was already designed and assembled in the Semester Project. However, significant improvements were made to the docking station, and an additional *emss* robot was assembled. As described in our previous work, the construction of docking station presented problems during repetitive use. After several docks the contact points for the computer power lines tended to loosen, sharply reducing the contact quality and often breaking the power connection. Therefore a new design was proposed and realized.

The second-generation docking station (shown in Figure 5-6) uses the same contact pieces as provided for the robot chassis. These contacts are angled and rounded just right for a flat piece of metal to glide on top of it. The new docking station has small incisions in the casing to allow for these secondary contact pieces to stick out and make contact with the laptop contacts. The contact pieces and neatly screwed to the bottom of the casing and soldered to the power lines. The final product is very clean and stable, with a high quality contact rate and power throughput for both batteries.

[3] The docking station is used to charge the robot's wheel drive batteries.

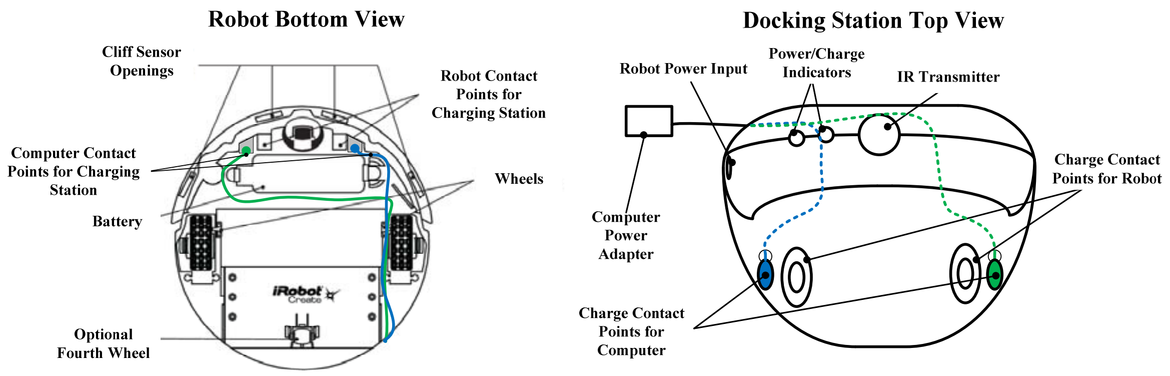


Figure 5-5: Blueprint Showing the Charging Modifications

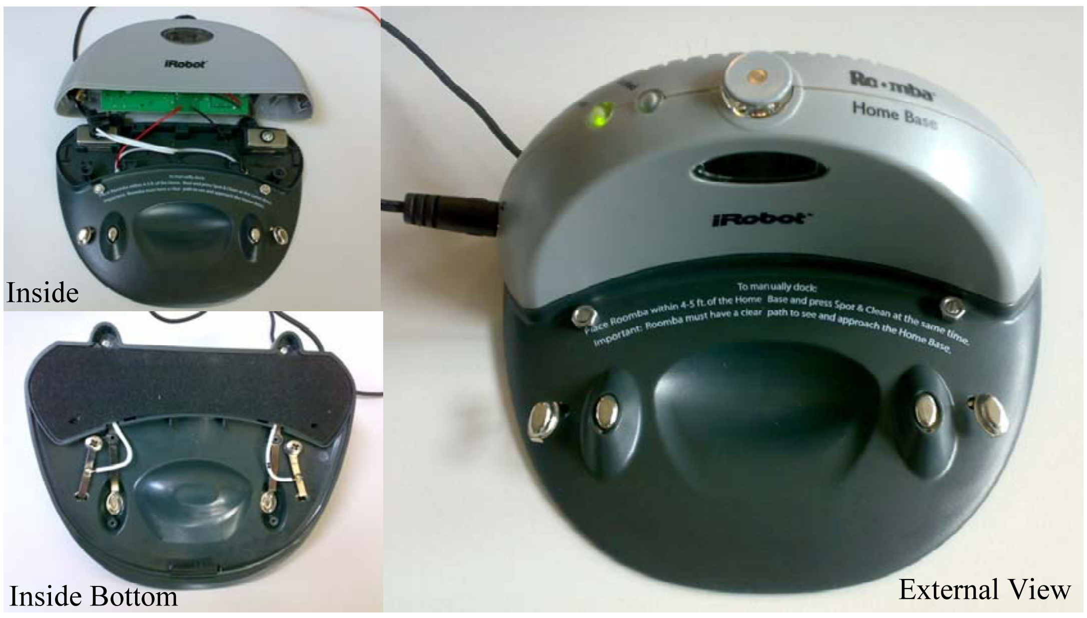


Figure 5-6: Second-Generation Docking Station

6 Software

The *emss* project touches on the subjects of many fields: mathematics, engineering, hardware, and finally software. However, the focus is clear: software. From a computer science enthusiast's point of view, this is where robotics gets interesting. The software related problems of the *emss* framework can be categorized into three domains: communicating with hardware, solving the problems of the given objectives, and presenting the state of the problem and solution to the user.

Throughout the development of the framework, a significant amount of energy was focused on maintaining a highly flexible architecture consisting of a set of modules which interact with each other to achieve a common task. Every added module and component has undergone a rigorous thought process to justify its need and make sure it is absolutely necessary.

6.1 Analysis & Design

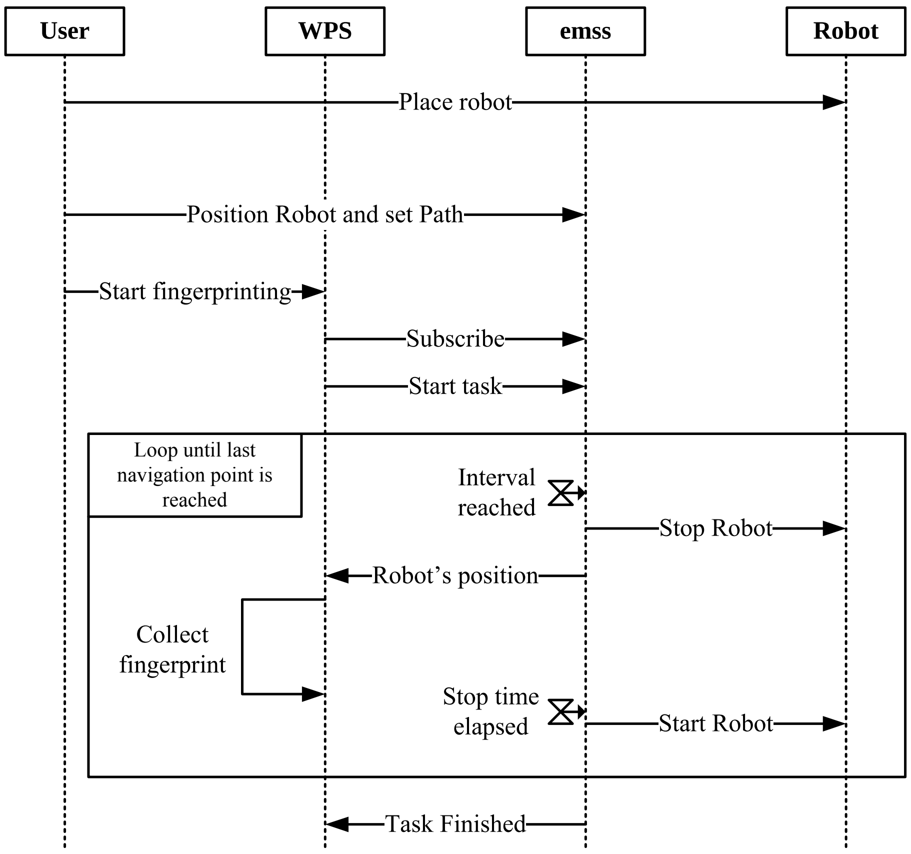


Figure 6-1: Fingerprinting Use Case System Sequence Diagram

Throughout the analysis of the software, the existing *emss* framework (Krüsi & Grob, 2008) was examined along with the new use cases. Upon examination, it was clear that the existing Navigation module would have to be redesigned to better suit the needs of the next generation of the framework. In addition, it was also clear that new modules would be added. The original framework, however, was built with this in mind, allowing a clear notion on how the new design would fit with the existing.

Figure 6-1 shows the most interesting use case (UC4, Section 4.2.2) as a system sequence diagram. It illustrates how the individual players must work together in order to collect fingerprints. The use case requires user interaction with both the third-party WPS software and *emss* framework. The interaction between WPS and *emss* is achieved without any further user interaction.

The *emss* framework should have the functionality to control the robot, track its position and perform localization, as well as execute the navigation. These modules must remain highly flexible and interchangeable depending on the underlying hardware and the requested use and purpose of that hardware. This allows the creation of tasks for a wide variety of topics without necessarily knowing the exact details of the underlying modules used. One can set navigation points and make the robot navigate through the resulting path without having to decide what kind of splines to create for the trajectory or how to avoid unexpected obstacles.

To enable such an environment, the following software stack, shown in Figure 6-2, has been designed. It shows the different layers and how they stack on top of each other to form the overall architecture of the framework. The very bottom represents the physical hardware which has proprietary software. This is not a part of the *emss* framework, but the framework makes use of this layer. Directly on top of the hardware lies the Hardware Abstraction Layer (HAL), which communicates directly with the hardware's interfaces but exposes a much more simple and unified interface to the layers above. This is the first layer in the *emss* Core – the central software of the framework. Sending commands to the HAL is the Controller, which is responsible for ensuring that the appropriate commands are sent to and from the hardware (through the HAL) at the right time. In the middle lies the Task Manager and its Tasks, which execute the different jobs which essentially control the robots actions. The top-most layer of the Core includes all the modules required for efficiently executing the different jobs (or Tasks). On top of the Core layers are the Interface layers, which enable the user to interact with the framework and present the current state of the different layers.

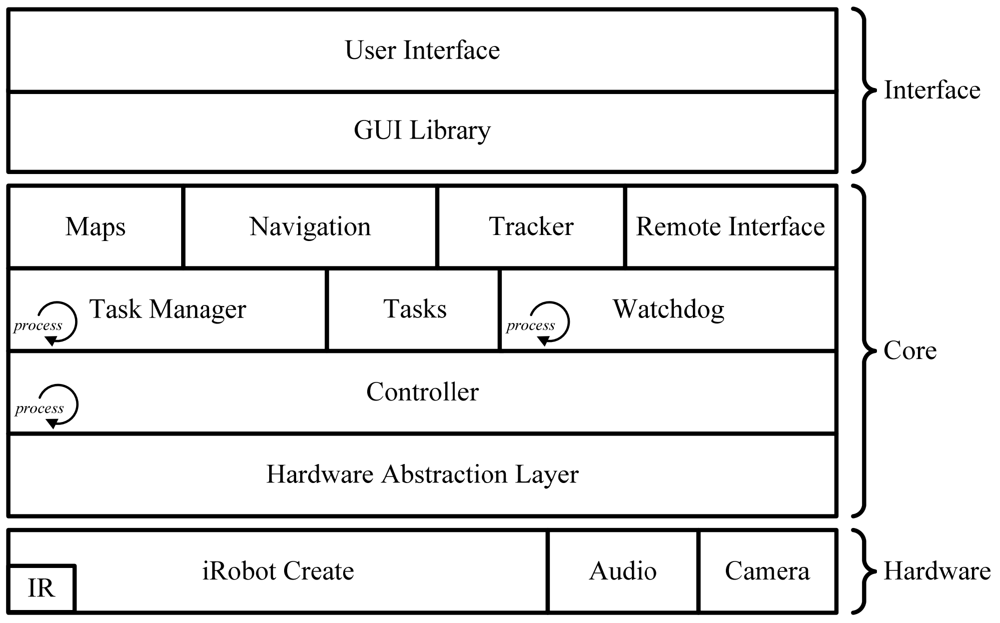


Figure 6-2: Layer Model

All these modules that make up the different software layers communicate with each other and exchange data to perform a common task. The basic lines of communications are illustrated below in

Figure 6-3. The Controller runs in its own thread and reads the sensory data from the robot over the Hardware Abstraction Layer. The data is then processed and forwarded to the Tracker module, which in turn performs the necessary localization based on the incoming data. From the other side, the Task Manager administrates a list of Tasks and sequentially schedules them for execution. The Task defines the action it wants to take and asks the Navigation module how it can achieve this (i.e. „how must I drive to do this?“). The Navigation in turn queries the Tracker for information about its whereabouts in order to determine the best course of action.

An important factor is the intern changeability of the modules. The interface of each module is defined as generically as possible, taking into account different scenarios and wishes of different Tasks. This allows the module to have several implementations, each with a different or extended approach in solving its task.

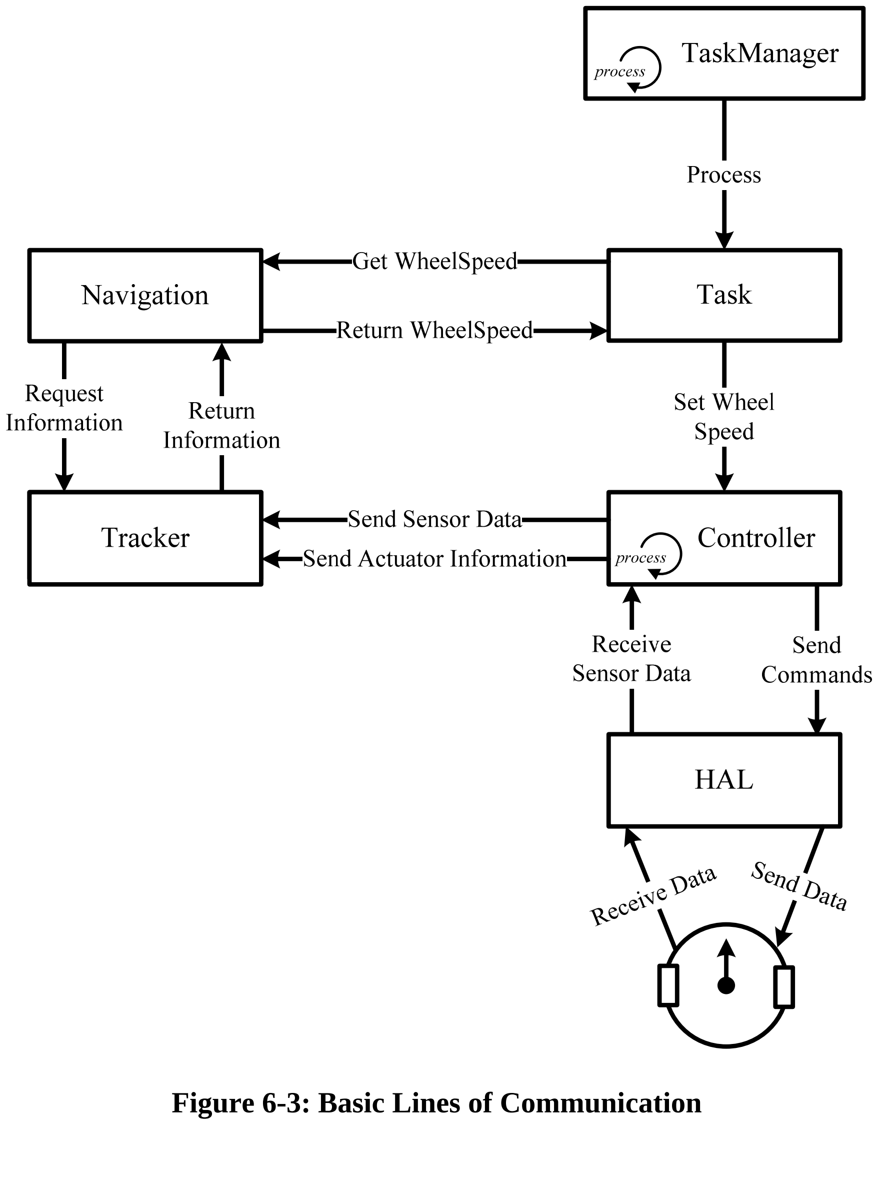


Figure 6-3: Basic Lines of Communication

6.2 Environment

Because of the natural progression of software languages and operating systems, the choice and understanding of the environment of software has become increasingly important. Working with microcontrollers in the field of robotics, we chose the programming language of *C++*, which is well proven in the industry as a robust middle level language[4]. *C++* is both a highly advanced and efficient language, and if used correctly results in very stable and robust applications.

C++ by itself does not offer any support in creating cross-platform graphical user interfaces, which is why we use the *Qt* framework from *Qt Software* (formerly *Trolltech*) to assist us. We are very proud to be able to offer a software framework in which every component, including modules such as serial communications, cross-compile on *Windows*, *Linux*, and *OS X*. All software components are written in *C++* and are fully compatible with any of the *GNU 4.x* compilers. Additionally, we have made use of software libraries. The Core modules of the *emss* software are all packaged into a single library, which in turn is linked to by any of the user interfaces.

The use of *Qt* Signals and Slots[5] has been used heavily throughout the framework. Signals and slots are used for the communication between objects. They are similar to callbacks using pointer functions, but have the advantage that they are type-safe, meaning the signature of a signal must match the signature of the receiving slot. One might ask how this is possible using *C++*: *Qt* uses a meta-object compiler (MOC) to achieve the signal and slot functionality by creating meta-objects for classes. The meta-object contains the names of all the signal and slot members, as well as pointers to these methods. The MOC parses the class declaration in a *C++* file and generates *C++* code that initializes the meta-object.

Constants typically have been avoided throughout the implementation for any value that has changed several times. Such values are defined in a configuration file, which in turn is loaded and cached by the code which needs it. This allows a much more flexible system, where reconfiguring does not require a tedious recompilation. In all, there are well over 150 different configuration settings which are documented in detail in Sections 10.3.3, 10.4.3, and 10.5.3. The amount of configuration settings portrays the complexity of the software.

Wherever possible and deemed appropriate, *C++* features such as class inheritance, operator overloading, and templates have been made use of. In addition, because of the multi-threaded nature of the *emss* framework, thread-safety precautions have been taken wherever necessary through the use of operating system level locks[6].

[4] Middle-level languages compromise a combination of high-level features and low-level advantages.
[5] If you are unfamiliar with this design concept, we recommend *Qt's* introductory document found on their website at `http://doc.trolltech.com/4.5/signalsandslots.html`.
[6] In particular, mostly read/write locks have been used.

6.3 Implementation

6.3.1 Core

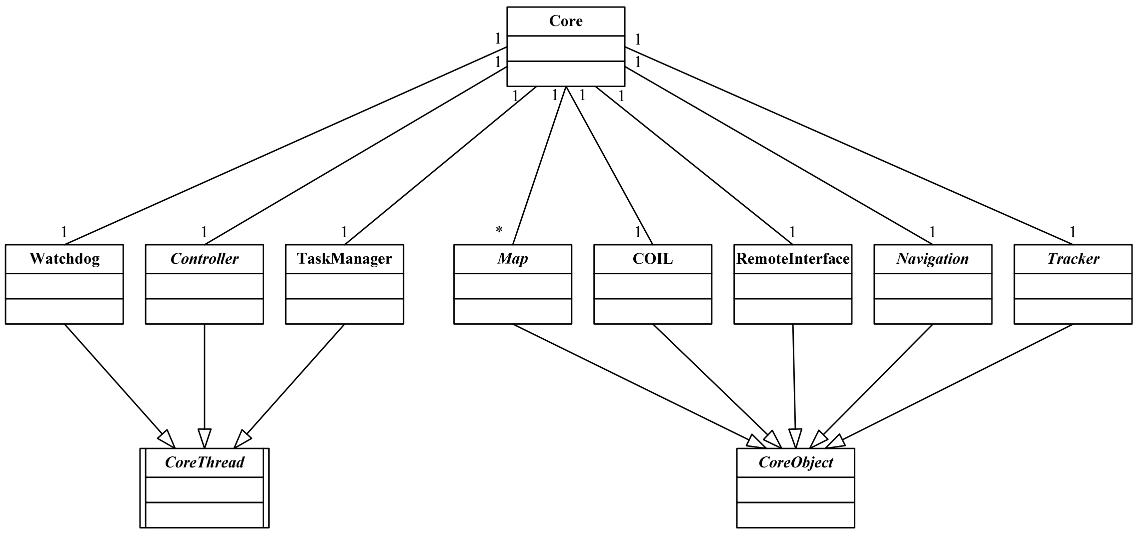


Figure 6-4: Core Domain Model

The software which essentially runs our *emss* robot is divided into different modules which ultimately make up the *emss* Core. Modules within the Core are built separately into the library emssCore (`libemssCore.a`). The Core initializes all the required data-layer objects, binds together all the different Core modules, and makes sure everything is cleaned up. Any application wishing to make use of the *emss* framework must instantiate its own Core. Communications with different Core modules are then proceeded over this Core object, mostly via signals and slots. Because the Core holds responsibility for all the modules, an interfacing application needs not to worry about cleaning up and managing memory– all it must do is disconnect the Core and delete the Core object.

Up until version 1.0, the modules of the *emss* Core changed slightly as needs changed for the framework. However, since version 1.1 the Core modules have remained unchanged as far as design. The current modules, shown in Figure 6-4, are Watchdog, Controller, TaskManager, Map, COIL, RemoteInterface, Navigation, and Tracker. These modules all play a significant role in the operation of controlling the robot and quite accurately reflect the contents of the software stack described in Section 6.1. Any module within the *emss* Core must inherit from either `CoreObject` or `CoreThread` class, which describes the two types of modules found within the Core. Furthermore, many modules have multiple implementations which solve the same problem but with a different approach.

The `Core` class itself offers some important functionality – the most important being the initialization and connection methods `initMapsAndObjects()` and `connect(…)`. In addition, also `start()` and `stop()` methods are provided which help in safely starting and stopping all the different `CoreThreads`. This resolves the Core into the following states (as shown in Figure 6-5): *Initialized*, *Connected*, *Started*, *Stopped*, *Destroyed*.

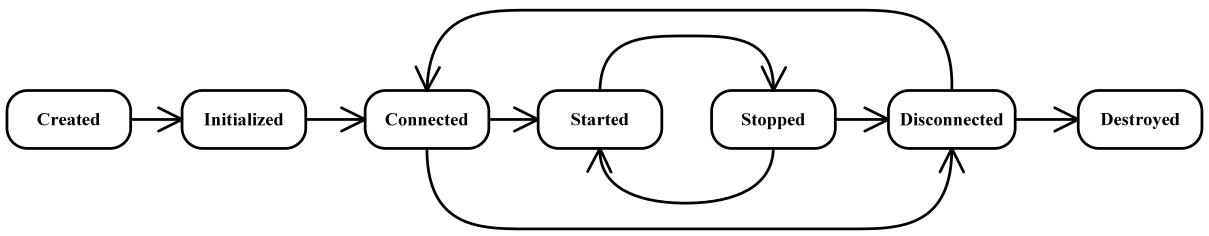


Figure 6-5: Core State Diagram

The following code shows how the Core might be initialized, connected, and started. It also demonstrates how to safely shut it down and cleanup. For more details see Section 10.3.2.

```
// Create a emss Core with settings specified in emssCore.config
Core *core = new Core();

// Connect the Core with the following configuration and start it:
//     Controller:       EmssController
//     Tracker:          SingleTracker
//     Navigation:       SystemOfWeightsNavigation
//     Serial Port:      /dev/TTYUSB0
//     Safe Mode:        true
//     Emulation:        true
if(core->connect("EmssController", "SingleTracker", "SystemOfWeightsNavigation",
                         "/dev/TTYUSB0", true, true)) {
     core->start();

     // The Core is running and ready now...

     // Shutdown the Core
     core->stop();
     core->disconnect();
}

// Cleanup
delete core;
```

Code 6-1: Core Initialization and Connection Example

6.3.1.1 Thread-Safety

Any module within the Core must be thread-safe where it has exposed methods, as there are different interacting threads which run in a connected Core. This is achieved by using system-level locks, mostly read/write locks. In most cases, a module will contain a private read/write lock for the data it must guard and perform lock operations around any internal code accessing this data. Always when possible a differentiation has been made between code which requires only read access and code which requires write access in order to boost performance.

6.3.1.2 CoreObject

A module in the Core which either does not require any continuous processing or is processed by another module inherits from the `CoreObject` class. The `CoreObject` is a simple interface which only requires a human-readable type name and a pointer to its Core in order to be constructed. In addition, when activated, HeapLogger routines are called in order to keep track of which `CoreObjects` are on the heap.

6.3.1.3 CoreThread

A module in the Core which requires continuous processing in the fashion of a thread must inherit from the `CoreThread` class. Similar to a `CoreObject`, `CoreThread` is a simple interface which only requires a human-readable type name and a pointer to its Core in order to be constructed. In addition a thread priority may be specified in the constructor. When activated, HeapLogger routines are called in order to keep track of which `CoreThreads` are on the heap.

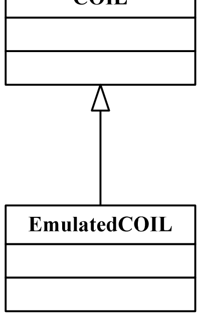
6.3.1.4 CoreFactory

The `CoreFactory` class serves as the factory for the entire Core. It is responsible for creating the different modules and their various implementations. For modules which have multiple implementations a name must be specified which corresponds to the human-readable type name given in `CoreObject` or `CoreThread`.

All factory methods return pointers to a created object on the heap when successful, and `NULL` otherwise. Objects returned by the CoreFactory remain under the responsibility of the callee, meaning that they must also be cleaned up by the one who called the factory method. However, in most cases this responsibility can easily be delegated.

The following factory methods are available: `createCOIL(…)`, `createTracker(…)`, `createMovementTracker(…)`, `createNavigation(…)`, `createTaskManager(…)`, `createController(…)`, `createRemoteInterface(…)`, `createWatchdog(…)`, `createGUIView(…)`, and `createTask(…)`.

6.3.2 COIL



The *C Open Interface Library*[7], or *COIL*, was originally implemented by Jesse DeGuire and Nathan Sprague as a *POSIX* compliant *C* wrapper for the *iRobot Open Interface*. We have created a *C++*

[7] For more information about the original *COIL*, please visit http://code.google.com/p/libcreateoi.

version of *COIL* which compiles on *Windows*, *Linux*, and *OS X*. The Core module COIL represents the Hardware Abstraction Layer, or HAL, in our software stack, and is solely responsible for communicating directly with the hardware.

COIL opens a serial port and directly communicates with the *iRobot Open Interface*. All the functionality defined by the *Open Interface* has been implemented as easy-to-use methods within the `COIL` class. Furthermore, the `COIL` class includes over a hundred different type-def values which correspond to the different bytes and bits used by the *Open Interface*. The two most important parts of COIL are the sending of wheel drive commands (handled by `drive(…)`, `driveDistance(…)`, `directDrive(…)`, and `turn(…)`), and the extraction of sensor information from the stream of data coming from the hardware (handled by `readRawSensor(…)` and `extractSensorFromData(…)`).

The following example drives the robot along the path of a square and demonstrates the simplicity which COIL offers when communicating with the hardware:

```
for(int i = 0; i < 4; i++) {
  coil->driveDistance(150,0,1000,1)   // Drive 1000 mm straight ahead at 150 mm/s
  coil->turn(150,0,90,1)              // Turn 90 degrees at 150 mm/s
}
```

Code 6-2: Using COIL to Drive along the Path of a Square

The above code will translate the COIL commands into a complex series of communications over the serial port with the *iRobot* hardware. These communications include:

1. Translation and transmission of controller commands on the bit level
2. Listening and translation of incoming sensory data
3. Timing of incoming and outgoing transmissions

6.3.2.1 EmulatedCOIL

The EmulatedCOIL implementation of COIL plays a very important role within the *emss* framework: it enables a completely emulated environment of the *iRobot Create* hardware. This is essential for rapid development and testing, as it allows a quick and easy environment for seeing the results of an algorithm or task. All the relevant sensory packets received by the hardware have been implemented and are available in the `EmulatedCOIL` class. Because of the thin documentation provided by *iRobot* regarding the *Open Interface*, many of the different sensor packets have been reverse engineered using comparison and trail-and-error methods. Everything from battery levels to infra-red signals have been implemented in EmulatedCOIL.

In order to be able to emulate the environment of the robot, the `EmulatedCOIL` class relies on the Tracker module and the PhysicalMap. The Tracker module provides the necessary information for the current position of the robot used when querying the PhysicalMap for the information about the surrounding environment for sensory data. In addition, timers are used internally for information returned by methods such as `getDistance()`, which returns the distance travelled since the last query. The most notable reverse engineering is the `getAngle()` method, which returns the change of angle since the last query. The mathematics for this method is based largely on our previous work (Krüsi & Grob, 2008) and is similar to the change of angle calculated by the ExpectedMovementTracker in Section 6.3.4.4.2.

An additional important role of the `EmulatedCOIL` class is not only to emulate the hardware behavior as it is desired, but also to emulate the undesired effects and inaccuracy in the hardware. This has been implemented by allowing EmulatedCOIL to select a specific additional MovementTracker (a specific localization implementation) within the Tracker module for determining its sensory information. If the selected MovementTracker has an error calculated into it, which is supported by MovementTrackers such as the CorrectedFrenetMovementTracker, then the returned sensory data will not be accurate in comparison with the Tracker module. This technique is best illustrated by Figure 6-6. The diagram shows two MovementTrackers mt_{EC} (*blue*) and mt_C (*yellow*) where mt_{EC} is the MovementTracker used specifically for EmulatedCOIL and mt_C is the MovementTracker used by the rest of the Core modules. The two detected collision areas c_1 and c_2 are a result from the MovementTracker mt_{EC} detecting the white wall, and the arrows indicate the offset for which the detection was actually registered in the HeatMap which stores information about the environment such as collision areas and safe areas (red/green spots). As one can quickly see, the configuration in Figure 6-6 results in a simulated error related to the EmulatedCOIL's selection of a error-injected MovementTracker. This is part of the continued effort to provide a robust emulation environment.

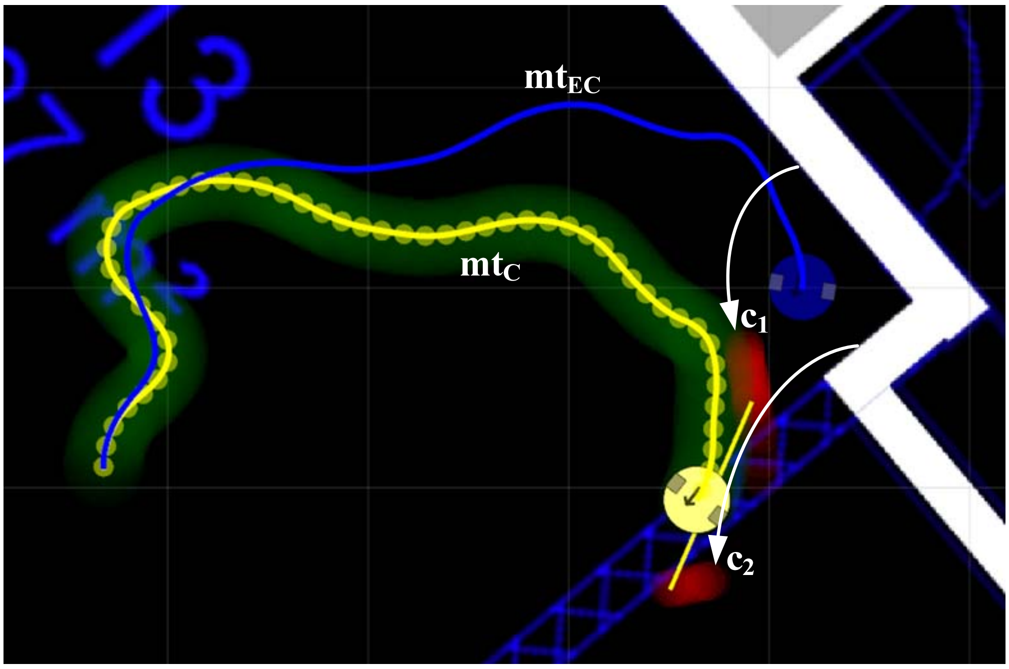
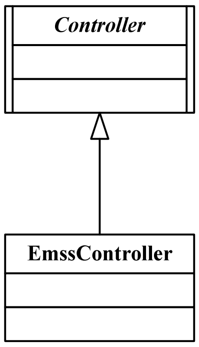


Figure 6-6: EmulatedCOIL with Hardware Error Emulation

6.3.3 Controller



The Controller module is responsible for safely controlling and maneuvering the hardware. It sends the control commands to COIL which in turn translates and transmits the commands over the serial interface. The Controller module is also responsible for receiving sensory data and providing it to other modules within the *emss* Core, such as the Tracker module and various Maps. The `Controller` class inherits from `CoreThread` and runs in its own thread. Implementations of the `Controller` class must implement the methods `process()` and `setWheelSpeed(…)`. The method `emergencyStop()` must be implemented to handle an emergency stop in further detail.

Originally the *emss* framework contained a series of different Controller implementations, however these differences have been refactored to the Tasks which originally required these features and now the Core only contains a single common Controller, the EmssController.

6.3.3.1 EmssController

The role of the EmssController is relatively simple: continuously and frequently retrieve sensor data and send movement commands while making sure to operate safely at all times. The main method for controlling the robot with the EmssController implementation is via the `setWheelSpeed(...)` method. This allows a Core module to set the desired wheel speed which is then transmitted by the controller to the hardware. If an unsafe movement is detected, such as driving down a drop or against a wall, the Controller will ignore any further commands until a reversing command is desired which is deemed safe. The EmssController will never take any counter-action to an unsafe command, it will just ignore the command. This delegates the resolving of an unsafe situation to other modules such as the Navigation module.

The `process()` method of the EmssController is detailed below in Figure 6-7 as a flow chart.

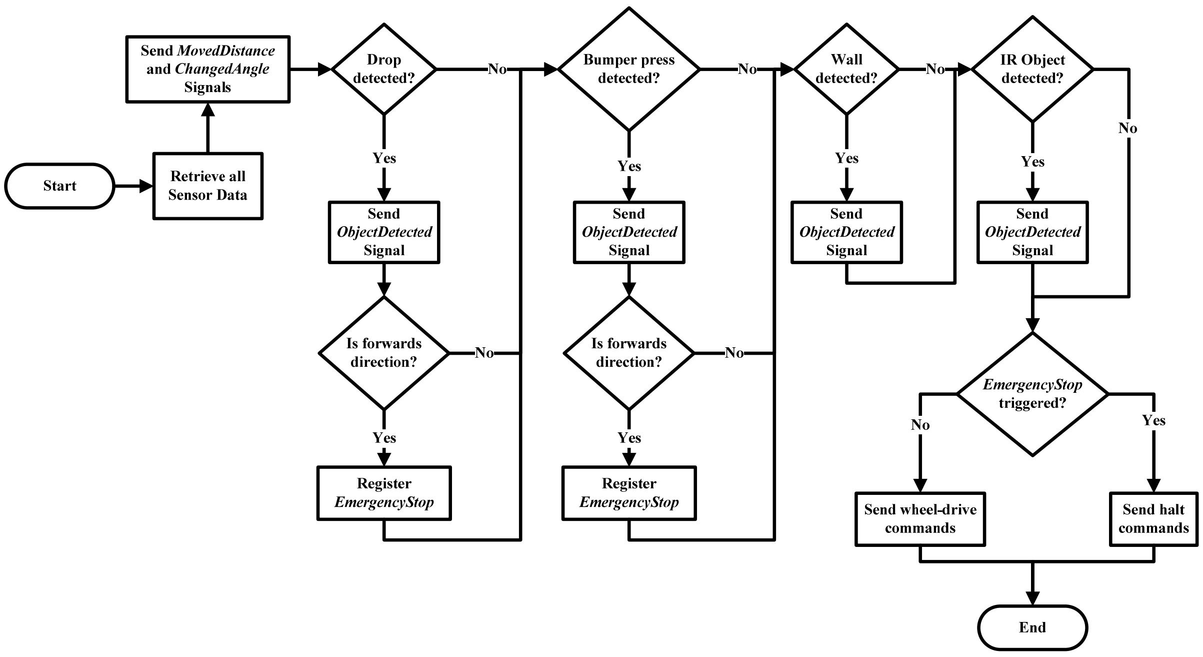
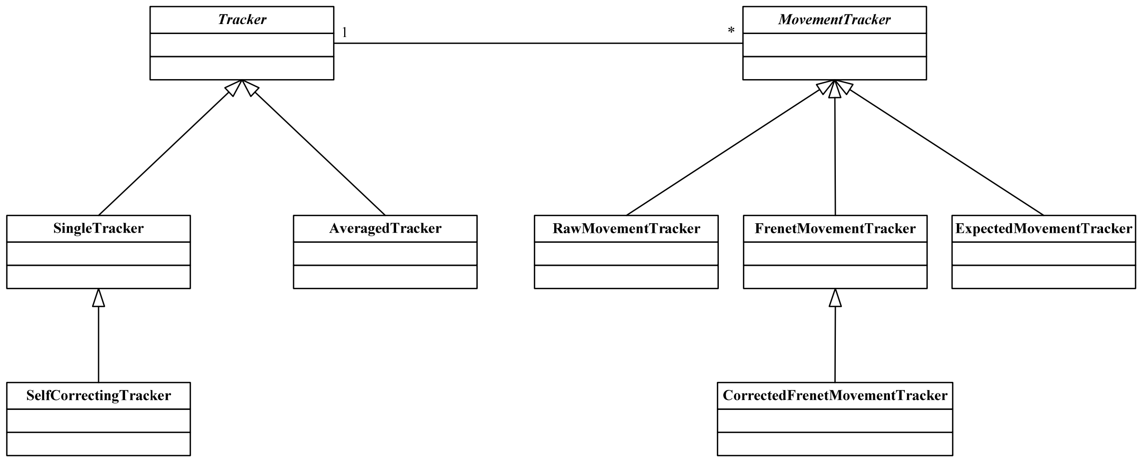


Figure 6-7: The EmssController Flow Chart

6.3.4 Tracker



The Tracker module is responsible for providing other modules with information about the localization, or positioning data, of the robot. However, this responsibility only goes so far as to delegating the necessary calculations to the internal MovementTrackers which it then uses to compile a single resulting position. MovementTrackers are therefore responsible for making calculations based on input from the Tracker on where the robot's position is. The Tracker can then use this information from the different MovementTrackers to determine the best suitable position. Even if a Tracker chooses to only use a single MovementTracker as its source of information for localization, having other MovementTrackers registered proves useful for error comparison et cetera. The interaction between an actor, such as a Task or any other Core module, and the Tracker is demonstrated below in Figure 6-8.

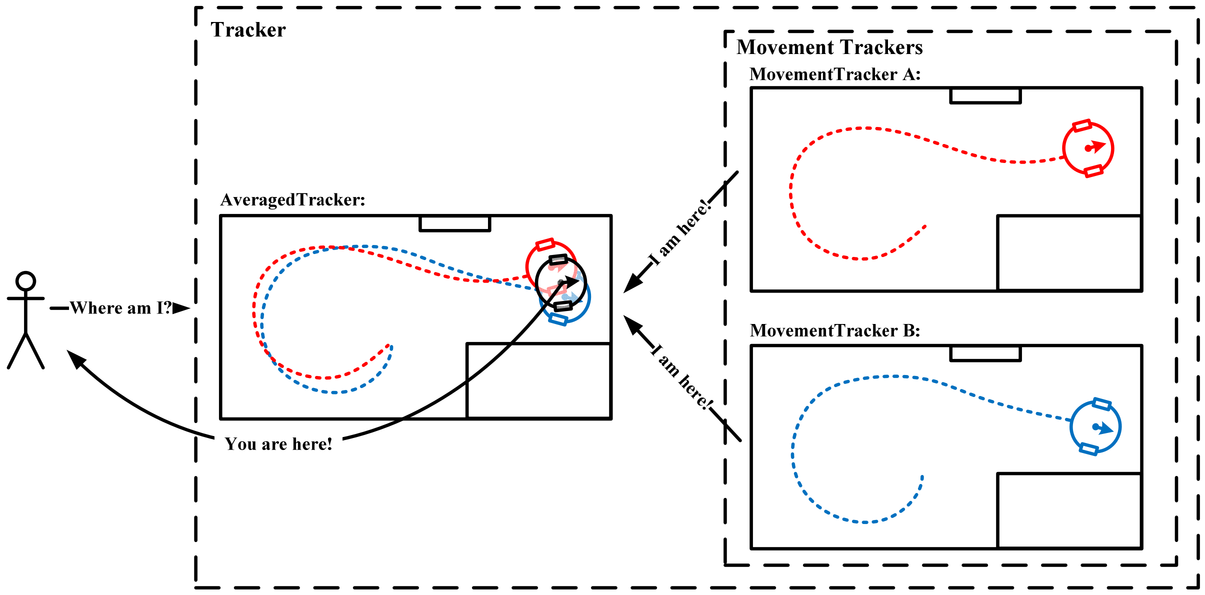


Figure 6-8: Representation of Interaction with Tracker

A Tracker mostly receives its input information from the Controller via signals. These signals include `signalMovedDistance(...)`, `signalChangedAngle(...)`, `signalChangedWheelSpeed(...)`, and `signalObjectDetected(...)`. As mentioned earlier, the Tracker is solely responsible for relaying these signals to its various MovemenTrackers, where the real calculations for localization are performed.

The following Tracker implementations are available in the *emss* Core: SingleTracker, AveragedTracker and SelfCorrectingTracker.

6.3.4.1 SingleTracker

A SingleTracker may contain one or more MovementTrackers but only uses a single MovementTracker for determining the robots position. The MovementTracker which is used is specified in the Core configuration file (see 0), and can be changed during runtime with the method `setSelectedMovemenTracker(...)`.

6.3.4.2 AveragedTracker

Unlike the SingleTracker, the AveragedTracker makes use of multiple MovementTrackers at the same time. The resulting localization is the mean, or average, of all the MovementTrackers. Additionally, each MovementTracker may have an assigned weight, which will skew the influence of the MovementTracker on the resulting average.

The following code segment shows how the `calculateTotalAngle()` method is implemented for the AverageTracker, which returns the total change of angle travelled.

```
double calculateTotalAngle(){
     // Find out the total weight. A MovementTracker does not necessarily have
     // to have a weight of 1. When the weight is increased the MovementTracker
     // will have a higher influence on the result.
     int totalWeight = 0;
     for(int i = 0; i < movementTrackers->count(); i++){
            totalWeight += movementTrackers->at(i)->getWeight();
     }

     // Iterate through every MovementTracker and add its value times the weight
     // to the total
     double total = 0;
     for (int i = 0; i < movementTrackers->count(); i++){
            total += movementTrackers->at(i)->getWeight() *
                   movementTrackers->at(i)->getTotalAngle();
     }

     // The end result is the skewed average
     return total / totalWeight;
}
```

Code 6-3: Example AveragedTracker Calculation

6.3.4.3 SelfCorrectingTracker

The SelfCorrectingTracker is an advanced Tracker which inherits from SingleTracker. This Tracker doesn’t change anything the SingleTracker does, but extends its functionality to be able to make corrections when deemed applicable. To do this, the SelfCorrectingTracker makes use of the currently loaded PhysicalMap to map correlations and determine if the overall localization has peered off in error. If such an error is determined, it is accordingly corrected by adjusting all the MovementTrackers positions. This Tracker looks to be promising for future work related to improving the quality, or accuracy, of the robot localization, and is described in larger detail than the other Trackers.

To realize the SelfCorrectingTracker, the data structure `CorrelationTriangle` (see Figure 6-9, top) and `SuspectedWall` has been defined[8]:

```
struct CorrelationTriangle {
     Trafo2D      position;
     Trafo2D      collision;
     Trafo2D      closestWall;
};
struct SuspectedWall {
     bool                     valid;
     CorrelationTriangle      start;
     CorrelationTriangle      end;
};
```

For every `signalObjectDetected(...)` which the SelfCorrectingTracker receives, a `CorrelationTriangle`, is pushed to a log which stores the current robot position, the collision position, and the closest wall position from the collision location – thus a correlation between the position, collision, and closest wall. If the log contains enough correlation triangles, all the collision positions and closest wall positions are checked if they represent similarities to a wall. If so, the SelfCorrectingTracker makes a correction to the MovementTrackers positions. Because such an algorithm naturally requires many processing cycles (determining closest wall, creating line structures, et cetera), a considerable amount of effort has been made to optimize the SelfCorrectingTracker. The simplified algorithm is described in detail below, step by step.

1. Determine the correlation triangle `ct`:

```
// Get current position and corresponding collision point
CorrelationTriangle ct;
ct.position = tracker position
ct.collision = object detected position

// Find closest 'wall' (ct.closestWall) to ct.collision.
// This is done by 'spiraling' out from the center (ct.collision)...
double r = 0;           // The current radius
double rmax = 2000;     // The maximum spiral radius
double a = 0;           // The current angle
double amax = 360;      // The maximum spiral angle
while(r < rmax) {
    a = 0;
    while(a < amax) {
          Trafo2D pos = ct.collision * Trafo2D::rot(a) *
                              Trafo2D::trans(0, r);
          if(pos is a wall on PhysicalMap) {
                ct.closestWall = pos;
```

[8] The class `Trafo2D` is the two-dimensional transformation matrix class in the *emss* Core library.

```
                break;
            }
            a++;
        }
        r++;
}
```

2. Add `ct` to our log if the closest wall could be determined:

```
// Add the ct to the log
correlationLog.append(ct);
```

3. Determine whether there are two straight lines (see Figure 6-9, bottom left) in the log made up of n `ct.collision`'s and n `ct.closestWall`'s which make up a `SuspectedWall` structure `wall`. First we need to detect the most distant two points in `ct.collision` in our log. This would be $O(n^2)$ but we optimize by first calculating the bounding box, then taking the points which are on the bounds, and finally finding the most distant of those. The best case is $O(n)$, and the worst case is $O(n^2)$. The worst case can only happen if all points are on a straight vertical or horizontal line, which in reality will hardly ever (if ever) be the case..

```
// Get the bounding box of the ct points
foreach (CorrelationTriangle ct in the last n in correlationLog) {
    if(ct.collision.x() > xmax) xmax = ct.collision.x();
    else if(ct.collision.x() < xmin) xmin = ct.collision.x();
    if(ct.collision.y() > ymax) ymax = ct.collision.y();
    else if(ct.collision.y() < ymin) ymin = ct.collision.y();
}

// Get all the ct points which ly on the bounds
foreach (CorrelationTriangle ct in the last n in correlationLog) {
    if(     ct.collision.x() == xmin ||
            ct.collision.x() == xmax ||
            ct.collision.y() == ymin ||
            ct.collision.y() == ymax   ) {
            // Lies on the bounds, add to candidates
            candidates.append(ct);
    }
}

// Now we have our candidates - find the most distant ct points!
i = candidates.constBegin();
double maxdist = 0;
foreach (CorrelationTriangle cti in the candiates) {
    foreach (CorrelationTriangle ctj in the candiates) {
            double distij = dist( cti.collision, ctj.collision );
            if( distij > maxdist ) {
                    maxdist = distij;
                    wall.start = cti;
                    wall.end = ctj;
            }
    }
}
```

4. Now that the two most distant `CorrelationTriangle` points have been determined, we need to check if all the other `CorrelationTriangle`'s in the log fall close to the line between the most distance points. There are actually two lines. The first being `lineWall`, which is the line along the detected `closestWall` points (from physical map). The second is `lineCollision`, which is the line along the detected `collision` points (from sensor). To determine if a point falls on a line with a permitted deviation `maxLineDeviation`, the distance d from a point to the line can be used (Kimberling, 1998): $d = \frac{|l_{x1}-l_{x0}, l_{x0}-ct_x|}{|l_{x1}-l_{x0}|}$ where l represents the line and ct the point to sample.

```
wall.valid = true; // Assume it is a valid wall
foreach (CorrelationTriangle ct in correlationLog) {
    // Get the distance of this ct point from the line. If the
    // distance is too large, then the suspected wall is invalid, as
    // the points do not fall on a straight line (what we assume to be
    // a wall.
    double dw = ( det(wall.end.closestWall - wall.start.closestWall,
                      wall.start.closestWall - ct.closestWall) ) / (
                      wall.end.closestWall.x() -
                      wall.start.closestWall.x() );
    double dc = ( det(wall.end.collision - wall.start.collision,
                      wall.start.collision - ct.collision) ) / (
                      wall.end.collision.x() - wall.start.collision.x()
                      );
    if(dw > maxLineDeviation || dw < -maxLineDeviation || dc >
                      maxLineDeviation || dc < -maxLineDeviation) {
          wall.valid = false;
          break;
    }
}
```

5. Finally, if the wall has been determined to be valid, the SelfCorrectingTracker can determine the angle between the two lines, and correct the position (see Figure 6-9, bottom right).

```
// Get the current transfomration
Trafo2D t = selectedMovementTracker->getTransformation();

// Get the distance to go back and forwards again
double d = dist (wall.end.collision.trans(),
wall.start.collision.trans());

// Get the angle to correct
Vector2D lc(wall.end.collision.x()-wall.start.collision.x(),
                 wall.end.collision.y()-wall.start.collision.y());
Vector2D lw(wall.end.closestWall.x()-wall.start.closestWall.x(),
                 wall.end.closestWall.y()-wall.start.closestWall.y());
double alpha = angle(lc,lw);

// Perform the correction
t = t * Trafo2D::trans( 0, -d ) * Trafo2D::rot(alpha) * Trafo2D::trans( 0,
d );
selectedMovementTracker->setTransformation(t);
```

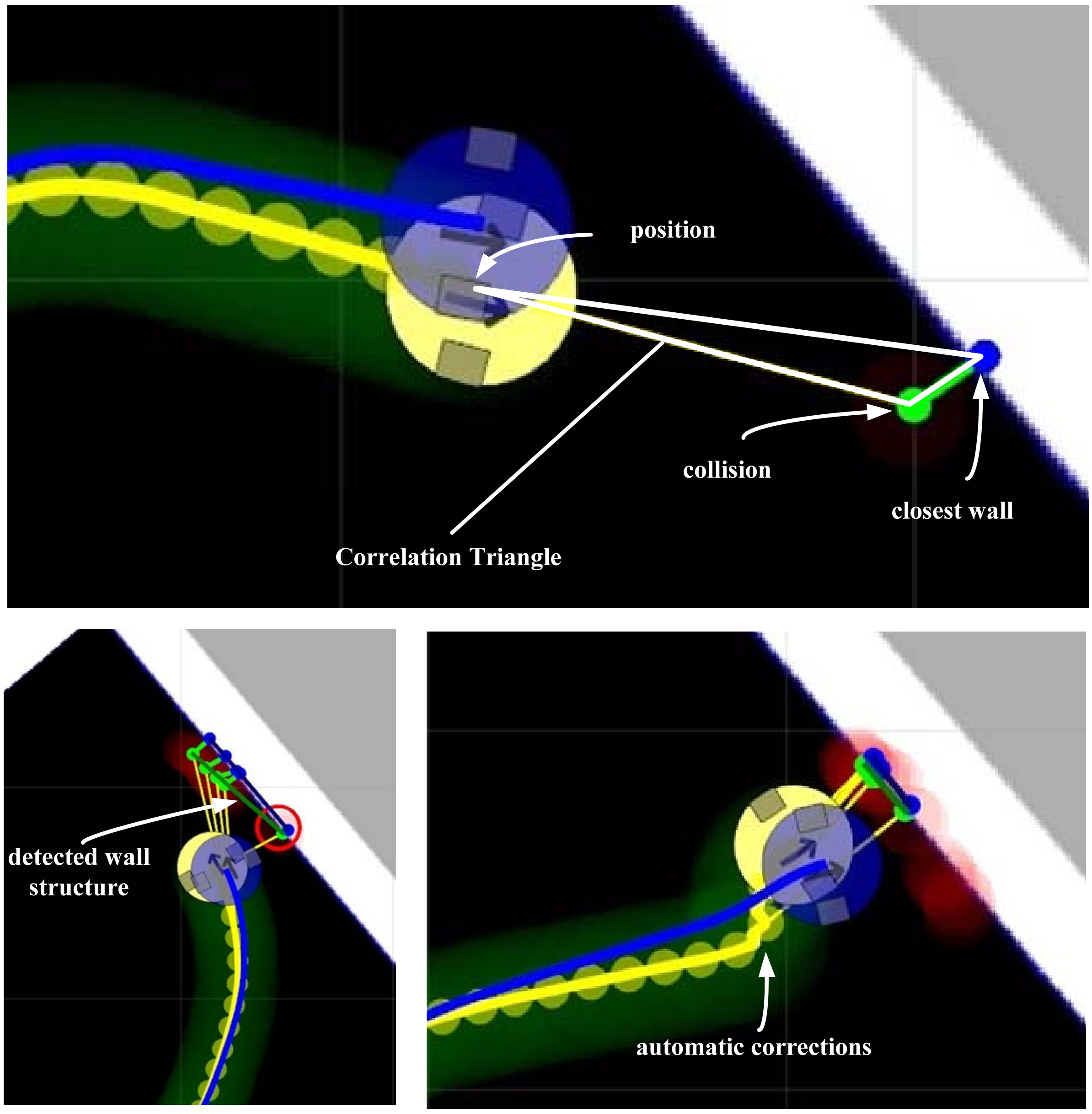


Figure 6-9: SelfCorrectingTracker in Action

6.3.4.4 Movement Tracker

A MovementTracker is responsible for receiving the Tracker's messages regarding changes in the state of the robot and performing localization based on this information. The methods a MovementTracker implementation must implement are `registerMovedDistance(...)`, `registerChangedAngle(...)`, and `registerChangedWheelSpeed(...)`. However, not all of these methods must react in some fashion – technically and mathematically it is sufficient to react solely to the `registerChangedWheelSpeed(...)` method.

6.3.4.4.1 RawMovemenTracker

The RawMovementTracker works with the raw sensor data of the robot. This means the Controller controls via COIL the robot and determines the individual wheel speeds. With every `process()` of the Controller the sensor data is queried and passed along to the Tracker and eventually the

RawMovementTracker. Within this sensor data is the change in angle and the distance driven, which is determined by the onboard-controller of the robot. It is this data which the RawMovementTracker reacts to and performs its localization via the methods `registerChangedAngle(...)` and `registerMovedDistance(...)`.

6.3.4.4.2 ExpectedMovementTracker

The ExpectedMovementTracker is based on our previous work (Krüsi & Grob, 2008) related to the movement of a differential steering system over time. The aim of the ExpectedMovementTracker is to perform localization based solely on what one would expect the hardware to do, that is, mathematically. While the results are very satisfactory, the ExpectedMovementTracker however is not mathematically sound – it is only an approximation.

The tackled problem here is that the *emss* robot has a differential steering system with independent wheel velocities $v_L$and v_R (provided by the method `registerChangedWheelSpeed(vl,vr)`). Our approach is based on the movement of each wheel as arcs of circles, as shown in Figure 6-10. The radius of these circular trajectories is given by the difference of velocities. With this approach one immediately assumes $v_L \neq v_R$, as when $v_L = v_R$ the radius $R = \infty$ and the emulation for $v_L = v_R$ is trivial. With this model one can formulate the local change in angle as:

$$\alpha = \frac{S_L}{R}$$

where S_L is the distance travelled by the arbitrarily chosen left wheel (arc length of c_L). The radius R is defined as

$$R = \frac{v_L d}{v_R - v_L}.$$

Thus the offset of the robot over time t can trivially be calculated using $R + \frac{1}{2}d$ and α, which is exactly what the ExpectedMovementTracker does.

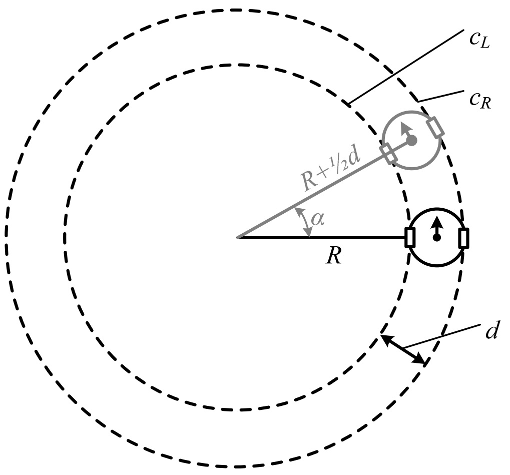


Figure 6-10: Robot Moving CCW on Circle Arcs

The precision of the ExpectedMovementTracker decreases as t increases because of the way the transformation is applied. However, as already stated the error remains very low since t is always small in relation to α.

6.3.4.4.3 FrenetMovemenTracker

Taking the ExpectedMovementTracker to the next step, the FrenetMovementTracker implements a mathematically sound tracker for the differential steering system of the robot. This Tracker uses the theory Jean Frédéric Frenet (Frenet, 1847) and Joseph Alfred Serret (Serret, 1851) formulated in the 19th century regarding kinematic properties of movement along a continuous, differentiable curve in three-dimensional Euclidean space R^3. The resulting formulas, now known as the Frenet-Serret formulas, specifically describe the derivatives of the tangent t, normal n, and binormal b unit vectors (Figure 6-11) in terms of each other:

$$\frac{dt}{ds} = \kappa n$$

$$\frac{dn}{ds} = -\kappa t - \tau b$$

$$\frac{db}{ds} = \tau n$$

where $\frac{d}{ds}$ is the derivative with respect to the arclength, κ is the curvature of the curve and τ is the torsion of the curve (Carmo, 1976).

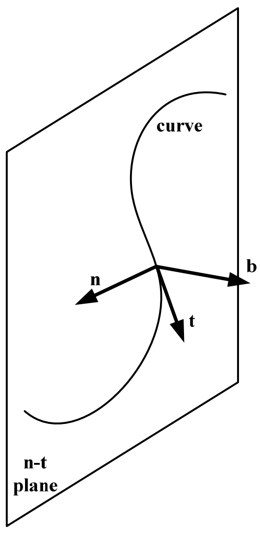


Figure 6-11: Illustration of Frenet Unit Vectors for Curve in R^3

Following do Carmo's literature (Carmo, 1976), a plane curve in R^2, such as the path for which the robot moves along, is simplified because $\tau = 0$, which results in:

$$\frac{dt}{ds} = \kappa n$$

$$\frac{dn}{ds} = -\kappa t$$

Since the curvature is directly related to the change in angle, the formula from Section 6.3.4.4.2 can be used to define κ (parametrized for time instead of arclength):

$$\kappa(t) = -\frac{2}{d} \cdot \frac{vr - vl}{vr + vl}$$

$$ds = \sqrt{dx^2 + dy^2}$$

The following differential equation must be solved in order to determine the movement through space over time in R^2:

$$\begin{pmatrix} \dot{x}_0 \\ \dot{y}_0 \\ \dot{x}_1 \\ \dot{y}_1 \\ \dot{x}_2 \\ \dot{y}_2 \end{pmatrix} = \begin{pmatrix} x_1 \\ y_1 \\ ds \cdot \kappa(t) \cdot x_2 \\ ds \cdot \kappa(t) \cdot y_2 \\ -ds \cdot \kappa(t) \cdot x_1 \\ -ds \cdot \kappa(t) \cdot y_1 \end{pmatrix}$$

where x and y represent the input vectors for position (x_0, y_0), speed (x_1, y_1), and acceleration (x_2, y_2), and ds represents the change in distance. The differential equation can be solved using common methods such as Euler or Runge-Kutta, which have both been implemented for this purpose in the Core math library.

Utilizing our templated `FrenetT` math class, the theory is realized using the steps described below. Special care has been taken to automatically determine the best h value when solving the differential equation. The following code demonstrates how the `FrenetT` is used:

1. First the curvature function is defined:

```
double k (double t) {
    // Note that t is not used because of the constant vr and vl
    return -( 2.0 / d ) * ( vr - vl ) / ( vr + vl );
}
```

2. Then the values are initialized for the calculation. Note that the calculations are done on a local scale (i.e. starting from point 0,0), and then applied globally.

```
double hcount = 100; // Move to t with h hcount times
double h = (t/1000.0)/hcount; // h value for Runge-Kutta
double phi = Rad(90); // straight ahead along the y-axis
DiffEqVectorD y0 = DiffEqVector<double>(0, 0, Cos(phi)*v, Sin(phi)*v,
                   Sin(phi)*v, -Cos(phi)*v);
```

3. Finally the `FrenetT` class is initialized with a pointer to the curvature function and the initialization vector `y0`, which is then used to approximate the new position.

```
FrenetD frenet(k, y0);
DiffEqVectorD newPosition = frenet.ApproximateDiffEqVector(
                   FrenetD::ApproximationMethodRungeKutta, t/1000.0, h);
transformation = transformation * Trafo2D::trans(newPosition.x0(),
                   newPosition.y0()) ;
```

We have found that an h value of 100 is best suited for performing accurate approximations.

6.3.4.4.4 CorrectedFrenetMovementTracker

The CorrectedFrenetMovemenTracker extends the FrenetMovemenTracker by inserting predefined error-values in all movements. This Tracker is used to mimic any error which is prevalent in the hardware. For example, if the hardware always tends to peer right, the CorrectedFrenetMovemenTracker can be used to create a Tracker which represents this behavior of the hardware. The Callibration TestMoveTask helps in determining the error values needed by the CorrectedFrenetMovemenTracker.

The following values modify the behaviors of the CorrectedFrenetMovemenTracker:

1. `evl`: defines how much percent the left wheel velocity deviates for all incoming movements.
2. `evr`: defines how much percent the right wheel velocity deviates for all incoming movements.
3. `dv`: defines the minimum difference required between the left and right wheel speeds.

The dv value is used to mimic hardware which cannot differentiate between very subtle movement changes. For example, if `dv` is 4, then the wheel speeds `vl=150` and `vr=152` will be translated as `vl=151` and `vr=151` (average).

```
if(dv != 0 && abs(left-right) < dv) {
     left = (left+right)/2;
     right = (left+right)/2;
}
processMovementByTime(t, left + left*evl, right + right*evr);
```

Code 6-4: Modifications to Wheel Speeds by CorrectedFrenetMovemenTracker

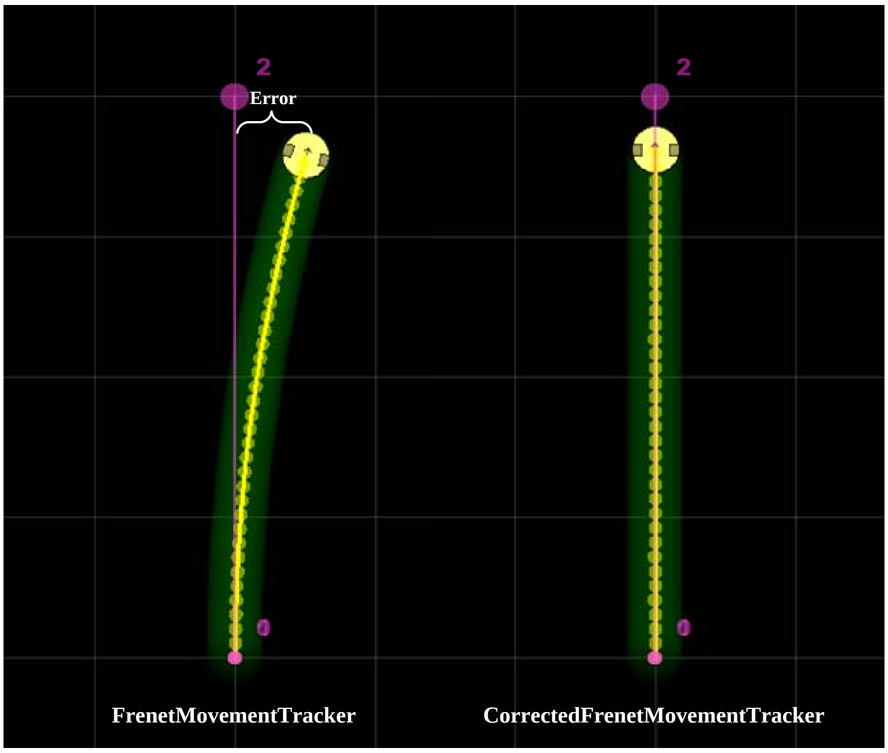
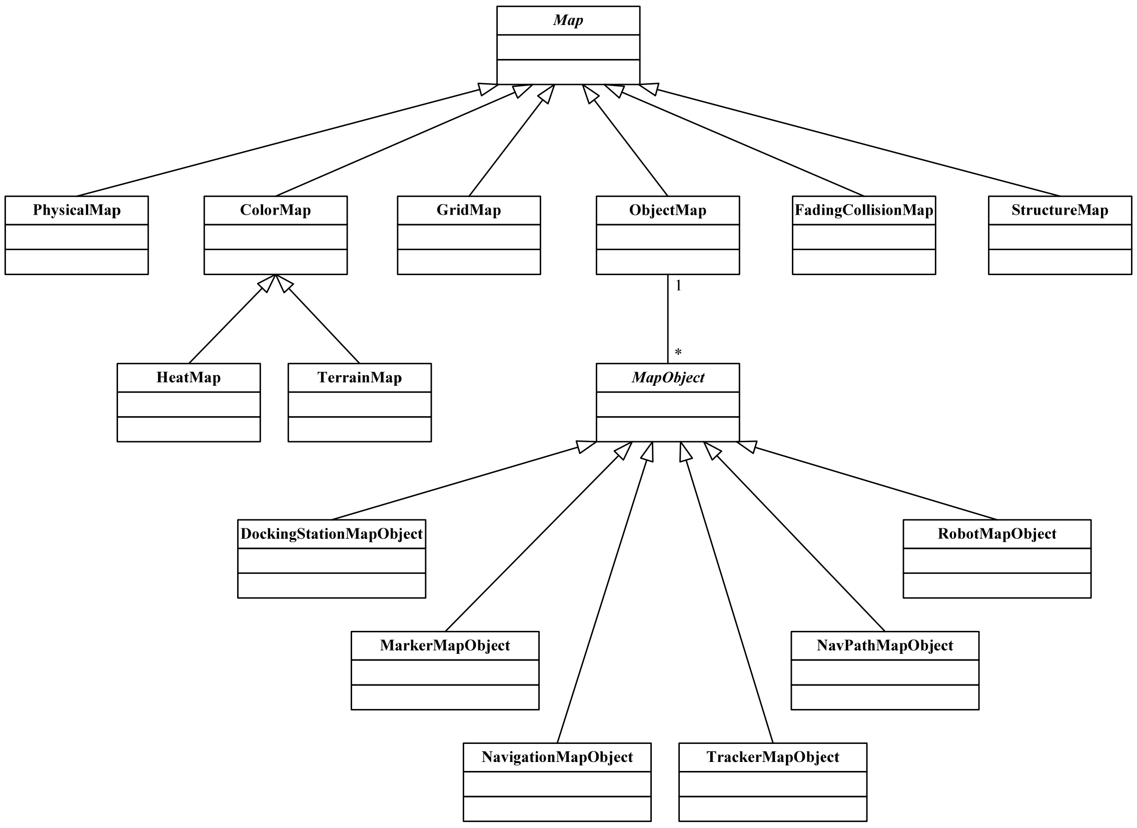


Figure 6-12: Comparison of FrenetMovementTrackers with Corrected Implementation

6.3.5 Map



Maps hold information about the environment. In the *emss* framework there exist several types of Maps, each serving a different purpose. Any Map must define the abstract class `Map`, however they enjoy a significant amount of freedom. The only significant virtual Map method is `paint(...)`, which is used by the Viewports for displaying the map to the user. In addition, any map must provide a width and a height. If a Map does not know its own dimensions, it can consult the *emss* Core for the basic world boundaries. A certain set of functionality shared by both the Heat Map and Terrain Map have been combined into the ColorMap. Self-explanatory Maps, such as the GridMap and ObjectMap, will not be discussed in further detail.

6.3.5.1 PhysicalMap

The PhysicalMap represents the physical environment surrounding the robot. This is used in part for simulating the hardware sensors in an environment, but also for specific navigation such as setting navigation points through a known space.

Both KML files (`.kml`) or image files (`.png`, `.bmp`, `.jpg`) can be loaded into a PhysicalMap. KML files are advantageous as they already contain GPS information for translating the local coordinates to global coordinates. If a plain image is loaded, the GPS offset `Map_PhysicalMap_GPSOffset` along with our implementation of the WGS84 system is used for performing the translation. More information about KML files can be found in „Indoor WPS“ (Aprile & Denzler, 2008).

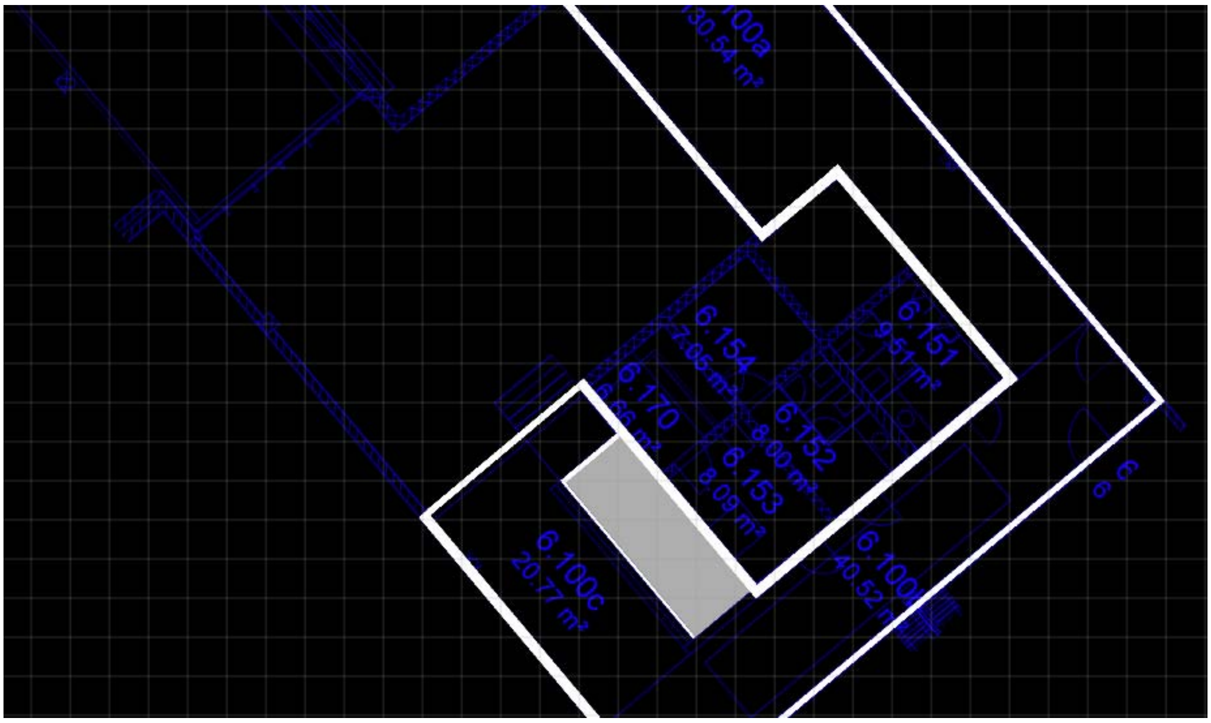


Figure 6-13: Example PhysicalMap Representing a Building Structure

The constructor of the PhysicalMap will attempt to load the file defined in the Core settings (see 10.3.3.4). If the file does not exist, no image is loaded and the PhyiscalMap remains empty. If the file is detected as a KML file, it is parsed by the `KMLGroundOverlay` class, which is a KML parser for Ground Overlay types provided by the Core library.

In order to be able to flexibly make sense of the contents of the image or KML file, some settings must be defined. `Map_PhysicalMap_Color_Wall` and `Map_PhysicalMap_Color_Stairs` define which colors correspond to what kind of data on the map. When the PhysicalMap is queried for information about a specific point on the map by a module, the PhysicalMap will check against these values to return one of the following:

1. `PhysicalMapAreaTypeOpen`
2. `PhysicalMapAreaTypeWall`
3. `PhysicalMapAreaTypeStairs`

6.3.5.2 StructureMap

The StructureMap represents the structure of a room as the robot sees it. It is built up sequentially over time, and requires a certain amount of exploration to be fully generated. The corner points of the Map are extracted from the individual collisions the robot detects. The StructureMap has a special property `isFinished()` which lets a module know if the Map is complete or not. The Map is complete when the last added point is within the defined distance[9] from the starting point.

[9] See the Core setting `Map_StructureMap_FinishTolerance_mm`.

Figure 6-14 shows how StructureMap looks like after performing a WallFollowerTask. Additionally, the density of the corner points is defined by a Core setting[10]. In the case of Figure 6-14, this setting was set to 1000mm (one grid space).

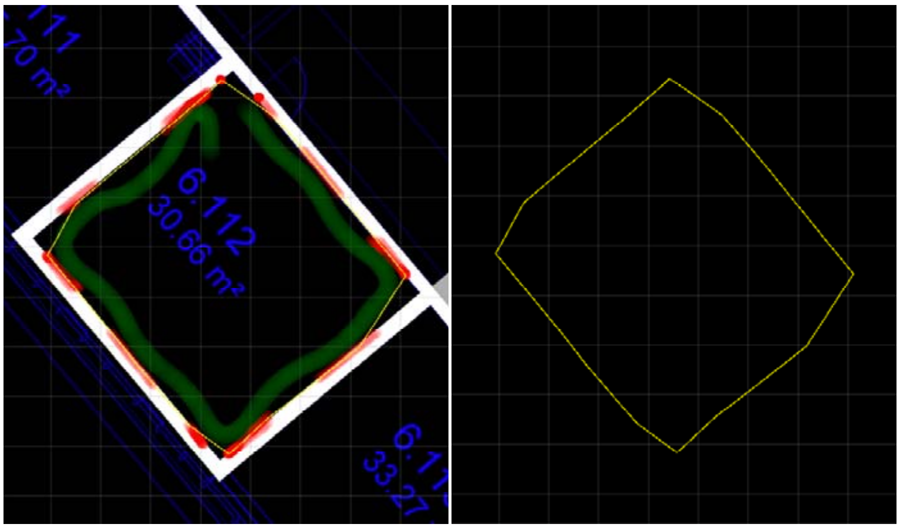


Figure 6-14: Comparison PhysicalMap to StructureMap

If the StructureMap is finished, a module can query the Map to find out whether or not a given point lies inside the closed structure or not. For this it must be determined if the point lies within the polygon which is formed by all the corner points in the StructureMap. This is achieved using the Jordan Curve Theorem (Veblen, 1905). The theorem states the following: a point is within the polygon when the number of intersections from that point from any arbitrary direction is odd, as shown in Figure 6-15.

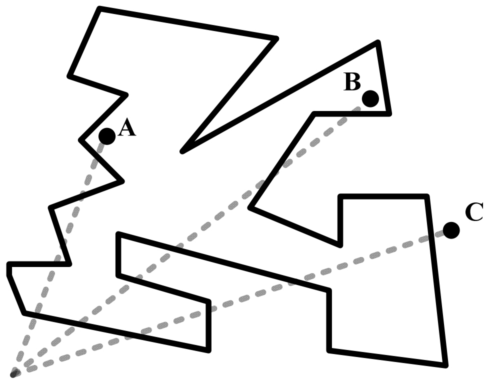


Figure 6-15: Jordan Curve Theorem

If we look at points A and B, we count five intersections with the polygon, which is odd. On the other hand, point C has only four intersections, which is even. This holds true with the Jordan Curve Theorem.

The following code segment shows the algorithm implemented to count the number of intersections and return whether the given point `p` is outside of the StructureMap:

[10] See the Core setting `Map_StructureMap_MinimumDistanceBetweenCollision`.

```
bool StructureMap::isPointOutside(Vector2D p){

     if (!finish) return false;

     double x1, x2;
     double eps = 0.0000001;
     int crossings = 0;

     for(int i = 0; i < polygon.count(); i++){

            // Whether the line goes from right to left or left to right shouldn’t
            // make any difference
            if ( polygon.at(i).x() < polygon.at( (i+1) % polygon.count() ).x() ){
                   x1 = polygon.at(i).x();
                   x2 = polygon.at( (i+1) % polygon.count() ).x();
            } else {
                   x1 = polygon.at( (i+1) % polygon.count() ).x();
                   x2 = polygon.at(i).x();
            }

            // Check if the line possible could intersect the point.
            if (p.x() > x1 && p.x() <= x2 && ( p.y() < polygon.at(i).y() ||
                    p.y() < polygon.at( (i+1)% polygon.count() ).y() )){

                   double dx =
                     polygon.at( (i+1)% polygon.count() ).x() - polygon.at(i).x();
                   double dy =
                     polygon.at( (i+1)% polygon.count() ).y() - polygon.at(i).y();
                   double m = 0;

                   // Lines which are perpendicular to the point p (dx < eps) may
                   // not be considered...
                   if (abs(dx) < eps )        m = INT_MAX;
                   else                       m = dy/dx;

                   // Calculate line axis intersection
                   double b = polygon.at(i).y() - (m * polygon.at(i).x());

                   // The line height can be determined using the slop m
                   // axis intersection b
                   double y2 = m * p.x() + b;

                   // If p.() is smaller than y2 then this line is intersected.
                   if (p.y() <= y2) crossings++;
            }
     }

     // If the number of crossings is event, the point is inside, otherwise
     // it is outside.
     if (crossings %2 == 1)     return false;
     else                       return true;
}
```

Code 6-5: Implementation of the Jordan Curve Theorem

6.3.5.3 ColorMap

The ColorMap incorporates common routines needed by Maps which work in a two-point-five-dimensional (2.5D) color space, meaning Maps which have a specific color value for every two-dimensional coordinate. In addition to providing query functions such as `getPixelValue(x,y)` and `getChannelValue(...)`, the `ColorMap` class manages the memory for the underlying data.

6.3.5.3.1 HeatMap

The HeatMap is built to visualize the discovered environment of the robot. When the robot moves through its environment, the MovementTrackers send signals to the appropriate Maps, such as the HeatMap, registering various kinds of "heat". The Heat Map supports two kinds of heat: *Open Area* and *Collision Area*. *Open Area* is displayed as green, and portrays the robots path through the environment, while *Collision Area* is displayed as red, and represents any sort of collision or obstacle, forming the environments boundary. The HeatMap can be consulted by different Core modules in order to make decisions, such as navigational choices. In addition, other influences, such as a user, can also color the HeatMap manually for diagnostic reasons such as staking out a territory.

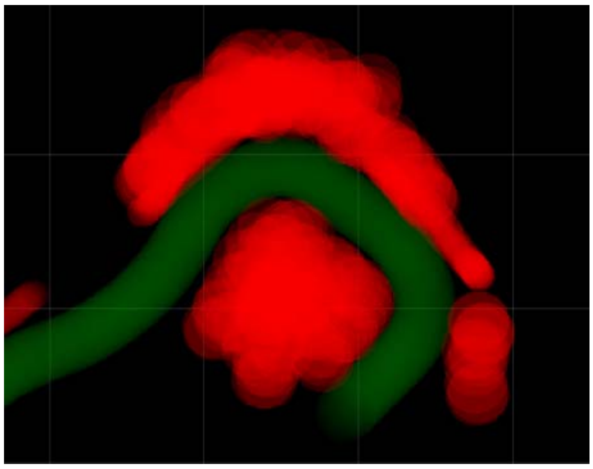


Figure 6-16: HeatMap Displaying Open Area (green) and Collision Area (red)

6.3.5.4 FadingCollisionMap

The small error in localization of the robot overtime leads to greater error, which in turn can result in „phantom objects". These phantom objects are the ghosts of previously detected obstacles, where the error in localization has shifted the robots position over time, misaligning the current position and the data on the HeatMap compared with the real world. However, where the HeatMap claims to see an object, there actually is no object anymore relative to the believed (localized) position. This yields a problem when trying to safely navigate using the HeatMap: suddenly the robot will avoid these phantom objects, although nothing is in its way. Using the current sensors alone is not efficient, as a detected drop needs to be remembered in some extent to make sure to avoid it completely – some sort of remembering map must be used. This is where the FadingCollisonMap comes to use. It does exactly what the name implies: it slowly fades away the detected collisions over time, only remembering the local most recent collisions. This has proven to work very well when navigating an unknown environment, even when the localization is not stable.

To register collisions in the Map, a new structure is defined:

```
struct FadingCollision {
     Vector2D position;
     double radius;
     QTime time;
};
```

Now, whenever the FadingCollisionMap is queried by, for example, the Navigation module, first the method `fadeOldCollisions(...)` is called, which in turn „fades away" any old collisions which are no longer considered relevant.

The reason the method of using time as a quantifier for deciding which collisions to use and which not works well is because, at time t, the accuracy of a given collision at time $t - dt$ is propertional to dt (older collisions have a greater dt value).

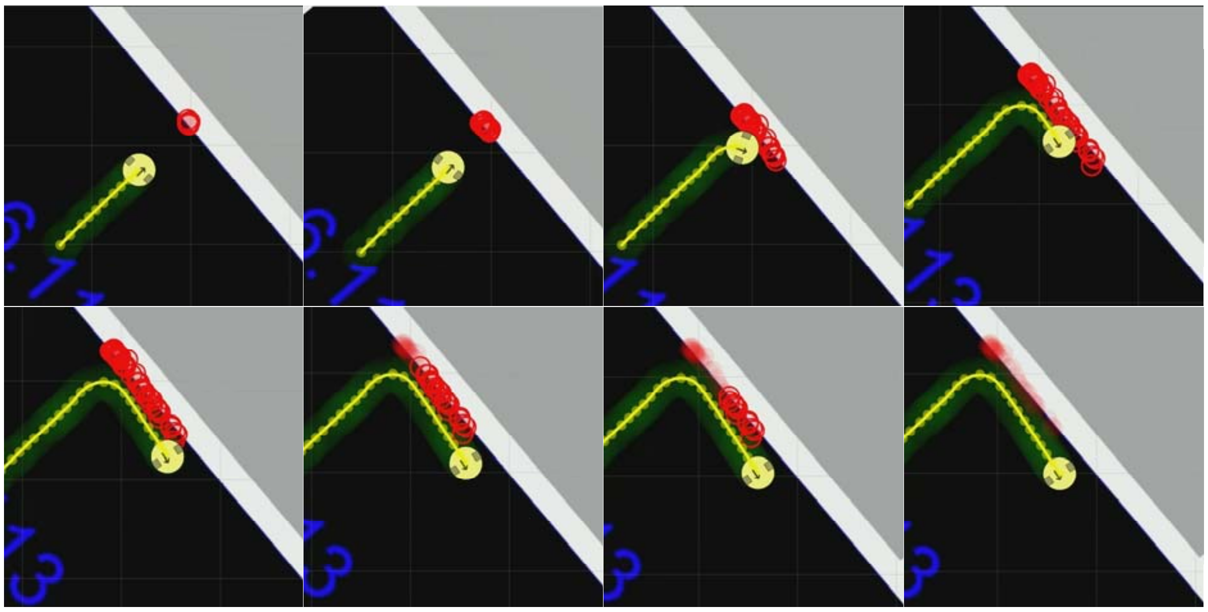
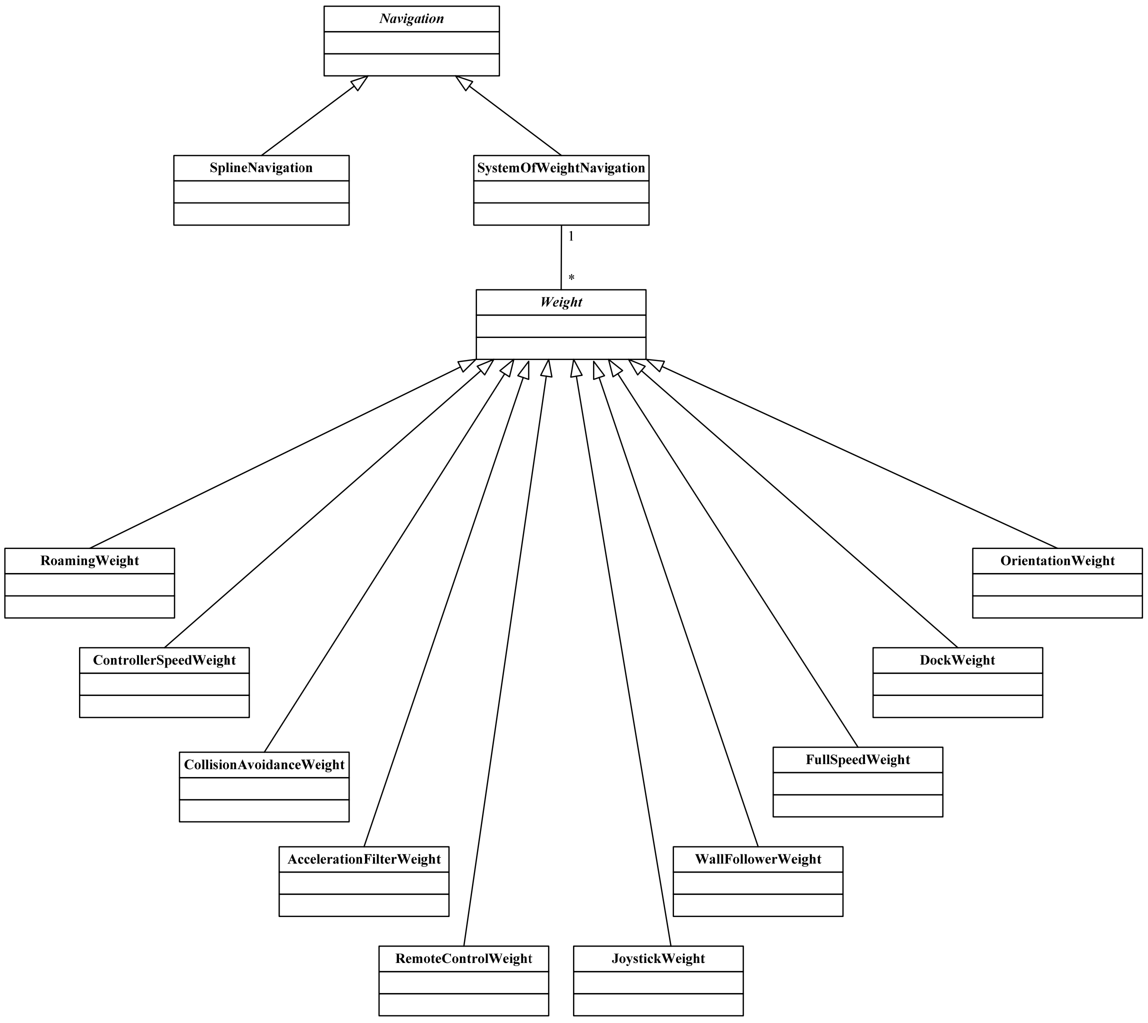


Figure 6-17: FadingCollisonMap in Action

6.3.6 Navigation



The Navigation module is responsible for accepting navigation points and translating them to commands with which the Controller can use to directly steer the robot through the path of these navigation points. Any implementation of the Navigation module must inherit from the `Navigation` class and implement the method `getWheelSpeed(...)`. Everything related to the management of navigation points is implemented by the `Navigation` class – implementations do not need to toil with this. The Navigation module by itself cannot actually navigate the robot – that is, actually send commands to the Controller. This must be done by a Task which collects the navigational information from the Navigation module and forwards it to the Controller. Typically such a task will automatically add new navigational points and make decisions when to abort or finish navigating.

6.3.6.1 SplineNavigation

The SplineNavigation module is the original navigational implementation in the *emss* framework, and has mostly been replaced by the newer, more dynamic, SystemOfWeightsNavigation. The underlying mechanism used for navigation by the SplineNavigation module are spline curves.

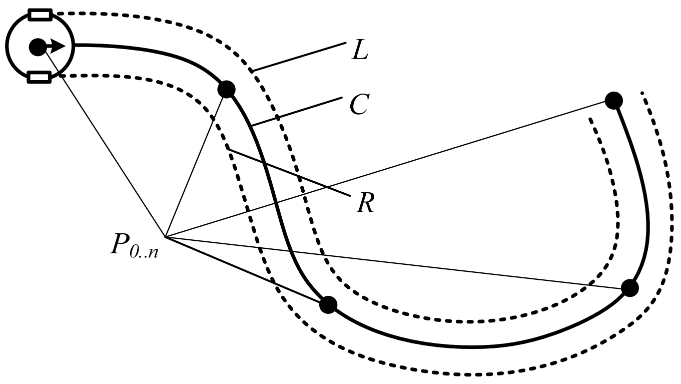


Figure 6-18: Navigation Using Splines

We can use spline curves to directly control the movement of the two-wheeled robot by calculating the first derivative of the spline; speed. In this scenario, each wheel must have its own spline curve to drive along, based on the given navigation points. The navigation points $P_{0..n}$ are defined by a finite series of n coordinates which the robot must visit in sequential order. Using these points we construct a spline curve C of n nodes which represents the navigational curve in a two-dimensional space. This curve is the path the center axis of the robot must pass through when traversing the points $P_{0..n}$. However, we need the curves for both the left and right wheel if we want to directly control the differential steering system. To create these curves all we need to do is traverse C and create and a corresponding offset curve L and R for each wheel (Figure 6-18). The nodes for these curves can be determined by sequentially calculating the first derivative of the navigational curve C, i.e. the tangent to the curve, and shifting it in the direction of the normal vector at that point on the curve either to the left or right. Care needs to be taken to create the wheel splines with a fixed distance between the nodes. Failing to do so will cause the yielding speeds from the wheel spline derivative to be disjoint from the navigational path.

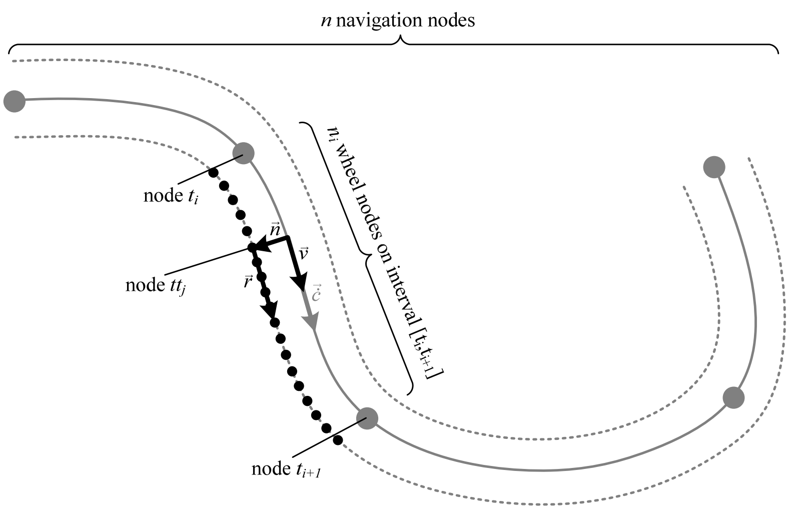


Figure 6-19: Creating Wheel Spline Nodes from a Navigation Curve

A problem with using splines with a non-real-time system, such as the *emss* framework, is that the small deviations in the interval at which Controller commands are sent result in inaccuracy throughout the navigation. In many cases, when navigating along a spline the robot will peer slightly off track. To correct this, we undertake three different means:

1. When a navigation point has been reached, the position of the navigation point is corrected to the current position of the robot and the spline is rebuilt. This keeps the spline an accurate reflection of how the robot must move.
2. If the interval at which the Controller is sent the movement commands varies, the spline is automatically rebuilt. This allows the defined time interval for the left and right wheel spline nodes to automatically adjust to the current Controller interval.
3. If during the navigation from one navigation point to another the robot moves off track from the spline, we immediately correct this. This is achieved using the following algorithm, called "magnet tracking":

```
// Get the transformation matrixes of our 'real' position and the position
// we should be on the spline. From these we calculate the correction
// matrix needed to undo the error. Based the correction angle we peer
// to the left or to the right...
Trafo2D wheels = internalGetWheelTransformation(node,t);
Trafo2D robot = core->tracker->getTransformation();
Trafo2D correction = wheels * robot.inv();

// Peer to the left or right based on the correction angle. The
// amount we peer is directly related to the size of the angle, so
// if the angles are very different, we will peer much faster to correct
// our angle...
double peerStrength = 150.0;
double angle = Deg(correction.angle());
if(angle > 0) {
    dvl = -peerStrength * angle/180;
    dvr = peerStrength * angle/180;
} else {
    dvl = peerStrength * -angle/180;
    dvr = -peerStrength * -angle/180;
}
```

The result of these three measures taken proves as a significant enhancement. When the robot tries to drift away from the navigational spline due to timing inaccuracies, it is automatically put back on track by the magnet tracking mechanism.

6.3.6.2 SystemOfWeightsNavigation

We consider the SplineNavigation module to be a mechanical method for controlling a differential steering system, as the entire path for navigation is pre-determined and then executed. The start and end are given, the execution is calculated, and then faithfully realized. When the state of the environment changes, such as an unforeseen obstacle appears, the spline must be altered by changing or appending navigation points – an undesired effect in the design. An alternative to the SplineNavigation approach, is the navigation using a system of weights – the SystemOfWeightsNavigation module. Unlike the spline approach, the SystemOfWeightsNavigation is completely dynamic and reacts (almost) solely on the current perception on the state of the environment at that moment of time. Thus we call it organic, because it constantly adapts to its surrounding environment. In a sense, it is not interested how it will exactly reach its goal, but rather how it will at that moment of time in that current state strive towards its goal.

Essentially, the system revolves around two variables; the left and right wheel speed v_L and v_R. These create a channel (or pipeline) of weights $W[v_L, v_R]$ in which different weights can be independently attached to, defined as

$$W\begin{bmatrix} v_L \\ v_R \end{bmatrix} = \vec{v} \Big] = w_{i-1}(\vec{v}) \cdot w_i(\vec{v}) \quad : \quad i = 1..n$$

where n is the number of weights in the channel and $w_{0..n}$ are the functions which define the weights.

Such weights influence the variables v_L and v_R by altering them based on external inputs such as sensors or information from maps. On the channels one end raw zero speeds $v_{L_{in}} = 0,\ v_{R_{in}} = 0$ come in, which are then altered by the system of weights, and on the other end the final speeds $v_{L_{out}}, v_{R_{out}}$ come out, which in turn are sent to the controller. Each weight in the system works independently from others, using only the channel inputs or its own inputs.

Such a channel is demonstrated below in Figure 6-20, where α is the angle to next navigation point, $s_{collision}$ is the distance to an obstacle ahead in percent relative to the maximum distance possible, and ε is either 0 or 1 indicating if a emergency stop should be undertaken. The example shows how a sequence of well placed weights can perform simple navigation.

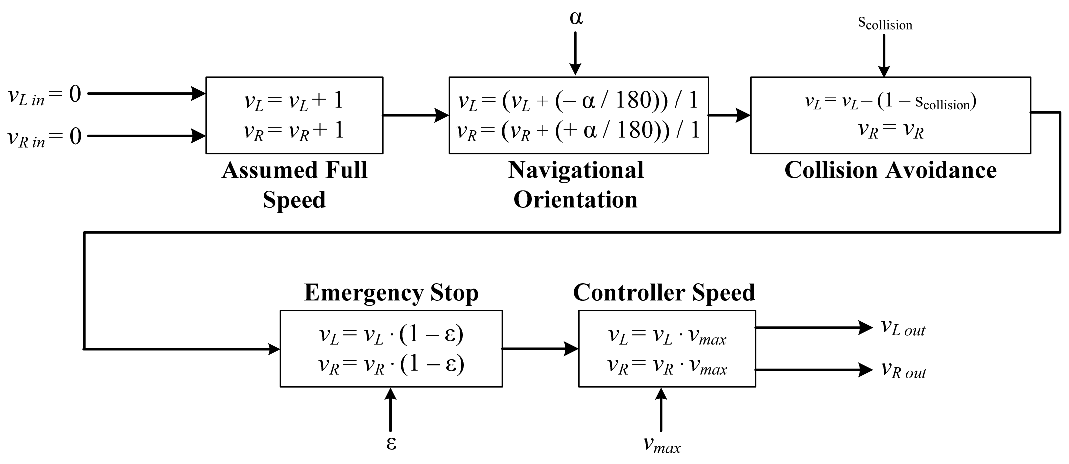

α
$s_{collision}$
$v_{L\,in} = 0$
$v_{R\,in} = 0$
$v_L = v_L + 1$
$v_R = v_R + 1$
Assumed Full Speed
$v_L = (v_L + (-\alpha / 180)) / 1$
$v_R = (v_R + (+\alpha / 180)) / 1$
Navigational Orientation
$v_L = v_L - (1 - s_{collision})$
$v_R = v_R$
Collision Avoidance
Emergency Stop
$v_L = v_L \cdot (1 - \varepsilon)$
$v_R = v_R \cdot (1 - \varepsilon)$
ε
Controller Speed
$v_L = v_L \cdot v_{max}$
$v_R = v_R \cdot v_{max}$
v_{max}
$v_{L\,out}$
$v_{R\,out}$

Figure 6-20: Example System of Weights Channel

A more complex system can be created by adding additional inputs to the different weights, and of course by adding additional weights, which has been realized in the *emss* framework. The `SystemOfWeightsNavigation` class is very simple in itself – only providing the necessary methods for the administration of weights, such as adding, removing, disabling, et cetera. The power in this Navigation module lies within the weights.

Any Task can easily configure the SystemOfWeightsNavigation module to suit it needs, as illustrated below for the DockAndChargeTask. Obviously, the order for which the weights are placed in the channel alter the way the system reacts.

```
navigation->deleteAllWeights();
navigation->addWeight(new JoystickWeight(core));
navigation->addWeight(new RemoteControlWeight(core));
navigation->addWeight(new DockWeight(core));
navigation->addWeight(new CollisionAvoidanceWeight(core,
                        CollisionAvoidanceWeight::AvoidanceDirectionAuto));
navigation->addWeight(new AccelerationFilterWeight(core));
navigation->addWeight(new ControllerSpeedWeight(core));
```

Code 6-6: Example Configuration of SystemOfWeightsNavigation Module

6.3.6.3 Weights

Each weight in the SystemOfWeightsNavigation weight-channel must inherit from the `Weight` class. The only method which needs to be implemented is the `process(...)` method, which is called sequentially for each weight in the channel when determining the output of the channel. The SystemOfWeightsNavigation passes its current channel value as a two-dimensional vector (for the left and right wheel) to the `process(...)` method. Each weight can then consequently alter the channel value as it pleases. Documented below are the most important Weights in the *emss* framework.

6.3.6.3.1 FullSpeedWeight

The FullSpeedWeight defines the starting value for any channel which assumes it should go ahead at full speed. All it does is set the left and right wheel speeds to full (1.0). The `process()` method of the FullSpeedWeight is as follows:

```
virtual void process(Vector2D &v) {
     v = Vector2D(1.0,1.0);
};
```

6.3.6.3.2 OrientationWeight

The OrientationWeight influences the channel value, or left and right wheel speed, so that the robot will orientate itself towards the next navigational point. To do this, the current position of the robot must be determined as well as the position of the destination. From this, the angle α to the destination is determined:

$$\alpha = 2 \cdot \tan^{-1}\left(\frac{dest_x - pos_x}{\sqrt{(dest_y - pos_y)^2 + (dest_x - pos_x)^2} + dest_y - pos_y}\right)$$

Using the angle α it is determined how to alter the wheel speeds. If the destination is directly behind the robot ($\alpha = 180°$), the wheel speeds must be changed drasticly, however, if the destination is directly infront of the robot $\alpha = 0°$, the wheel speeds must not be altered at all. This is realized by the following code segment:

```
Vector2D position = core->tracker->getTranslation();
Vector2D destination = core->navigation->getCurrentDestination();
double alpha = -Deg(angle(position,destination)) - core->tracker->getRotation();
if(alpha > 180.0) alpha = -360.0 + alpha;
if(alpha < -180.0) alpha = 360.0 + alpha;
v = v + Vector2D( (-alpha/180.0)/1.0 , (+alpha/180.0)/1.0 );
```

Code 6-7: OrientationWeight Modification in Weight-Channel

6.3.6.3.3 JoystickWeight

The JoystickWeight binds the signals from a Joystick widgets into the channel. When the joystick's yokes are idle (zero), the JoystickWeight will have no influence. However, when the yokes are active the Weight will alter the wheel speeds to correspond to the movement of the joystick.

```
double yokeX = core->joystick->getYokeX();
double yokeY = core->joystick->getYokeY();
double tolerance = 0.06;
if (yokeY == 0 && yokeX == 0) return;
else if (yokeY <= tolerance && yokeY >= -tolerance) {
     v = Vector2D( -yokeX, yokeX );
} else {
     v = Vector2D(yokeY - (yokeY * yokeX), yokeY + (yokeY * yokeX));
}
```

Code 6-8: JoystickWeight Modification in Weight-Channel

6.3.6.3.4 RemoteControlWeight

So that the robot can also be controlled via a remote-control, the RemoteControlWeight is provided. This weight checks the incoming infra-red signals from a remote-control and reacts correspondingly.

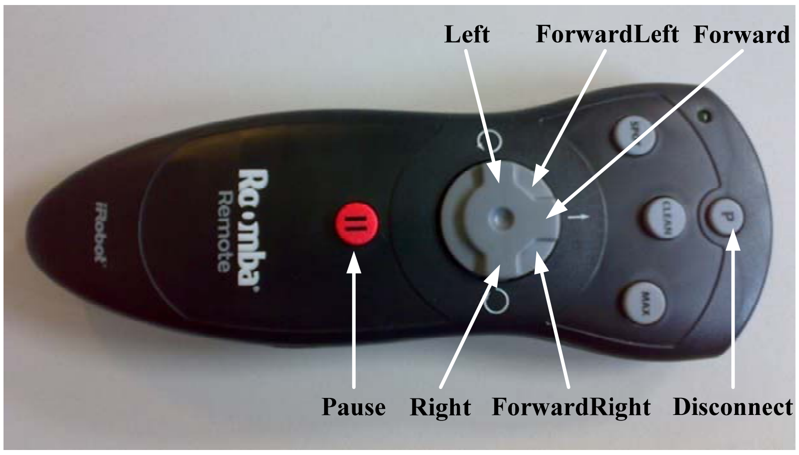


Figure 6-21: Remote Control Button Layout

The following functions are implemented:

Button	Description
Left	Turns the robot left around its own axis
ForwardLeft	Moves the robot forwards while peering to the left
Forward	Moves the robot forwards
ForwardRight	Moves the robot forwards while peering to the right
Right	Turns the robot right around its own axis
Pause	Interrupts the currently running Task (if any)
Disconnect	Core is disconnected

Table 6-1: Description of Remote Control Commands

6.3.6.3.5 CollisionAvoidanceWeight

This Weight is responsible for avoiding all kinds of collisions. It must avoid collisions in the distance (via the IR-sensor), contact collisions (via the bumper), and drop collisions (via cliff-sensors). In addition to attempting to avoid these collisions, it also must be able to resolve a situation if a collision was encountered. The CollisionAvoidanceWeight relies heavily on the FadingCollisionMap, detailed in Section 6.3.5.4. This Map serves as the underlying data source for preemptively avoiding a collision. The Weight has five different modes for handling the various situations:

1. `NORMAL`: No collision or obstacle detected, continue ahead…
2. `OBSTACLE_ENCOUNTER`: An obstacle has been encountered, mark where it is and try to decide which direction to avoid it.
3. `OBSTACLE_AVOIDANCE`: We've made a decision how to avoid the obstacle, move away from it!
4. `DROP_AVOIDANCE`: A drop has been detected, avoid it by reversing a given distance.
5. `BUMPER_AVOIDANCE`: The bumper was pressed, avoid the obstacle by reversing.

When in `OBSTACLE_ENCOUNTER` mode, the Weight intelligently avoids an obstacle by turning away from it and if needed by correcting the original direction for which it turned away. This is achieved by first arbitrarily choosing any direction to turn (this is in fact the last direction which was used to avoid the last seen obstacle). Initially turning before making a proper decision is necessary because no information about the obstacle can be gathered from the IR-sensor if the robot drives straight towards it. Once the robot has started turning, and the Weight has waited a small distance, it can assess the situation again to determine if the direction it is turning is incorrect, or, in other words, if the obstacle it is trying to avoid is actually getting closer.

The assessment is accomplished by keeping track for the first original encounter with the object cp_1 as well as the position of the robot at that time tr_1, and the current encounter with the object cp_2 along with the current position of the robot tr_2 (as shown in Figure 6-22). Then the angle β between the two vectors $\overrightarrow{tr1cp1}$ and $\overrightarrow{cp1cp2}$ is:

$$\beta = \cos^{-1}\left(\left\|\overrightarrow{tr1cp1}\right\| \cdot \left\|\overrightarrow{cp1cp2}\right\|\right).$$

If β is less than 90°, the direction must have been wrong and should be corrected.

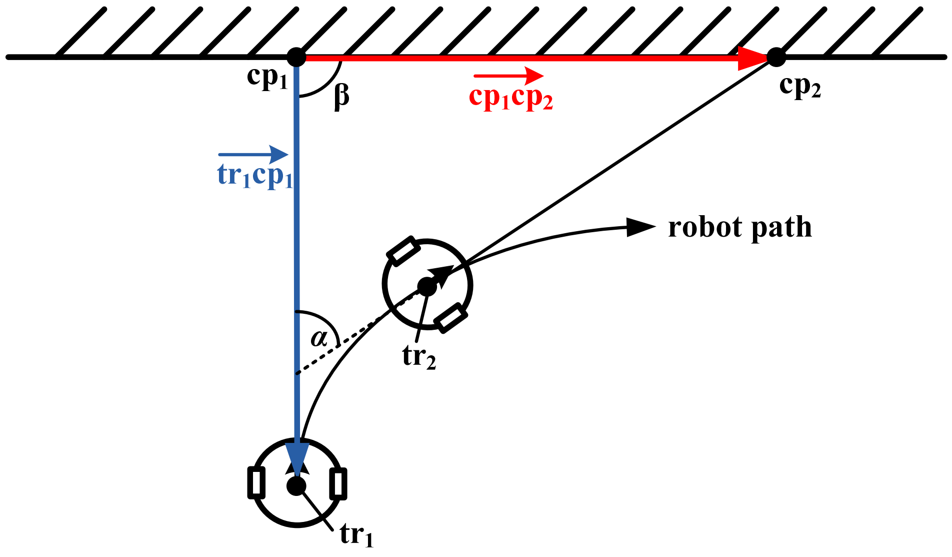


Figure 6-22: Making the Collision Avoidance Assessment

6.3.6.3.6 WallFollowerWeight

This Weight is used to follow walls. The first step is to find the wall. Because the robot may not have any idea about the current structure of the room, it begins by driving straight ahead until it detects an obstacle. At this point, if the obstacle was detected using the forward-looking IR-sensor, the obstacle must be avoided. If, however, the obstacle was detected using the wall-sensor, this obstacle (presumed to be a wall) must be followed. When such a wall has been found, the WallFollowerWeight will continuously go back and forth between seeing and not-seeing the wall, trying to navigate along the wall at the edge of the wall-sensors range. If the wall is lost or unseen for a longer period of time, the WallFollowerWeight will restart, searching for a new wall. The exact workings of the WallFollowerWeight are detailed in Figure 6-23 below.

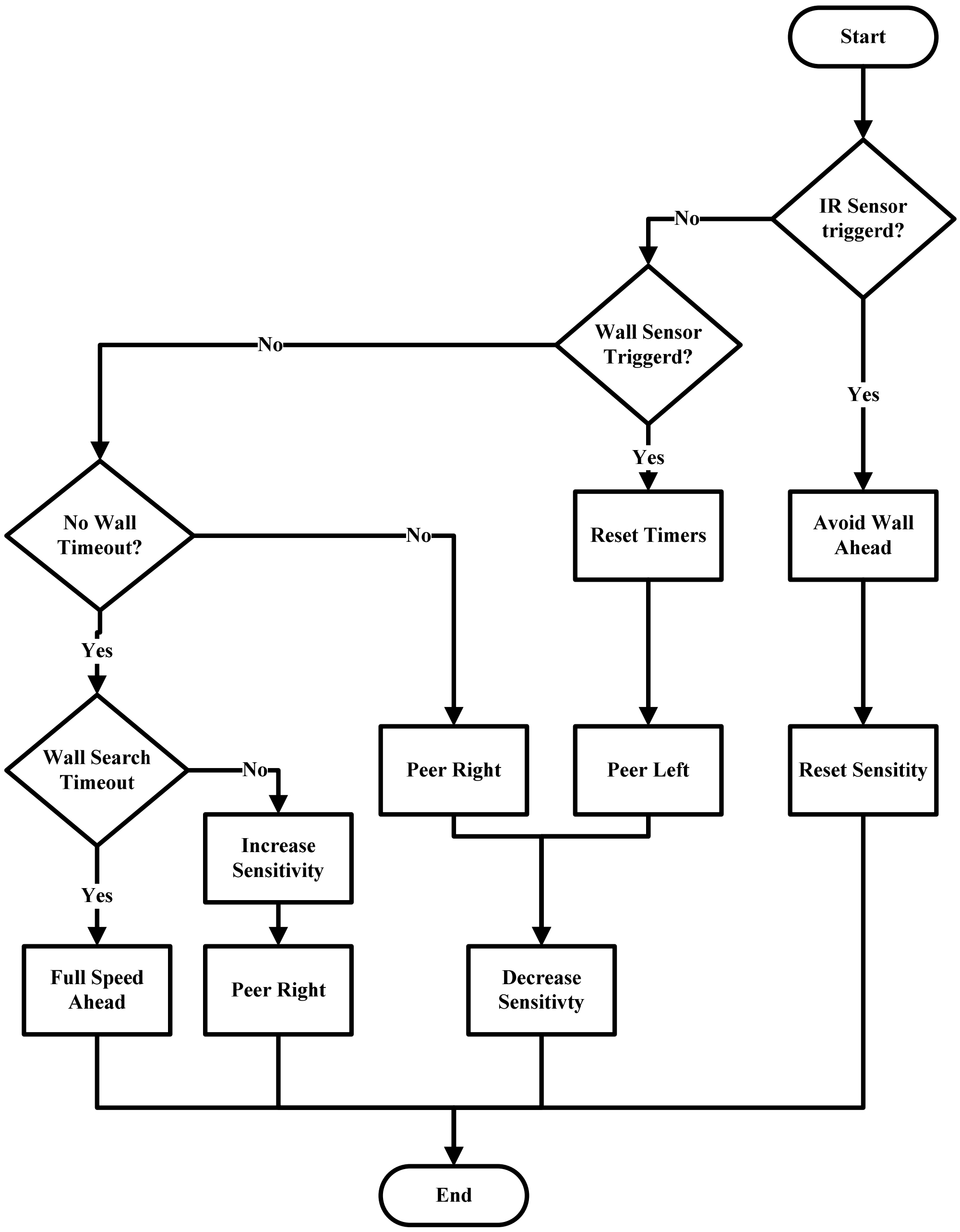


Figure 6-23: Flow Chart of the WallFollowerWeight

6.3.6.3.7 DockWeight

The DockWeight is responsible for docking the robot on the docking station when it is close by. Docking the robot requires a complex dance in which the different IR-beams are followed and avoided until the robot places all its charging contacts on top of the docking station contacts. This procedure is very complex in the real world because of the inaccuracy of the IR-beams as well as the precision required to successfully dock. To be able to dock the robot, the charging station sends out several beams, as illustrated in Figure 6-24.

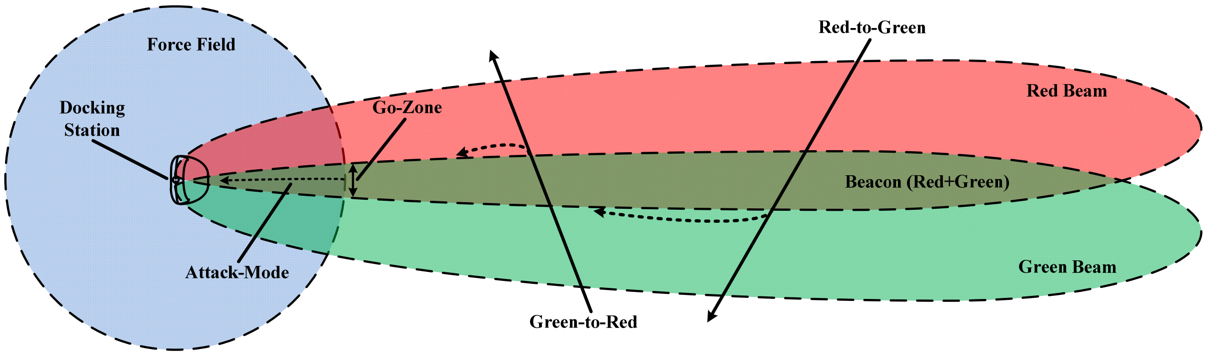


Figure 6-24: Docking Station Schematics

The following describes the schematics of the docking station and the strategy in which the robot is docked:

1. Force Field: Signal that is received when close to the docking station.
2. Red Beam: Signal that is received typically to the right of the docking station.
3. Green Beam: Signal that is received typically to the left of the docking station.
4. Beacon: Area in which both the red and green beam is received.
5. Red-to-Green: Passing of the red beam to the green beam.
6. Green-to-Red: Passing of the green beam to the red beam.
7. Go-Zone: Boundary of the force field in which the attack-mode is executed.
8. Attack-Mode: Last sprint to dock the robot. Extra speed is required here.

From looking at the schematics, it is obvious how the docking strategy works. When passing red-to-green, the robot must turn right. Similarly, when passing green-to-red, the robot must turn left. This is repeated until the force field is arrived, for which the robot will go straight to attempt docking. However, this strategy is far more complex when you leave the simulation environment. There are many differences in the real world, particularly to do with the red and green beams and the resulting beacon. These beams tend to "move" depending on the environment. Furthermore, as the robot moves, it influences the signals by reflecting them, making the behavior of the signals confusing to determine. In addition, interference can occur at any time where signals may temporarily be lost, causing a flickering effect. All these factors make the docking procedure complicated.

Similar to the CollisionAvoidanceWeight, the DockWeight also has several modes:

1. `unknown`: An IR-beam has not yet been detected, go straight ahead
2. `homing`: A red or green IR-beam has been detected, follow the beacon
3. `attack`: The force-field is detected, try to dock the robot
4. `search`: The IR-beams have been lost, try to search for them again
5. `retry`: Docking was unsuccessful, retry the whole scenario

The most important mode is the `homing` mode, which is responsible for bringing the robot to the Go-Zone. To overcome the difficulties described above, a data structure as been defined which encapsulates a snapshot of the docking station IR-signal. Each time the signal changes its state, it is appended to the `irlog` – a list of all the states. The list then can be parsed to determine the latest red-to-green or green-to-red state, for example, which is the key to successfully docking. Using the `irlog`, any mode can filter through the list and grab the information it needs while ignoring any other, such as a unrecognized signal due to interference.

6.3.6.3.8 AccelerationFilterWeight

The AccelerationFilterWeight regulates the acceleration in the weight-channel. Upon each `process(...)`, the Weight compares the new incoming value with the last value. If the difference is greater than the maximum allowed difference, the new value is cut short. This prevents jumps in velocity from, for example, 0 (stopped) to 1 (full speed). Such jumps are unfriendly for the hardware and are prevented by the AccelerationFilterWeight.

```
f = Weight_AccelerationFilterWeight_MaxSpeedChange;
dv = v - vOld;
if( dv.x() > f || dv.x() < -f ) dv = dv.x()*f , dv.y();
if( dv.y() > f || dv.y() < -f ) dv = dv.x() , dv.y()*f;
v = vOld + dv;
```

Code 6-9: AccelerationFilterWeight Modification in Weight-Channel

Figure 6-25 shows the difference of resulting speeds of similar actions. The top is without the acceleration filter, and has much harder changes in velocity, while the bottom is with the filter, and has much smoother changes.

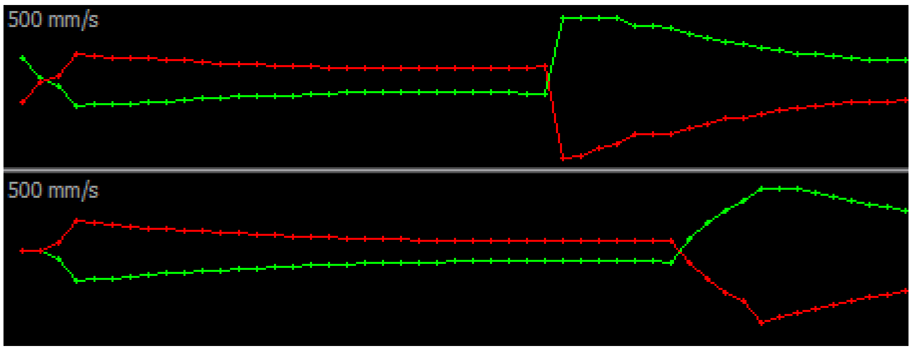


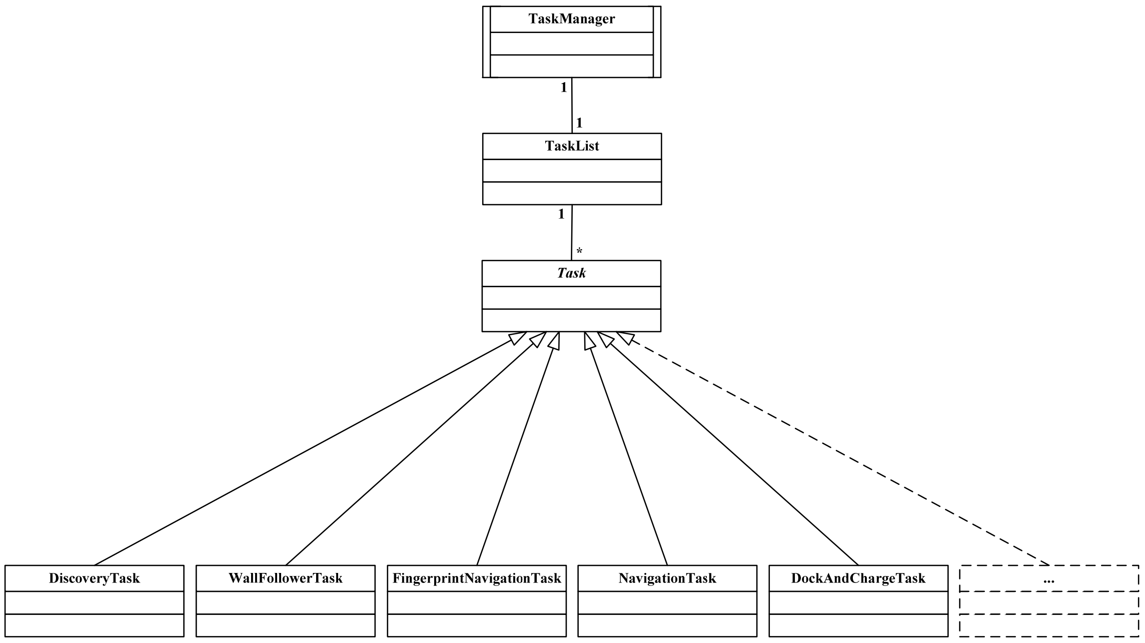
Figure 6-25: Speed Graph with AccelerationFilter and without

6.3.6.3.9 ControllerSpeedWeight

The ControllerSpeedWeight is only needed to move the weight-channel from a spectrum of `0..1` to $0..v_{max}$, where v_{max} is the maximum desired speed (or target speed) of the robot. This greatly simplifies the implementations of other Weights as they need only work with percentages, and need not to take into account the target speed of the robot.

```
virtual void process(Vector2D &v) {
     v = v * core->controller->targetSpeed;
};
```

6.3.7 Task



6.3.7.1 TaskManager

The TaskManager is an essential part of the *emss* Core and is responsible for scheduling and executing Tasks. It inherits from `CoreThread`, so it runs in its own thread. The scheduling and execution of Tasks occur within the same run-loop.

Internally, the TaskManager maintains a special queue called TaskList. This data structure is similar to a queue, except it extends features to enable the extraction of specific Tasks, such as *ready-for-execution* Tasks only. When a Task is added to the TaskList and scheduled for execution, its `process()` method is called repetively by the TaskManager which in turn performs the execution of the Task. Because of this architecture, the `process()` method of an individual Task may not block or delay for a long time as the Watchdog will kick in and report the TaskManager as a runaway `CoreThread`.

When enabled, the TaskManager maintains a special Task called the IdleTask. This Task is automatically scheduled for execution when there are no Tasks within the TaskList which are waiting to be executed. Commonly, the IdleTask is a diagnostic Task, such as a JoystickNavigationTask which allows the navigation of the robot by joystick.

Tasks may have the following statuses:

1. `Waiting`: Task is waiting to be scheduled for execution.
2. `Running`: Task is currently being executed.
3. `Finished`: The Task has finished its execution successfully.
4. `Interruped`: The Task has been interrupted by an external module and is no longer being executed.

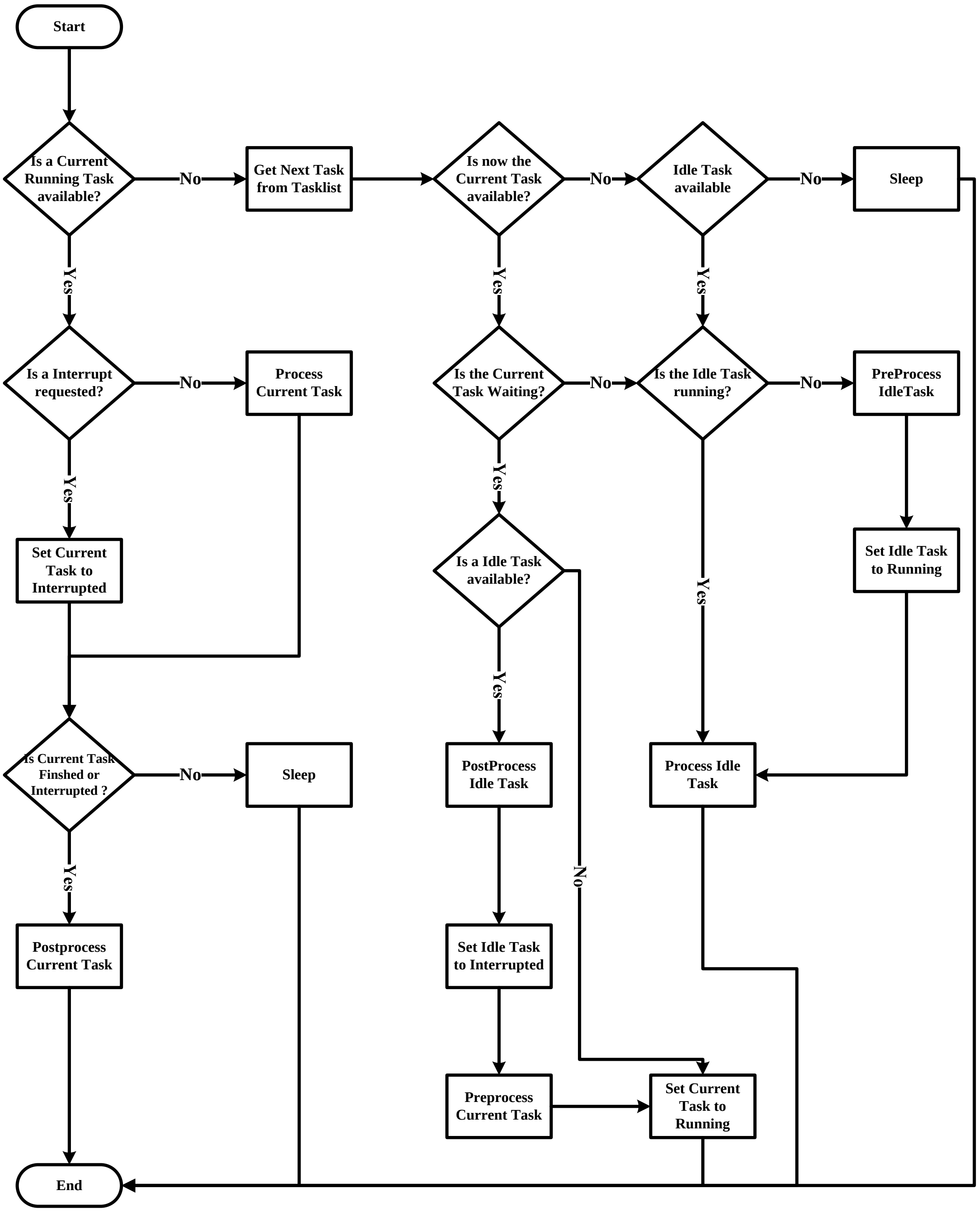
In addition to the status, each Task may also have a priority assigned to it:

1. `Normal`: Task is put at the back of the waiting list.

2. `Immediate`: All other Tasks are interrupted and the Task is executed immediately.

Because a Task may be interrupted at any time, and possibly re-scheduled at a later time, a `preProcess()` and `postProcess()` may optionally be implemented. The `preProcess()` method is called just before the Task is scheduled for execution, and `postProcess()` just after.

The TaskManager scheduling routine is described in detail below in Figure 6-26. The most important Tasks are described in Sections 6.3.7.2 through 0.



Start
Is a Current Running Task available?
No
Get Next Task from Tasklist
Is now the Current Task available?
No
Idle Task available
No
Sleep
Yes
Yes
Yes
Is a Interrupt requested?
No
Process Current Task
Is the Current Task Waiting?
No
Is the Idle Task running?
No
PreProcess IdleTask
Yes
Yes
Set Current Task to Interrupted
Is a Idle Task available?
Set Idle Task to Running
Yes
Yes
Is Current Task Finshed or Interrupted ?
No
Sleep
PostProcess Idle Task
Process Idle Task
No
Yes
Postprocess Current Task
Set Idle Task to Interrupted
Preprocess Current Task
Set Current Task to Running
End

Figure 6-26: TaskManager Scheduling Routine

6.3.7.2 WallFollowerTask

The boundary of a room is best found by following its wall – if the room is closed, at least. To allow the robot to follow walls and investigate the structure of the room the WallFollowerTask has been implemented. This Task initializes the SystemOfWeightsNavigation weight-channel best suited to follow walls. The weight-channel is setup as follows:

$$\rightarrow FullSpeedWeight \rightarrow WallFollowerWeight \rightarrow CollisionAvoidanceWeight \\ \rightarrow AccelerationFilterWeight \rightarrow ControllerSpeedWeight \rightarrow$$

The most important Weight is the WallFollowerWeight, which is described in detail in Section 6.3.6.3.6. The StructureMap is finished or completed (the polygon is closed), the WallFollowerWeight finishes.

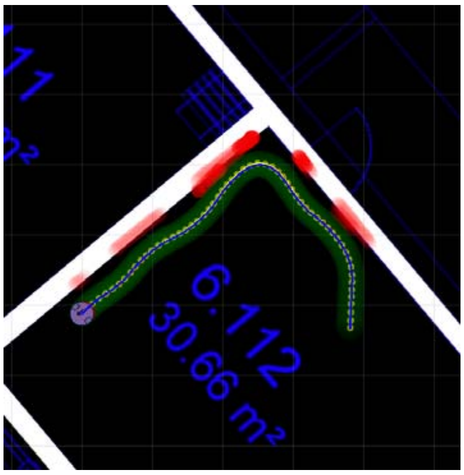


Figure 6-27: Use of WallFollower

6.3.7.3 NavigationTask

The NavigationTask sequentially navigates through all the navigation points contained within the Navigation module. Essentially, all the NavigationTask does is query the Navigation module for the wheel speeds which it then forwards to the Controller. For the SystemOfWeightsNavigation module, the following Weights are added during the Task's `preProcess()`:

$$\rightarrow FullSpeedWeight \rightarrow OrientationWeight \rightarrow CollisionAvoidanceWeight \\ \rightarrow AccelerationFilterWeight \rightarrow ControllerSpeedWeight \rightarrow$$

In this case, the OrientationWeight (see Section 6.3.6.3.2) is the most important Weight as it moves the robot towards the next navigation point. When the SplineNavigation is used, no further configuration is required by the NaviagtionTask.

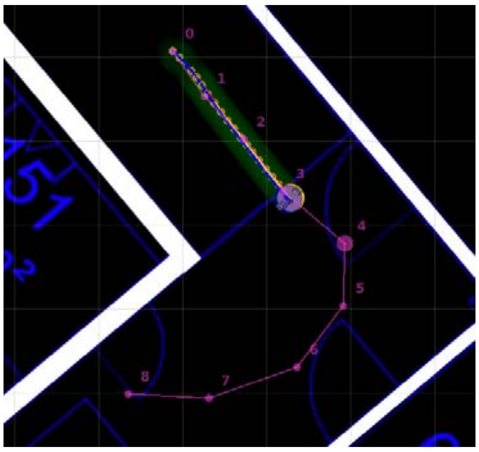


Figure 6-28: Robot follows navigation points

6.3.7.4 FingerprintNavigationTask

The assignment of the FingerprintNavigationTask is to navigate the robot through a room while pausing regularly at fixed intervals, allowing third-party software such as a Wireless Positioning System to collect data and use the robots current position. This is realized by sending a `fingerprint` message over the Remote Interface (see Section 6.3.8).

The Task has two different modes: `discovery` and `navPoints`. Both modes require the SystemOfWeightsNavigation module in order to function.

For the `discovery` mode the following Weights are added to the weight-channel:

$$\rightarrow FullSpeedWeight \rightarrow \ WallFollowerWeight \rightarrow \ CollisionAvoidanceWeight \\ \rightarrow AccelerationFilterWeight \rightarrow \ ControllerSpeedWeight \rightarrow$$

In this mode the environment is completely unknown. For this reason, first the walls are followed until the room has been closed. At this point, when the StructureMap is finished, a Discovery2Task is scheduled, which covers the entire room defined by the StructureMap. The Task finishes when a certain percentage of the room has been „discovered“.

When in `navPoints` mode, the following Weights are added to the weight-channel:

$$\rightarrow FullSpeedWeight \ \rightarrow OrientationWeight \ \rightarrow CollisionAvoidanceWeight \\ \rightarrow AccelerationFilterWeight \ \rightarrow ControllerSpeedWeight \rightarrow$$

This mode requires a series of navigation points to follow, which are placed against a known map of the room. In the `navPoints` mode, the Task finishes when all the navigation points have been reached.

During the pause for the sending of the `fingerprint` message it is desirable for the robot to softly stop and start again. This is achieved by temporarily deactivating any Weights which cause the robot to move: FullSpeedWeight, OrientationWeight, and WallFollowerWeight. Using this technique allows the robot to come to a soft stop because the AccelerationFilterWeight and ControllerSpeedWeight are still engaged.

6.3.7.5 Discovery2Task

This Task can „discover“ an environment by covering the entire area within a room[11]. It requires that the StructureMap be finished (its polygon closed) before starting. The Discovery2Task navigates the entire area based on the closed room defined by the StructureMap.

If the SystemOfWeightsNavigation module is being used, the following Weights are setup in the weight-channel:

$$\rightarrow FullSpeedWeight \rightarrow\ OrientationWeight\ \rightarrow CollisionAvoidanceWeight \\ \rightarrow ControllerSpeedWeight \rightarrow$$

The first thing the Discover2Task does is to evaluate all the HeatMap heat-spots which are inside the StructureMap and added to a list `navigationPoints`. This is realized in the `preProcess()` method. To optimize this process a grid is defined over the surrounding area:

```
int gridSize = 10;
Vector navigationPoints;
if ( structureMap->isFinish() ){
   for(int x = 0; x < heatMap->width(); x+= gridSize){
      for (int y = 0; y < heatMap->height(); y+= gridSize){
         if (structureMap->isPointOutside(Vector2D(x,y)) == false){
            navigationPoints.push_back(Vector2D(x,y));
         }
      }
   }
}
```

Code 6-10: Evaluating HeatMap Heat-Spots against the StructureMap

Not all points added to the `navigationPoints` list will be navigated. The list is trimmed and optimized to create short and smooth paths through the area to be discovered, while ensuring that the entire area is covered. To achieve this the `discover()` method is called after evaluating the HeatMap and whenever there are no more navigational points to drive to. This method calculates a new path to discover. First all the points are searched which have not yet been covered and which are in the vicinity. The point which is the closest to the current position is taken and the longest path through all points starting at this point is calculated. The minimum distance between each point can be defined.

The following code segment demonstrates the `discover()` method:

```
if (unknownAreaPoints.count() > 0){
   QList<Vector2D> tempList;
   int minDistance = INT_MAX;
   int position = 0;

   // Search point with the shortest distance to robot
   for(int i = 0; i < unknownAreaPoints.count(); i++){
      int temp = distanceBetween(unknownAreaPoints.at(i),
                       tracker->getTranslation());
```

[11] The Discovery2Task has its name derived from the original DiscoveryTask described in previous work (Krüsi & Grob, 2008).

```
      if (temp < minDistance){
         position = i;
         minDistance = temp;
      }
   }
   tempList.push_back(unknownAreaPoints.at(position));

   foreach(Vector2D p1, unknownAreaPoints){
   if (distanceBetween(tempList.last(), p1) == distanceBetweenNavPoints){
      bool isNearAnOtherPoint = false;
      foreach(Vector2D p2, tempList){
         if (distanceBetween(p1,p2) < distanceBetweenNavPoints){
            isNearAnOtherPoint = true;
         }
      }
   if (isNearAnOtherPoint == false){
      tempList.push_back(p1);
   }
}
```

Code 6-11: Discover Function of the Discovery2Task

In the `process()` method, the Maps are evaluated to see how much percent of the room has been covered when the robot reaches its last navigation point. If the percentage is at a defined minimum value, the Task is finished.

```
bool DiscoveryTask2::isExplored() {
   if(navigationPoints.count() < 1) return false;

   int explored = 0;
   foreach(Vector2D p,navigationPoints){
   if ( p is OpenArea | p is CollisionArea ){
       explored++;
      }
   }

   double percentage = 0.95;
   if( explored / navigationPoints.count() > percentage){
      return true;
   }
   return false;
}
```

Code 6-12: Discovery2Task Evaluation of Room Coverage

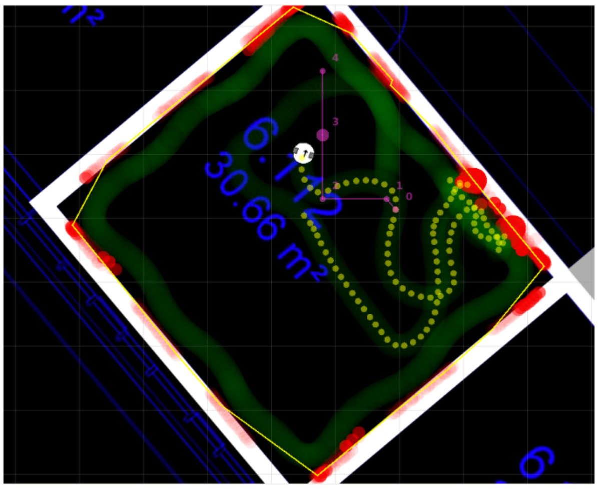


Figure 6-29: Discovery2Task after a WallFollowerTask

6.3.7.6 DockAndChargeTask

If the robot needs to be docked on the docking station, this Task is executed. It requires the following Weights in the SystemOfWeightsNavigation weight-channel:

$$\rightarrow DockWeight \rightarrow CollisionAvoidanceWeight \rightarrow ControllerSpeedWeight \rightarrow$$

While most of the work is performed by the DockWeight, the DockAndChargeTask must perform some additional modifications to the SystemOfWeightsNavigation weight-channel during runtime. The most significant modification is the deactivation of the CollisionAvoidanceWeight during the DockWeight's `attack` mode. This must be done because the CollisionAvoidanceWeight would naturally disallow the DockWeight to properly dock, as it would consider the docking station as an obstacle and try to avoid it. This is realized by connecting to the DockWeight's `modeChanged(...)` signal. When a mode change is signaled, the CollisionAvoidanceWeight is either activated or deactivated depending on the mode that was changed into.

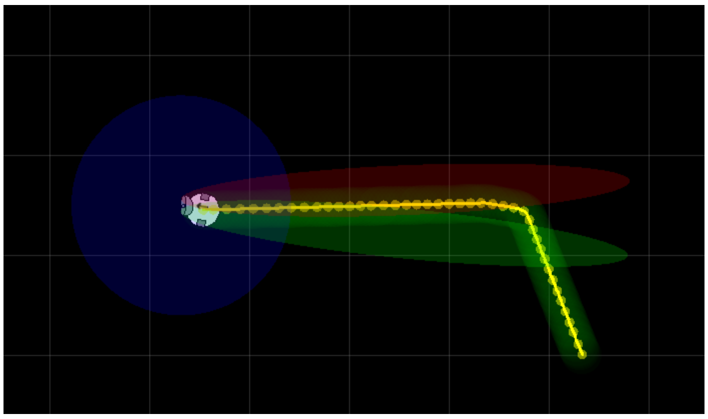
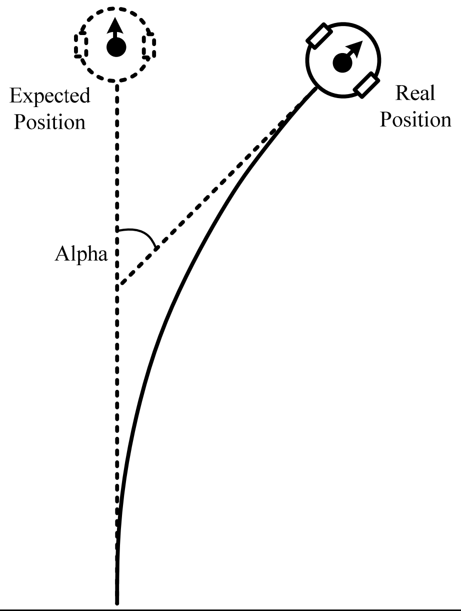


Figure 6-30: A Successful Docking

6.3.7.7 TestMoveTask

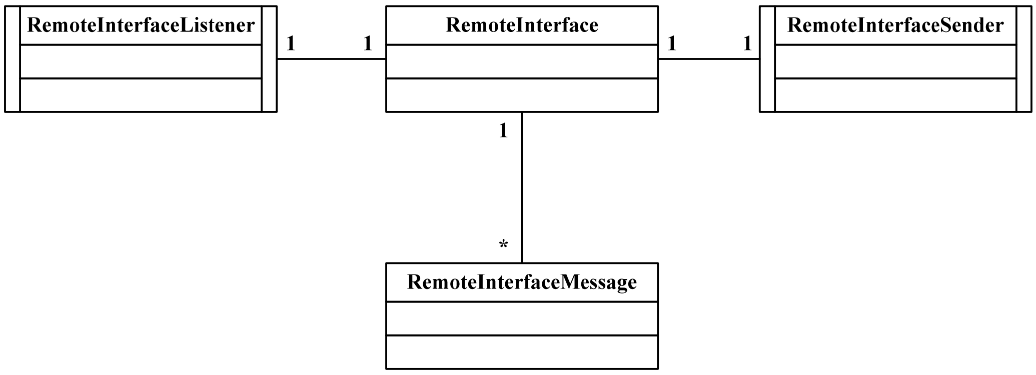
The TestMoveTask was implemented to serve as testing ground of different functionality within the hardware. It is made up of ten different test movements:

Test	Description
Square	Drives along the path of a square with each side being the distance defined in the Core settings.
Rotate 90	Rotates 90 degrees counter-clockwise and then back again 90 degrees clockwise.
Rotate 360	Rotates 360 degrees counter-clockwise and then back again 360 degrees clockwise.
Triangle	Drives along the path of a triangle with each side being the distance defined in the Core settings.
Straight	Drives straight ahead the distance defined in the Core settings.
Circle	Drives a circle with the defined radius in the Core settings. The wheel speeds are calculated using the formula developed in our previous work (Krüsi & Grob, 2008).
Accuracy Test	The Accuracy Test test uses navigation points which must be traversed. To do this the SystemOfWeightsNavigation module is used. The navigation points always remain the same and have been designed to stress different problematic factors in navigation.
WallFollowerAccuracy	This test helps resolve issues related to wall-following algorithms. It is designed to be executed in a small room. When the Task is finished or interrupted, the following information is returned: 1. Start and end positions 2. Angle difference between the start position and end position 3. Distance between start and end position 4. Distance travelled
Tracker Callibration	The Tracker Calibration test serves to output calibration data used for setting up a MovementTracker which accepts calibration data, such as the CorrectedFrenetMovementTracker. It drives the defined distance at a given speed. When finished, the angle alpha must be entered (by physically measuring it), and the system performs the necessary calculations for returning calibration data. 

Straight with Weights	This test sets a single navigation point straight in front of the robot. The test is used to verify the performance of different modules and implementations, such as the CorrectedFrenetMovementTracker or the CollisionAvoidanceWeight.
Custom Move	The Custom Move test allows one to define specific wheel speeds via the console. The move is then executed either over a given time or distance, depending on what was entered in the console.

Table 6-2: Different Test Movements of the TestMoveTasks

6.3.8 Remote Interface



In order to enable third-party software to be able to make use of the *emss* framework, including access to its Maps and Tracker, and the ability to start and stop Tasks, the Remote Interface has been realized and implemented. When the Remote Interface is enabled, the Core will initialize it and start the appropriate listener and sender `CoreThread` classes. The Remote Interface then is ready to send and receive messages which in turn either provide information or cause actions. The Remote Interface can be used both for remotely sending and receiving control information with the robot, but also for binding third-party applications which run locally on the robot hardware with the *emss* Core. Any module which wishes to use the Remote Interface may do so by connecting to its appropriate signals.

An example application is the communication between the Wireless Positioning Software *PointZero* and the *emss* framework required for fingerprinting, where the two softwares can easily communicate even though the software environments are very different.

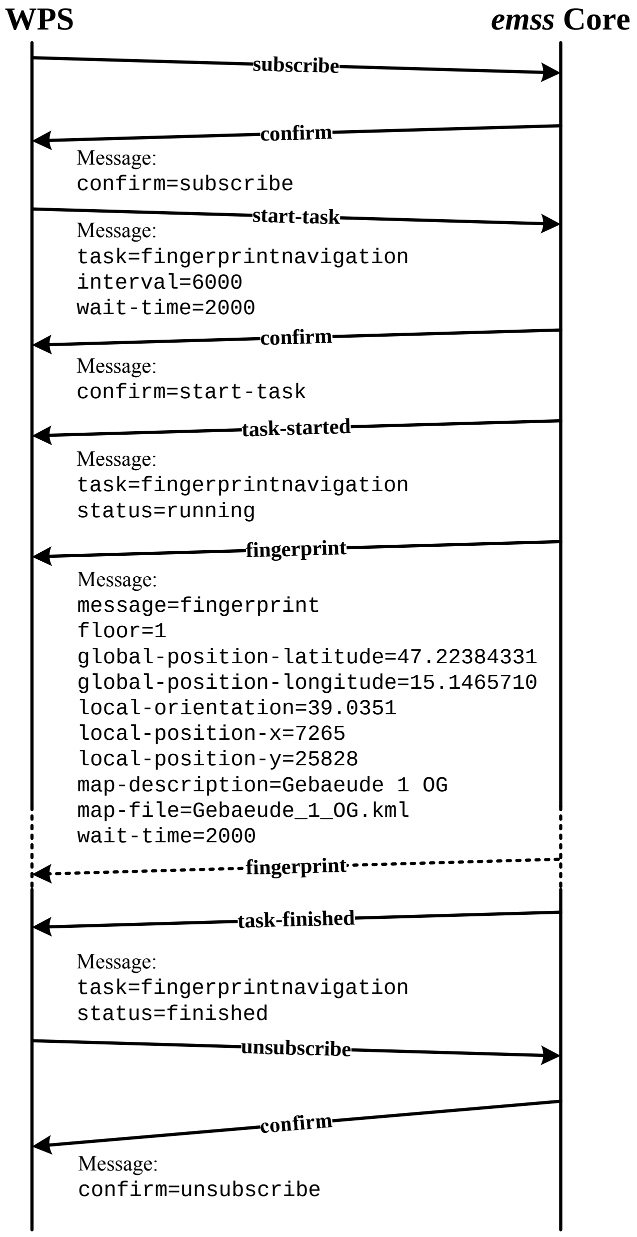
6.3.8.1 Protocol

The protocol or the Remote Interface is connectionless, and the medium used is *UDP* over *IP*. This allows a fast and light-weight implementation which can be easily realized by third-party software. The protocol allows for a subscription based broadcast of internal messages. If a third-party application would like to receive messages pushed from the server, it must subscribe to the server using the `subscribe` message. Such an application must send the `unsubscribe` message in order to unsubscribe. Because the Remote Interface is connectionless, messages pushed to the server do not require any sort of connection or subscription.

Messages are sent as a line-separated key-value collection over *UDP*. The separator defined for a key and value is the `=` character. The separator defined for a key-value pairs is the `\n` character (`\r\n` is incorrect). The key-values should not have a trailing `\n` character at the end of the data, however, the *emss* Core will accept this.

```
message=subscribe
reply-ip=127.0.0.1
reply-port=9000
```

Code 6-13: Example Remote Interface Message



Message:
```
confirm=subscribe
```

Message:
```
task=fingerprintnavigation
interval=6000
wait-time=2000
```

Message:
```
confirm=start-task
```

Message:
```
task=fingerprintnavigation
status=running
```

Message:
```
message=fingerprint
floor=1
global-position-latitude=47.22384331
global-position-longitude=15.1465710
local-orientation=39.0351
local-position-x=7265
local-position-y=25828
map-description=Gebaeude 1 OG
map-file=Gebaeude_1_OG.kml
wait-time=2000
```

Message:
```
task=fingerprintnavigation
status=finished
```

Message:
```
confirm=unsubscribe
```

Figure 6-31: Example Communication between Third-Party Application and *emss* Core

6.3.8.1.1 General Message Keys

1. `message`: required, defines what type of message it is.
2. `reply-ip`: optional, defines a reply IP if the incoming request originated from a different IP/port than the listen server is.

3. `reply-port`: optional, defines a reply port if the incoming request originated from a different IP/port than the listen server is.
4. `timestamp`: optional, the timestamp of the message creation.
5. `id`: optional, unique identifier.

6.3.8.1.2 Defined Messages

Message	**Description**

`error`	• Indicates an error
	• Actor: server
	• Additional keys needed: `error`
	• Example:
	`message=error`
	`error={already-subscribed|not-subscribed|unknown-task|invalid-message-type|...}`

`confirm`	• Confirms a message or action
	• Actor: server
	• Additional keys needed: `confirm`
	• Example:
	`message=confirm`
	`confirm={subscribe|unsubscribe|start-task|...}`

`subscribe`	• Subscribes to the servers push stream • Actor: client • Returned message: `{error|confirm}` • Example: `message=subscribe`
`unsubscribe`	• Unsubscribes from the servers push stream • Actor: client • Returned message: `{error|confirm}` • Example: `message=unsubscribe`

`start-task`	• Starts a *emss* Core Task
	• Actor: client
	• Additional keys needed: `task`, task related keys
	• Returned message: `{error|confirm}`
	• Example:
	`message=start-task`
	`task={fingerprintnavigation|splinediscovery|splinenavigation|...}`

Fingerprint Navigation `start-task`	• Starts a fingerprintnavigation task in the Core
	• Actor: client
	• Additional keys needed: `interval, wait-time`
	• returned message: `{error|confirm}`
	• Example:
	`message=start-task`
	`task=fingerprintnavigation`
	`interval={milliseconds}`
	`wait-time={milliseconds}`

`fingerprint`	• Indicates that fingerprint can be taken for the given wait time • Actor: server • Additional keys needed: `wait-time, global-position-latitude, global-position-longitude, local-position-x, local-position-y, map-description, map-file, local-orientation`

	• Note: local-orientation is the current rotation in degrees where the y-axis (north) is represented by 0 degrees and, -y (south) as 180/-180 degrees, x-axis (east) as -90/270 degrees, and -x (west) as 90/-270 degrees.
	• Example:
	`message=fingerprint`
	`wait-time={milliseconds}`
	`floor={integer}`
	`global-position-latitude={latitude, double}`
	`global-position-longitude={latitude, double}`
	`local-position-x={millimeters, long}`
	`local-position-y={millimeters, long}`
	`local-orientation={degrees, double}`
	`map-description={string}`
	`map-file={string}`

`task-started`	• Indicates that the given task has started
	• Actor: server
	• Additional keys needed: `task, status`
	• Example:
	`message=task-started`
	`task={fingerprintnavigation|splinediscovery|splinenavigation`
	`|...}`
	`status={running}`

`task-finished`	• Indicates that the given task has completed
	• Actor: server
	• Additional keys needed: `task, status`
	• Example:
	`message=task-finished`
	`task={fingerprintnavigation|splinediscovery|splinenavigation`
	`|...}`
	`status={finished|interrupted}`

6.3.8.2 RemoteInterface

The `RemoteInterface` class is responsible for initializing and starting the `RemoteInterfaceSender` and the `RemoteInterfaceListener` threads. In addition, it holds the responsibility for all the data related to the emss Remote Interface. The following are the most important data structures:

1. `subscribers`: List of the current subscribers and their information.
2. `sendQueue`: Current `RemoteInterfaceMessage` objects which are waiting to be sent.
3. `messages`: List of sent and received `RemoteInterfaceMessage` objects.

Both the listener and sender are not exposed by the `RemoteInterface` class and kept private, so the `RemoteInterface` class must be able to delegate incoming messages and outgoing messages. This is achieved largely through the following methods:

1. `broadcastMessage(message)`: Broadcasts the given message.
2. `sendMessage(ip,port,message)`: Sends the message to the given address.
3. `subscribeToServer(ip,port)`: Subscribes to the server at the given address.
4. `unsubscribeFromServer(ip,port)`: Unsubscribes to the server at the given address.

6.3.8.3 RemoteInterfaceSender

The `RemoteInterfaceSender` class inherits from `CoreThread` and is responsible for working through the `sendQueue`, consequently sending the message. It must extract the contents from each

`RemoteInterfaceMessage` contents and pack it up as a *UDP* packet and send it off. The run loop of the `RemoteInterfaceSender` class is quite simple:

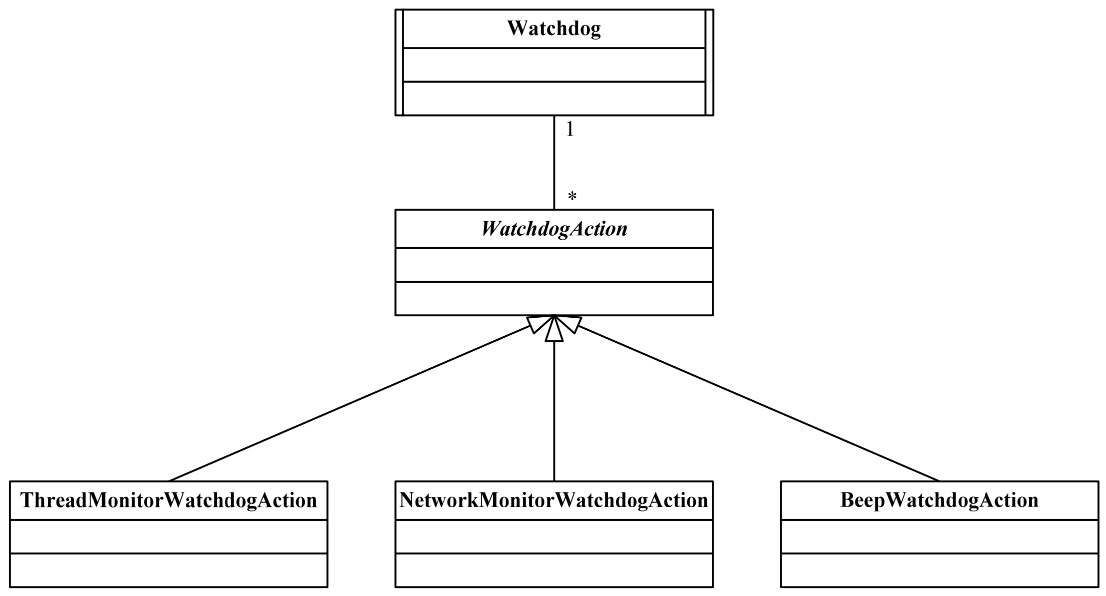
```
// Enter processing loop...
stopRequested = false;
while (stopRequested == false) {
     while(!server->isSendQueueEmpty()){
            RemoteInterfaceMessage *message = server->dequeueSendQueue();
            sendMessage(message);
     }

     // Sleep wait
     QThread::msleep(core->intSetting("RemoteInterface_SenderInterval"));
}
```

Code 6-14: RemoteInterfaceSender Run-Loop

6.3.8.4 RemoteInterfaceListener

The `RemoteInterfaceListener` class is also a Core Thread and is responsible for listening to and receiving incoming messages. When a *UDP* packet arrives, it must be unpacked and parsed into a `RemoteInterfaceMessage` object.

6.3.9 Watchdog



The Watchdog runs in a separate thread and monitors different aspects of the *emss* Core during its runtime. It is responsible for reporting any detected fatal errors, such as a deadlock, or taking action when certain problematic situations come about.

Running at a constant interval, the Watchdog periodically monitors the Core by processing a given series of actions. These actions are defined by the abstract class `WatchdogAction`. Any action must implement the `process()` method, which must first assess the health of the Core component it is monitoring, and then react appropriately.

The following actions are the most important WatchdogAction implementations: `ThreadMonitorWatchdogAction` and `NetworkMonitorWatchdogAction`. They can be activated and disabled, along with the Watchdog itself, in the Core configuration file.

6.3.9.1 ThreadMonitorWatchdogAction

The ThreadMonitorWatchdogAction is instantiated (when enabled) by most of the Core modules which inherit from `CoreThread`. When such an action is created by a Core Thread, the thread is responsible for pinging the action at the defined interval by calling its `ping()` method. When the ThreadMonitorWatchdogAction is processed by the Watchdog, the action checks if the most recent ping is within the bounds of the defined interval. If the ping is not frequent enough, the WatchdogAction will trigger and attempt to restart the Core. Each ThreadMonitorWatchdogAction may have its own ping interval and flexibility defined.

```
if(isActive && lastPingFromThread.elapsed() > expectedPingInterval*flexibility) {
     Debug::warning("[ThreadMonitorWatchdogAction] component %1 is no longer
                         responding", component);
     core->reset();
}
```

Code 6-15: ThreadMonitorWatchdogAction Process

6.3.9.2 NetworkMonitorWatchdogAction

When the robot travels across connectivity borders, the remote connection to the robot may be temporarily or permanently lost. This might render undesirable results where the robot is freely roaming in an unknown environment without any supervision. To hinder this, the NetworkMonitorWatchdogAction monitors the robot’s connectivity and shuts down the Core when a connection has been lost, ultimately stopping the robot.

This is realized by periodically checking the IP addresses of the machine against a known set of IP addresses. If none of the IP's are present on the machine, the NetworkMonitorWatchdogAction will trigger. Each IP can be specified by a either a full address or a prefix. For example, both `152.96.100.127` and `152.96.` will match the IP `152.96.100.127`.

6.3.10 Library

The Library is not considered a Core module, but however is an important part of the *emss* Core as it provides a substantial amount of functionality. It is a collection of classes which are used by many different components, such as math structures or debugging routines. The Core Library is made up of over 20 classes which serve a distinct purpose throughout the framework.

Most notable are the operator-overloaded math classes. Included are template classes which represent vectors, splines, complex numbers, transformation matrixes, GPS conversions, and differential equations.

```
// Create two splines, one for each dimension and add some nodes
Spline1D Sx = Spline1D(SplineKernelNRNatural);
Spline1D Sy = Spline1D(SplineKernelNRNatural);
Sx.addNode(0.0); Sy.addNode(0.0);
Sx.addNode(1.4); Sy.addNode(1.1);
Sx.addNode(3.1); Sy.addNode(2.0);
Sx.addNode(6.7); Sy.addNode(5.4);
Sx.addNode(8.0); Sy.addNode(1.1);

// Draw each spline segment with fixed number of dots
int DOTS_PER_SEGMENT = 20;
for (int n = 0; n < Sx.getNodeCount() - n; n++) {
     for (int t = 1; t < DOTS_PER_SEGMENT; t++) {
            double px = Sx.getValue(n, (double)t / (double)DOTS_PER_SEGMENT);
            double py = Sy.getValue(n, (double)t / (double)DOTS_PER_SEGMENT);
            graph.drawPoint(px, py);
     }
}
```

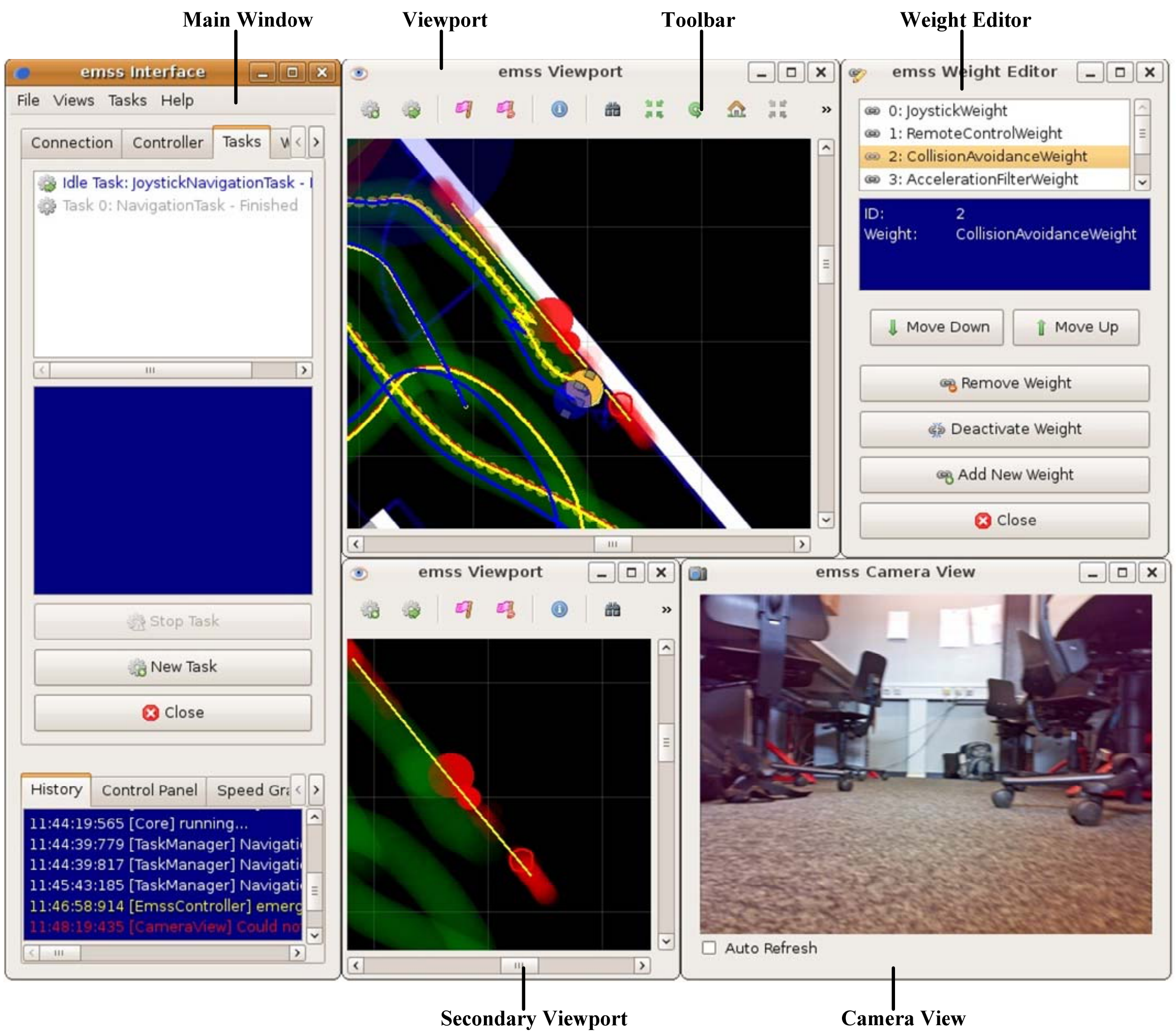
Code 6-16: Example Usage of Spline Class: Drawing a Curve

6.3.11 GUI

In order to reflect the current state of the Core modules, different GUI widgets have been created. These all inherit from `QWidget`, and can be either embedded in an existing layout of displayed in a separate window. Over fifteen different widgets have been implemented – each with good reason. The roles of the widgets vary from displaying all the Maps to outputting sensor data from the robot. Thus the Core offers any interface using it a wide variety of functionality in the graphical user interface domain. The widgets can easily be instantiated using the CoreFactory and can be automatically linked to any instantiated Core.

GUI widgets which rely on a Core all implement the slot method `registerCore(...)`, which in turn provides the widget with a means of registering a specific instantiated Core. This allows any interface application to only have to connect to this slot and not worry about keeping the widget up-to-date with a valid Core pointer.

Some of the more important widgets include Viewport, JoystickView, RobotControlPanel, RobotSpeedGraph, TaskEditor, and WeightEditor. The widgets are described in detail in Chapter 10.4.2.



```
11:44:19:565 [Core] running...
11:44:39:779 [TaskManager] Navigati
11:44:39:817 [TaskManager] Navigati
11:45:43:185 [TaskManager] Navigati
11:46:58:914 [EmssController] emerg
11:48:19:435 [CameraView] Could no
```

ID: 2
Weight: CollisionAvoidanceWeight

Figure 6-32: Composition of Different GUI Widgets

6.3.12 Unit Tests

All unit tests are built on top of the *QTestLib* framework, which is the official *Qt Unit Test* framework. The header file `UnitTestMacros.h` includes a set of extensions to *QTestLib* to meet the needs of testing within the *emss* framework. In addition, abstract classes such as `CoreTest` provide additional functionality to making the testing of a "hot" *emss* Core easier. It is worthwhile to mention that unit testing within the *emss* framework can prove to be very tedious, and sometimes very limited. This is due to the nature that much of the code needs to be tested against hardware (emulation is in the end still only an abstraction), as well as many of the data structures rely on meaningful input data (from sensors et cetera) to be tested thoroughly. However, we believe the tests provided with the *emss* framework are robust and test the most significant elements of the *emss* Core.

```
double actual = 0.000000;
double expected = 0.000001;
QCOMPARE2(actual, expected); // Compares actual with expected with a leniency of
                             // DOUBLE_PRECISION
QCOMPARE3(actual, expected, 0.5); // Compares actual with expected with a
                                  // leniency of 0.5*expected
```

Code 6-17: Example Extended Macros for the Testing Framework

The individual tests will not be discussed in further detail here, however `CoreTest` and `HeapTest` worthwhile describing.

6.3.12.1 CoreTest

If a unit test needs a running *emss* Core it must inherit from `CoreTest`. The `CoreTest` creates in the `initTestCase()` method a Core instance and calls `connect` on it. At the end in `cleanupTestCase()` the Core instance will be disconnected and deleted.

Calling `initTestCase()` will just create a default Core based on the settings in `emssCore.config`. In many cases it might be necessary to create a Core with specific modules. This can be achieved by calling `initTestCase(controller, tracker, navigation)`. Furthermore, a unit test might require very specific settings which are independent from the Core connection. This can be achieved by specifying a `customSettings` argument. This string argument should contain line-separated key-value pairs just as in a `.config` file. The settings specified by `customSettings` append the `emssCore.config` settings, overwriting existing settings where there exists a conflict. The exact definition of `initTestCase` is as follows:

```
virtual void initTestCase(     QString controller = "EmssController",
                               QString tracker = "SingleTracker",
                               QString navigation = "SplineNavigation",
                               QString serialPort = "COM4",
                               bool emulation = true,
                               bool safeMode = false,
                               QString customSettings = ""      );
```

Code 6-18: Initialization of a CoreTest

For example, to create an *emss* Core with custom settings, one can just call the following from within the unit test:

```
CoreTest::initTestCase(  "EmssController",
                         "SingleTracker",
                         "SplineNavigation",
                         "COM4",
                         true,
                         false,
     "Tracker_DefaultMovementTrackers=RawMovementTracker\nTracker_SelectedMovement
Trackers=RawMovementTracker"
                        );
```

Code 6-19: Initialization of a CoreTest with Custom Settings

6.3.12.2 HeapTest

This test inherits `CoreTest` and checks whether all `CoreObject` instances are properly deallocated from the heap upon `core->disconnect()` and `delete core`. This is realized with help of the `HeapLogger`, which is part of the *emss* framework. Every test within `HeapTest` consists of the following steps:

1. Initialization of Core
2. Core connect
3. Creation of some Tasks
4. Sending of some messages over Remote Interface

5. Core disconnect
6. Deletion of Core
7. Check Heap Logger if everything is freed

If a test fails, the still-allocated objects are listed for debugging convenience.

7 Results

The resulting *emss* framework, made up of a set of interchangeable modules, provides an extensible design, which allows a wide array of functionality and supports different strategies for the same problem. It has been designed with future developments in mind, presenting a robust architecture which may be extended for additional functionality. The framework features a full blown multi-threaded software stack which allows the autonomous controlling and interfacing of the robot. All important modules required for the navigation, maneuvering, and safe controlling of the robot have been implemented. In addition, the simulated environment yields an accurate, feature-complete, and flexible workspace for testing the software.

Safe navigation has been achieved by intelligently avoiding drops, obstacles, and walls by constantly generating and updating the various supporting data structures. Furthermore, small areas can be autonomously navigated and mapped using different space-filling algorithms and map structures. Other routine tasks, such as docking the robot on its docking station, have been implemented and tested. Collaboration with third-party software has been realized with the Wireless Positioning System *PointZero* by automatically collecting the necessary signal reference points, called fingerprints. Finally, a rich graphical user interface is provided by the framework, allowing user interaction with all the different modules within.

This chapter compares and analyzes the initial goals of the project with its end results. In addition, a self-assessment has been undergone which describes the quality of other aspects of the *emss* project.

7.1 Safe-Navigation within a Simple Room

Safe navigation through a simple room was realized by the SystemOfWeightsNavigation module. It contains the CollisionAvoidanceWeight which identifies objects and performs a maneuver around them in order to traverse the room without any collisions.

Collision free movement was consistently achieved in the test room. However, when put in new and different environments some problems arose. Among them were the non-uniform responses of the infrared sensors to concrete, metal, plastic or polished walls and obstacles. This resulted in inaccurate distance measurements, which led to errors in calculated location and less than optimal avoidance maneuvers. However, the robot never put itself in harms way or underwent a fatal accident. The collisions which did occur only included small bumps with static obstacles and sometimes the slipping of wheels from their grip to the floor as the robot pushed against an immoveable object.

7.1.1 Measurements

7.1.1.1 Avoiding a Cardboard Box

After selecting a start and end navigation point, a cardboard box was placed directly between the two points. In this scenario the robot must avoid the obstacle in order to reach the determined endpoint.

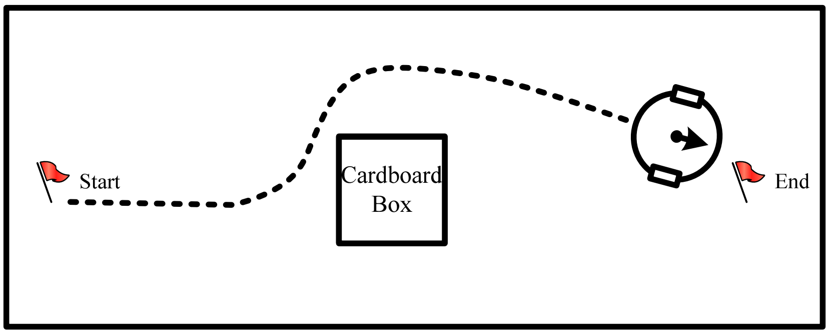


Figure 7-1: Schematic of Collision Avoidance

Number of Tests	Success	Failure	Success Rate
10	10	0	100%

Table 7-1: Measured Results of Collision Avoidance

7.1.1.2 Avoiding a Concrete Wall

During this test the robot was required to maneuver around a concrete wall as shown in Figure 7-2 .

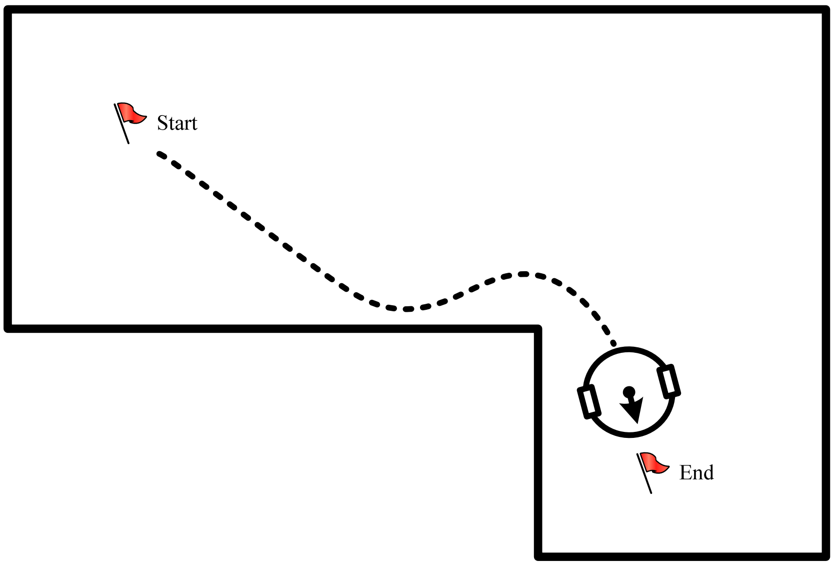


Figure 7-2: Schematic for Collision Avoidance (Concrete)

Number of Tests	Success	Failure	Success Rate
10	10	0	100%

Table 7-2: Measured Results for Collision Avoidance

7.1.1.3 Approaching a Drop

Another scenario involved setting the final waypoint on a set of stairs. If the robot would approach the stairs, recognize the drop with its downward-pointing IR-sensors, and then stop before falling off, the test was considered a success.

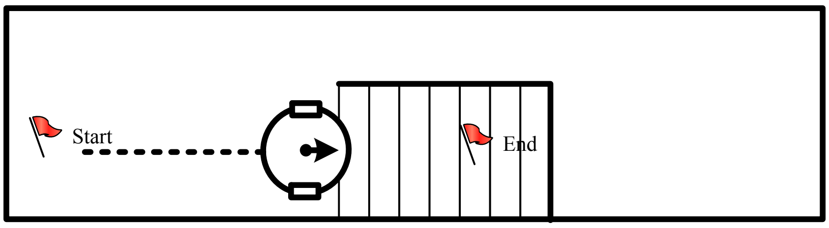


Figure 7-3: Schematic for Drop Detection

Number of Tests	Success	Failure	Success Rate
10	10	0	100%

Table 7-3: Measured Results for Drop Detection

7.1.1.4 Executing Randomly Assigned Tasks in a Multiple Scenario Space

This scenario involves a combination of the before mentioned scenarios. The robot is placed within a closed-off space that includes obstacles, wall corners and drop-offs, and then assigned a RoamingTask which must be executed for 10 minutes. The test is considered a success if after 10 minutes the robot has avoided contact with all walls and obstacles and not fallen down the stairs.

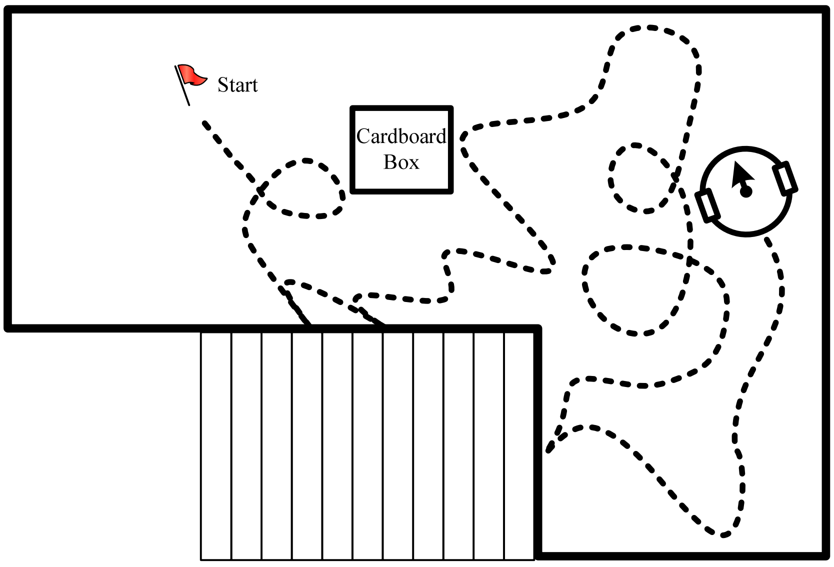


Figure 7-4: Schematic of RoamingTask Test

Test No.	No. of Wall Collisions	No. of Cardboard Box Collisions	No. Failures to Identify Stairs (Falls)
1	0	1	0
2	0	0	0
3	1	0	0

Table 7-4: Measured Results for RoamingTask

7.1.2 Evaluation

The robot's capabilities for safe navigation were excellent. The only problems arose when an obstacle was located in a blind spot (area not covered by sensors), and was never identified and collided with. The robot always identified and safely stopped before drops.

7.2 Basic Environment Mapping Skills

The WallFollowerTask, in which the robot finds a wall and closely follows it, was specifically developed for environment mapping. In Discovery2Task, the robot added the wall following information to the knowledge of the location of the wall and was able to map the entire layout of the floor-plan within a room.

7.2.1 Measurements

7.2.1.1 Wall Follower

Once the robot was initialized in a room, it had to find a wall and begin to follow it. This test measured if the robot recognized the object as a wall, neared the wall with help of the sensors, and then was able to follow the wall.

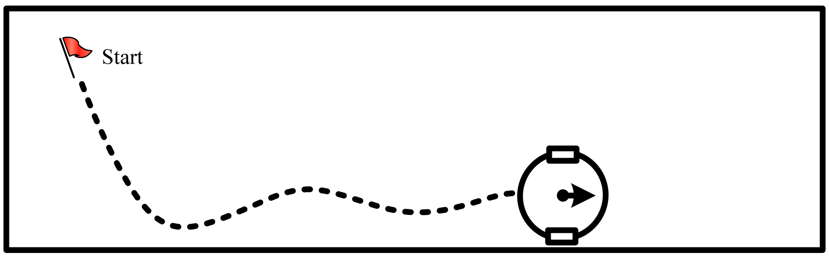


Figure 7-5: Schematic for Wall Follower

No. Tests	Object Identified	Wall Identified	Wall Followed (at least 10m)	Success Rate
20	20	18	18	90%

Table 7-5: Measured Results for Wall Follower

7.2.1.2 Identifying Basic Structure of a Rectangular Room

The robot must identify the basic geometrical structure of a simple rectangular room. Once the map is closed, the robot should stop and the floor-plan is checked.

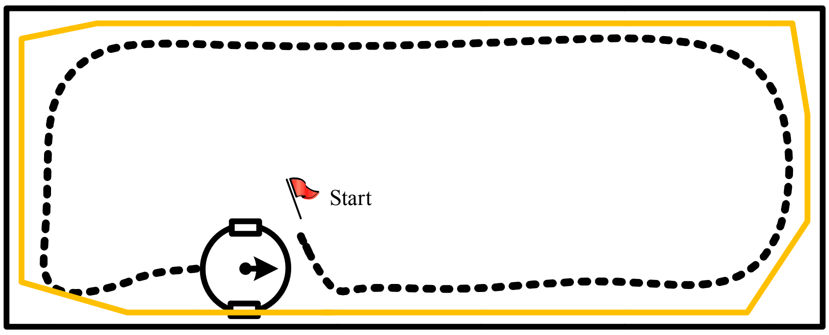


Figure 7-6: Schematic of Mapping Floor-Plan

No. Tests	Wall Identified	Geometry of Room Identified	Success Rate
10	10	6	60%

Table 7-6: Measured Results for Mapping Floor-Plan

7.2.2 Evaluation

The results showed that once a wall was identified the robot was always able to follow it. The primary source of the problems for identifying a wall came from the short-sightedness of the wall sensors (they only see 10cm ahead). If the parameters of the CollisionAvoidanceWeight were configured too strong, then the wall was identified as an obstacle and avoided before it could ever be identified as a wall and followed.

The predominant difficulty of the WallFollowerTask was recognizing when the structure of a room had been completely identified. The root of this problem rested in inaccuracies in determining the robots own location, making the determination of the geometry of the room very difficult.

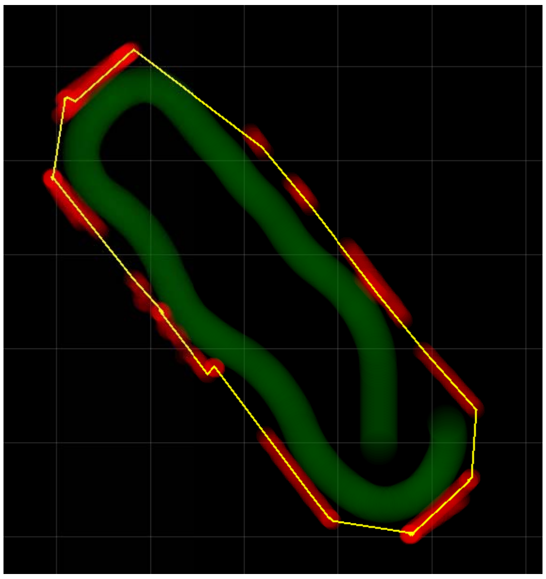


Figure 7-7: Results from Mapping a Rectangular Closed Hallway

7.3 Basic Localization using Different Data-Sources and Hardware

Various tracking methods were probed in order to find the most accurate way of determining the robots own position. After much testing, the results showed that determining the robots location from the feedback from its servos yielded large inaccuracies that made certain tasks impossible. The most accurate method discovered, mathematically calculated the robots position from the speed commands sent to each wheel (FrenetMovementTracker). Even though this calculated position only reflects how the robot *should* drive, and not what it *actually* did drive, tests showed that it was much more accurate than using feedback from the robots internal hardware.

7.3.1 Measurements

7.3.1.1 Deviation of Commanded versus True Motion

This test involves measuring the deviation between movement commands given to the robot compared to the actual path traversed. The robot was told to move 15 m in the forwards direction.

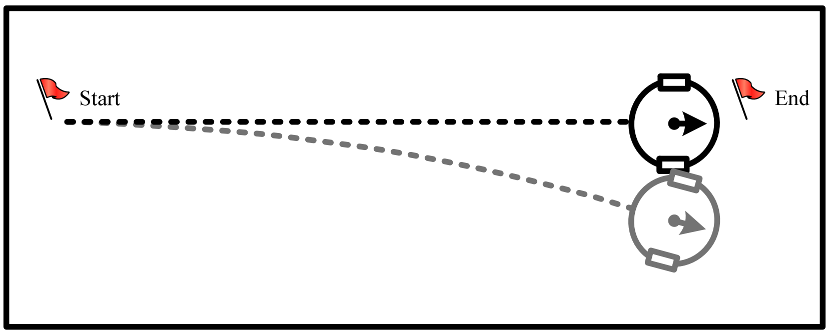


Figure 7-8: Deviation of Commanded versus True Motion

Test No.	Deviation from Y-axis (mm)	Deviation from Y-axis (percent)	Deviation from X-axis (mm)	Angular Deviation (degrees)
1	1087	7.25%	772	3.18
2	494	3.29%	700	2.77
3	1010	6.73%	740	3.03
4	802	5.35%	721	2.91
5	820	5.47%	725	2.93
6	1218	8.12%	771	3.21
7	1280	8.53%	773	3.23
8	960	6.4%	736	3.01
9	1477	9.85%	790	3.35
10	1035	6.90%	765	3.14

Table 7-7: Measured Deviation from a Straight Line

7.3.2 Evaluation

Whenever a command was given for the robot to drive straight it drifted slightly either to the right or the left. An attempted solution to this problem was made in CorrectedFrenetTracker which removed the deviations in the simulation of the robot. However, when applied to the hardware, the robot could not correct its movements due to its inability to react to the small changes in wheel speeds. Only the calculated position with error could be determined, which was quite accurate. Nonetheless, the current localization still remains inaccurate over time, especially when complex movements are performed.

7.4 Protocol for Third-Party Applications

The Remote Protocol was developed to access for third-party applications to access the core. This yielded many benefits such as running tasks on the robot over the network and retrieving current system information.

The Wireless Positioning System *PointZero* is already using this feature for collecting fingerprints by actively connecting to the *emss* framework and exchanging messages.

7.5 Assembly of Additional Units

Hardware for a second robot was purchased, assembled, and modified to the same specifications of the first robot. The onboard computer was installed with *Linux* and the *emss* framework as well as the necessary configuration files. Additional docking stations were also ordered and modified so that both the robot and the onboard computer could have their batteries charged while on the docking station.

Both units are working and healthy and are able to run the *emss* software.

7.6 Additional and Optional Features

The fundamental idea of the modular framework allows for endless possibilities to quickly and easily develop more tasks and even solve the same problems from different angles. This idea was proven by the implementation of all the optional features which seamlessly integrated with the framework.

7.6.1 Self-Charging Algorithm

The *iRobot Create* already came furnished with an excellent, built in self-docking algorithm. However, once the modifications were made to the *iRobot*, notably mounting an onboard computer on top of it, it became too heavy for the built in self-docking algorithm to properly dock. A docking algorithm that could vary the speeds[12] of the *iRobot* needed to be developed. This proved to be a very difficult task, as the docking station remains largely a black box, and the precision required for a successful dock and contact with both charging power lines is in the millimeter domain.

[12] Specifically, charge towards the docking station with increased speed.

7.6.1.1 Measurements

7.6.1.1.1 Successful Docking

Docking is considered successful once the robot locates and mounts itself on the docking station so that both the *iRobot* and laptop begin charging. This requires all four contact points on the docking station (shown in Figure 5-5) to make a solid contact with its partner contact on the mobile hardware.

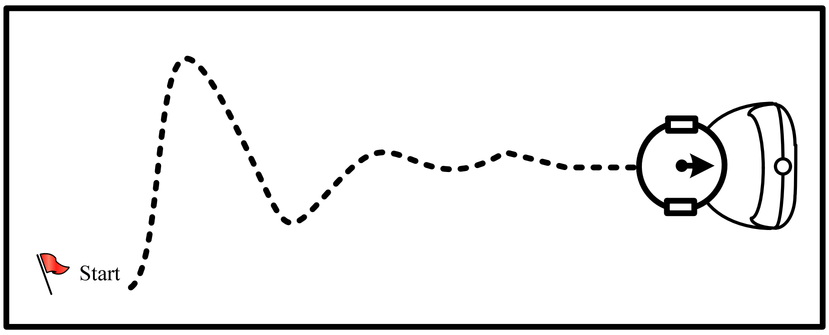


Figure 7-9: Schematic for Docking

No. Tests	Docking Station Found	Docked: Only robot	Docked: Only laptop	Docked: Both robot and laptop	Success Rate: Both robot and laptop docked
30	28	15	0	2	6.666%

Table 7-8: Results for Docking Test

7.6.1.1.2 Successful Undocking

If the starting waypoint for the robot is in a docked position, it must first drive a short distance backwards to release itself before it can begin a new task.

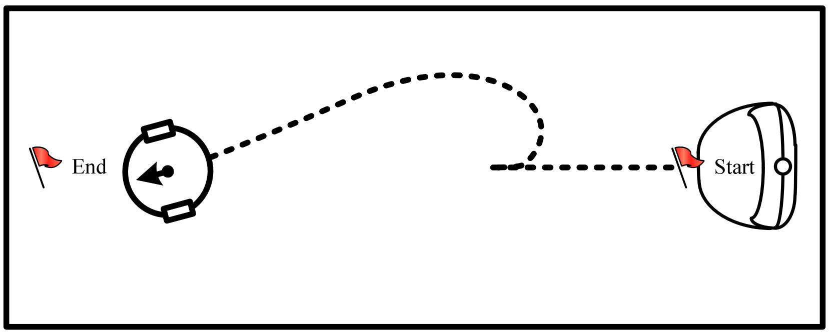


Figure 7-10: Schematic for Undocking

No. Tests	Successful Undock	Arrived at End Waypoint	Success Rate
10	10	10	100%

Table 7-9: Results for Docking Undocking Test

7.6.1.2 Evaluation

The test results show that the robot had no problems to release itself from the docking station and continue executing tasks. However, the docking algorithm was far from stable. While the robot found the docking station most of the time, even when started from an off-angle to the docking station, the robot almost always failed to make contact with the charging contact points for the laptop. Because these small contact points were located in the middle outside of the charger (see Chapter Figure 5-5) and the heightened approach velocity needed to dock both the weight of the *iRobot* hardware and laptop, there was very little room for error[13]. The smallest 5-8mm offset would fail the successful dock. The Additional difficulties arose from the complete lack of any official literature from *iRobot*, as well as from the community. However, some of its traits were discovered through careful observation of the standard docking maneuver.

7.6.2 Self-Healing Tracker

A first-stage implementation of a self-healing Tracker was realized by the SelfCorrectingTracker (see Section 6.3.4.3 for more details). This advanced Tracker is able to make corrections in the localization error when deemed appropriate. To do this, the Tracker makes use of a pre-loaded floor-plan in order to make correlations between its perceived virtual world and the physical world. In a simulated environment, where error is artificially injected into the robots localization, the SelfCorrectingTracker was able to make minor adjustments improving the localization quality by reducing part of the injected error. Over time the error overwhelms the Tracker and corrections made are no longer correct, however this could be resolved by making the corrections in movement more carefully.

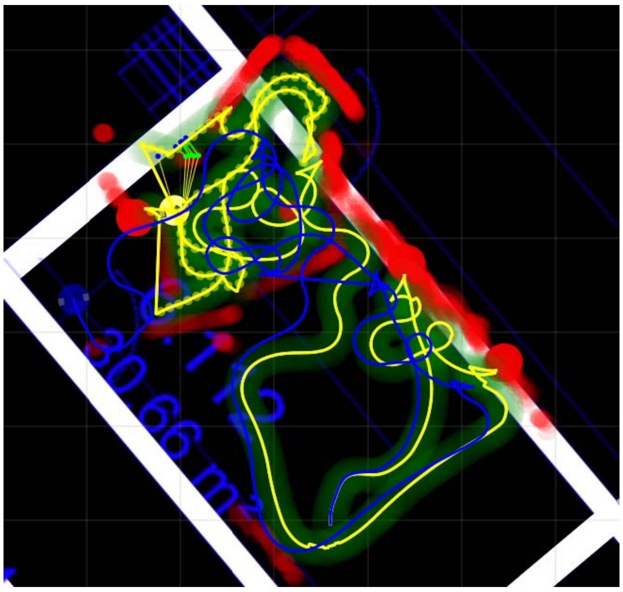


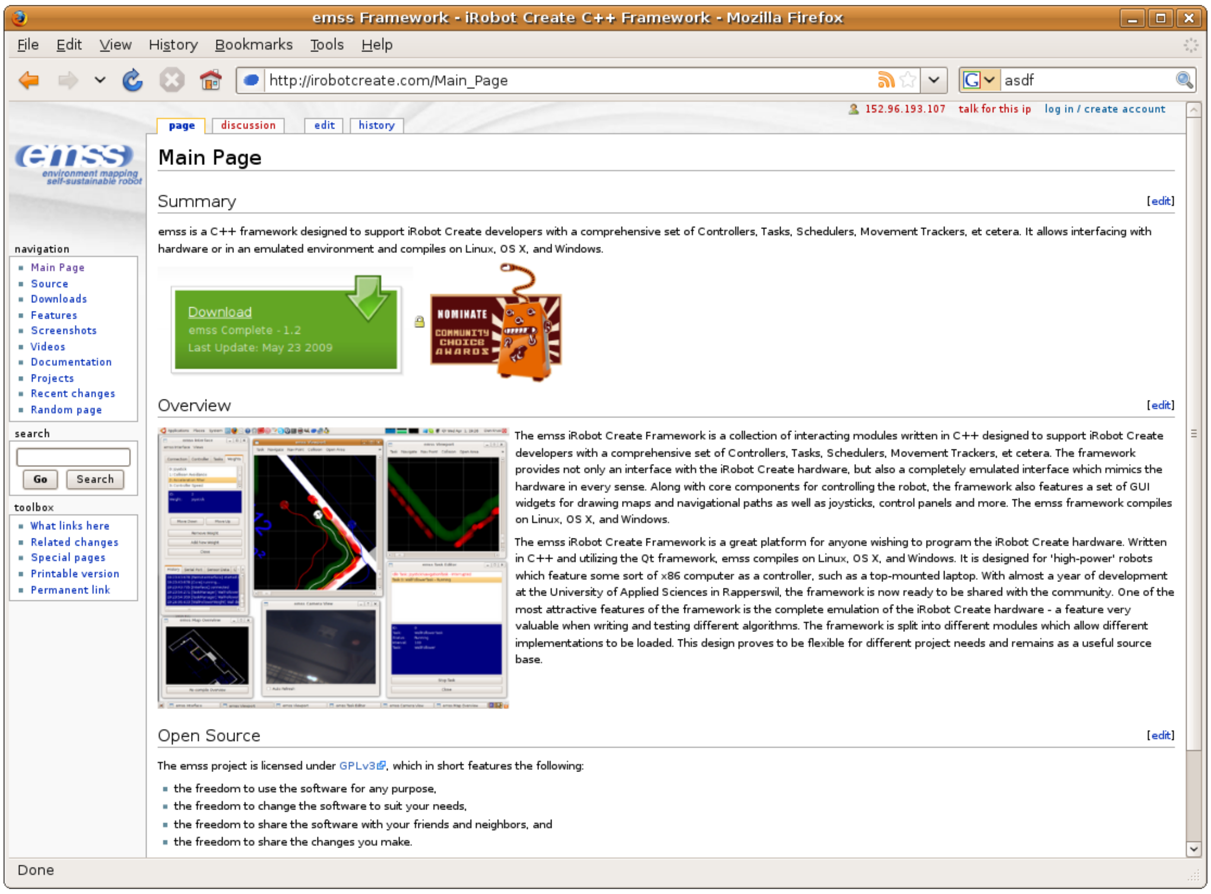
Figure 7-11: Self-Healing Tracker Slowly Degrading in Quality of Corrections

[13] Watch a video of the *emss* robot docking in action at `http://irobotcreate.com/Videos`.

7.6.3 Publishing of the Project to Robotics Community

The entire source code and all releases with ready to run binaries were made publicly available under the *GPLv3* license. The project is now hosted by *SourceForge*, an important open-source distributor. Anyone can access the code base by checking out the SVN repository on *SourceForge*.

In addition, a *MediaWiki* at `http://irobotcreate.com` was created to host the entire documentation for the software, explanatory videos and photographs, and actively updated information relevant to the *emss* project.


emss Framework - iRobot Create C++ Framework - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://irobotcreate.com/Main_Page
asdf
152.96.193.107 talk for this ip log in / create account
page discussion edit history
emss environment mapping self-sustainable robot
navigation
Main Page
Source
Downloads
Features
Screenshots
Videos
Documentation
Projects
Recent changes
Random page
search
Go Search
toolbox
What links here
Related changes
Special pages
Printable version
Permanent link
NOMINATE COMMUNITY CHOICE AWARDS
Done

Main Page

Summary [edit]

emss is a C++ framework designed to support iRobot Create developers with a comprehensive set of Controllers, Tasks, Schedulers, Movement Trackers, et cetera. It allows interfacing with hardware or in an emulated environment and compiles on Linux, OS X, and Windows.

Download
emss Complete - 1.2
Last Update: May 23 2009

Overview [edit]

The emss iRobot Create Framework is a collection of interacting modules written in C++ designed to support iRobot Create developers with a comprehensive set of Controllers, Tasks, Schedulers, Movement Trackers, et cetera. The framework provides not only an interface with the iRobot Create hardware, but also a completely emulated interface which mimics the hardware in every sense. Along with core components for controlling the robot, the framework also features a set of GUI widgets for drawing maps and navigational paths as well as joysticks, control panels and more. The emss framework compiles on Linux, OS X, and Windows.

The emss iRobot Create Framework is a great platform for anyone wishing to program the iRobot Create hardware. Written in C++ and utilizing the Qt framework, emss compiles on Linux, OS X, and Windows. It is designed for 'high-power' robots which feature some sort of x86 computer as a controller, such as a top-mounted laptop. With almost a year of development at the University of Applied Sciences in Rapperswil, the framework is now ready to be shared with the community. One of the most attractive features of the framework is the complete emulation of the iRobot Create hardware - a feature very valuable when writing and testing different algorithms. The framework is split into different modules which allow different implementations to be loaded. This design proves to be flexible for different project needs and remains as a useful source base.

Open Source [edit]

The emss project is licensed under GPLv3, which in short features the following:

- the freedom to use the software for any purpose,
- the freedom to change the software to suit your needs,
- the freedom to share the software with your friends and neighbors, and
- the freedom to share the changes you make.

Figure 7-12: Start Page of Project Website

Web Addresses	Description
`http://irobotcreate.com`	*MediaWiki* with entire documentation, screenshots, photos, videos, and downloads.
`http://emssframework.sourceforge.net`	Official *SourceForge* address
`http://sourceforge.net/projects/emssframework`	*SourceForge* project page
`http://youtube.com/group/irobotcreate`	*YouTube* video group

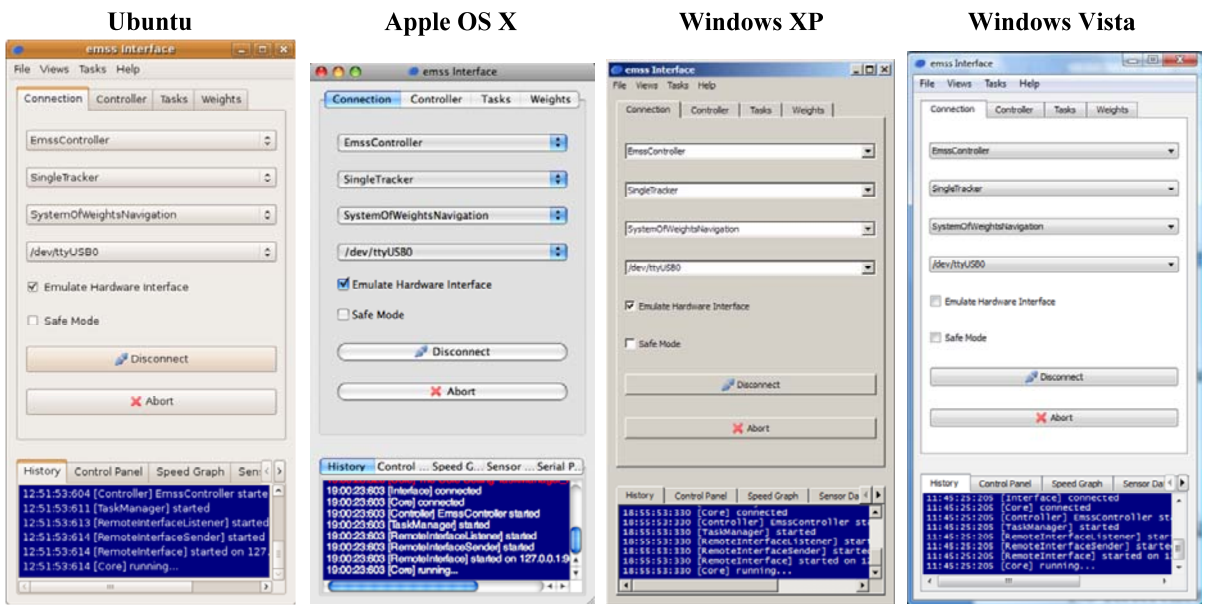
7.7 Qualitative Achievements

7.7.1 Software Stability

The *emss* framework version 1.3 is very stable and never crashes. Even when the underlying hardware stops responding (due to battery failure, et cetera), the user interface remains responsive and a clean shut down of the software can be performed. Care has been taken to avoid null-pointer runtime errors, and where necessary locks have been implemented for thread-safety. It is worthwhile to mention that this was achieved without the use of exceptions, which were not used for performance reasons due to the underlying *x86* architecture used.

7.7.2 Cross-Platform Support

The entire *emss* framework can be built across the following platforms: *Linux*, *OS X*, and *Windows*. We are proud to offer a cross-platform robotics framework, written in *C++*, which not only provides a mature library, but also a high quality user interface. All the widgets and views are compatible with the above mentioned platforms.



EmssController
SingleTracker
SystemOfWeightsNavigation
/dev/ttyUSB0
Emulate Hardware Interface
Safe Mode

```
12:51:53:604 [Controller] EmssController starte
12:51:53:611 [TaskManager] started
12:51:53:613 [RemoteInterfaceListener] started
12:51:53:614 [RemoteInterfaceSender] started
12:51:53:614 [RemoteInterface] started on 127.
12:51:53:614 [Core] running...
```

```
19:00:23:603 [Interface] connected
19:00:23:603 [Core] connected
19:00:23:603 [Controller] EmssController started
19:00:23:603 [TaskManager] started
19:00:23:603 [RemoteInterfaceListener] started
19:00:23:603 [RemoteInterfaceSender] started
19:00:23:603 [RemoteInterface] started on 127.0.0.1:9
19:00:23:603 [Core] running...
```

```
18:55:53:330 [Core] connected
18:55:53:330 [Controller] EmssController st
18:55:53:330 [TaskManager] started
18:55:53:330 [RemoteInterfaceListener] star
18:55:53:330 [RemoteInterfaceSender] starte
18:55:53:330 [RemoteInterface] started on 1
18:55:53:330 [Core] running...
```

```
11:45:25:205 [Interface] connected
11:45:25:205 [Core] connected
11:45:25:205 [Controller] EmssController st
11:45:25:205 [TaskManager] started
11:45:25:205 [RemoteInterfaceListener] star
11:45:25:205 [RemoteInterfaceSender] starte
11:45:25:205 [RemoteInterface] started on 1
11:45:25:205 [Core] running...
```

Figure 7-13: Interface Application Running on Ubuntu, OS X, XP, and Vista

8 Further Developments

8.1 Design Improvements

8.1.1 Hardware

When one uses ready-made off-the-shelf hardware, there are naturally going to be constraints and restrictions. For example, one may have no control or influence to the internal components beyond the interface provided by the manufacturer. With the *iRobot Create*, this is exactly the case, and while the advantages have been enjoyed of the simplicity of the product, its lack of depth has caused a significant problem.

8.1.1.1 Wheel Encoders

One of the major setbacks in the design of the *Create* hardware is the inability to receive the individual data from the wheel encoders. This data is presented to the user in millimeters, which would not be so bad, but unfortunately it is in a combined format. The only data pertaining to the robots movement is a distance value based on the average velocity of the two wheels. This is a shame, as the raw wheel encoder data would increase the quality of the localization greatly.

An improvement could be made by completely replacing the underlying hardware which has better support for wheel encoder data. An alternative solution would be to "break" into the *Create* hardware and manually retrieve the data through some sort of means.

8.1.1.2 Laptop Computer

The laptops currently mounted on the *emss* robots are too heavy and too large. This has reduced the performance of the underlying hardware and in many cases caused troubles during navigation. Figure 8-1 shows how the laptops edges are greater than the body of the robot. This causes difficulty when navigating close to wall and other objects, as the corners from the laptop can hang against the obstacle. In addition, the extending corners sometimes prevent the bumper from being fully pressed, disabling any chance of further detection of an object in the blind spot of the robot.

This problem can be easily solved by using a smaller laptop model instead. For example, the popular *eee PC 901* from *Asus* has a very small body, measuring only 225 x 175.5 x 22.7mm.

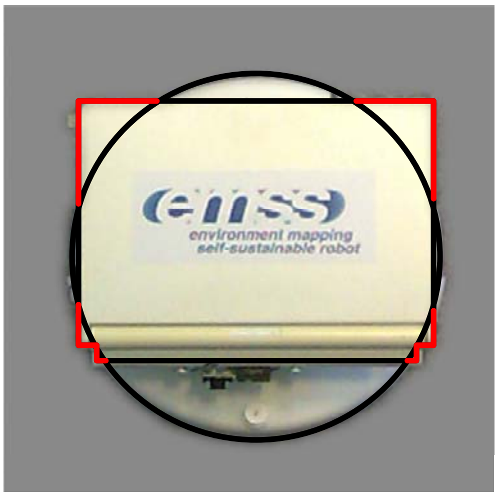


Figure 8-1: Laptop Compared with Robot Body

8.1.1.3 Sensors

Although an additional range sensor has already been added, it is clear that it is not enough. The current hardware of the robot still renders the robot as almost blind. The framework can only see in the distance with its two IR sensors – one which is pointed forwards, and the other which is pointed towards the right. It is very difficult to assess situations when approaching a collision because of the limited input. The reason the *emss* robot does not feature more range finders is because the iRobot Create only supports a single analog input.

The sensor data of the robot could be greatly improved by adding a controller for which additional range finders could be connected to and queried. The current Navigation module could then be improved by being able to react to a larger surrounding area as the robot's field-of-view would increase (see Figure 8-2).

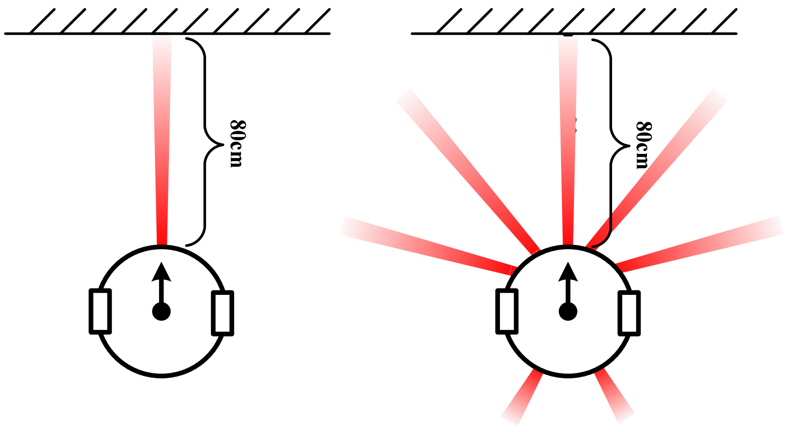


Figure 8-2: Current Range Finders (left) Compared with Extended Configuration (right)

8.2 Implementation Enhancements

Because of the modular architecture, individual modules can easily be replaced by improved or extended versions, or even entirely new ones. New Tasks and Weights can be quickly developed to perform a more complete cache of actions suited to a user's preference. A larger suit of generic actions and tasks would create a more interesting and attractive robot. For example, it would only take a miniscule effort to create a greeter-robot (one which greets visitors when it comes across them) by piecing together the current Weights and Tasks – one just has to *do* it.

8.2.1 Improvements to Current Implementations

The docking algorithm implemented by the DockWeight still needs further research, changes, and testing. The complete docking process should be more robust in off-situations which occur unexpectedly.

An important improvement would be to eliminate the robots drift to the right or left by means of software. This was already attempted by the CorrectedFrenetTracker implementation, which tried to solve the problem at a single point which would affect the entire framework. The current implementation only works in the simulated environment, but should extend to the physical environment.

Furthermore, the localization of the robot can be improved by a deeper study into the error model of the hardware behavior and the corresponding changes and implementations in the current model. In addition, external sources could be used to enhance or re-align the localization. Such sources could include specific marks in the environment which the robot could detect when encountered.

8.2.2 Other Enhancements

The robot currently has eyes but doesn't know how to use them. Computer vision could be added to the framework by making use of the VGA camera, which currently is not used by the modules for making decisions. We believe, if correctly implemented, the processing power is available on the current hardware without the need for adding a new processor.

An interesting further enhancement would be the enabling of communication between two *emss* robots. This way a whole swarm of robots could investigate and explore an area with a combined and central effort. For such an application it would be important to first master the tracking and environment mapping features. The underlying communications protocol already exists in the Remote Interface.

A further use of the *emss* robot could be to monitor a specific area at night. This would require a robust localization implementation, and the ability to dock and charge when needed, but would yield a useful remote agent that would act as a set of security officer.

9 Project Management

9.1 Prototypes

The approach together with the resulting milestones, described in Chapter 4.3, define the *emss* prototypes, which are more clearly defined in the following sections.

9.1.1 Prototype I

The first prototype takes advantage of the robot's sensors in order to maneuver around obstacles and safely navigate through an unknown space. It must also identify drops, such as stairs, and maneuver around them. The first prototype also implements basic environment mapping skills, in which the unknown space is mapped out based on the incoming sensor data.

9.1.2 Prototype II

The second prototype combines various data sources in order to calculate its position in real-time. By taking advantage of multiple data sources, such as data from onboard sensors or emulated and saved locations, a more precise position should be calculated.

9.2 Releases

Releases are complete software packages which contain all necessary components and are ready for deployment on the hardware. Each release should be hosted publicly on *SourceForge*[14] and contains the complete source code along with executable binaries and default resources.

Version	Description
v1.0	The 1.0 release contains the work achieved in our Semester Project.
v1.1	Released during Week 6, *emss* v1.1 includes the preliminary work and improvements as well as the results of Prototype I.
v1.2	The 1.2 release includes the results of Prototype II and is released during Week 9.
v1.3	The most current version of *emss* along with software documentation is included in *emss* v1.3 which is released during Week 16.

Table 9-1: Project Releases

9.3 Project Organization

[14] The *emss* framework and all its releases can be found on *SourceForge* at `http://sourceforge.net/projects/emssframework`.

9.3.1 Project Members

Name	E-Mail	Role
Daniel Krüsi	`daniel.kruesi@hsr.ch`	Project leader, Development, Documentation
David Grob	`david.grob@hsr.ch`	Development, Documentation
Prof. Stefan Keller	`sfkeller@hsr.ch`	Advisor, Examiner
Dr. Joachim Wirth	`wirj@zhaw.ch`	External Expert

Table 9-2: Project Members

Name	E-Mail	Role
Prof. P. Sommerlad	peter.sommerlad@hsr.ch	Co-Examiner
Sachin Patney	spatney@hsr.ch	*PointZero* WPS Developer

Table 9-3: Additional Contributors

9.3.2 Weekly Meetings

Weekly meetings were held each Monday with our advisor and expert in which we discussed the work accomplished during the previous week, as well as addressed mathematical, conceptual and software problems in our project.

9.3.3 Code Versioning

The code for *emss* is managed with *Tigris Subversion* (SVN), which allows us to view or return to any previously committed version of the code. The SVN server `svn.nerves.ch` which hosts our documentation is backed up nightly and serves as our backup system. The source code is managed by the *SourceForge* SVN server `svn.sourceforge.net`, which is backed up and mirrored by over fifty servers worldwide.

9.3.4 Code Comments

Comments throughout our code are well maintained. Self-explanatory methods, such as setters and getters, were omitted from comments in order to prevent bloated files. In the *Eclipse* IDE we defined three comment tags, which are automatically compiled into a visual list during compilation:

1. IDEA: A possible approach how something could be implemented.
2. TODO: Things not implemented yet, minor corrections to change.
3. BUG: An unsolved problem (bug) in the code.

9.3.5 Infrastructure

The predominant workplace is the Bachelor project-room (Room 1.258) at the University of Applied Sciences in Rapperswil. Tests of the robot and hardware components were conducted in the hallway between buildings 1 and 6 with the additional possibility of testing in the basement of building 5.

9.3.5.1 Programming Tools

Software	Producer	Version
Eclipse	*Apache Software Foundation*	3.4.1
Eclipse C/C++ Development Tools	*Apache Software Foundation*	5.0.1
Qt C++ Eclipse Integration	*Qt Software, Nokia*	1.4.3
Qt Framework	*Qt Software, Nokia*	4.5.1
GNU G++ Compiler	*Free Software Foundation*	4.3.2

Table 9-4: Programming Tools

9.4 Risk Management

Risk	Effect	Precautions	Maximum Delay	Probability	Weighted Damage	Priority
R01: Hardware Failure	Continuation of project no longer possible	Construction of backup robot and development of robot emulator in order to reduce time of hardware usage	30h	10%	3h	1
R02: Insufficient “Know-How” for problem solving	Delays for additional research	Consultation with Prof. Keller and Dr. Wirth for mathematical solutions	50h	40%	29h	2
R03: Loss of project member due to health or accident	Continuation of project by one team member	Careful documentation of progress and communication between members so that know-how can be transfered if needed	360h	5%	18h	3
R04: Unobtainable goals	Not all goals met during time constraints	Consolidation of goals	2h	50%	1h	4
R05: WPS fingerprints become very tedious	Extra time consumption infringes on other parts of project	Address early in project so that this foundation is realized and tested	20h	20%	4h	5
Total Time Buffer					55h	

Table 9-5: Risk Management

The extra 55 hours are scheduled in Chapter 1.5 as buffer-time.

9.5 Timetable

In order to reach the defined goals, 783 work hours were scheduled. The following layout is used to describe the different artifacts:

Artifact	**Total Effort in Hours**
Task 1	Effort for Task 1
Task 2	Effort for Task 2

Table 9-6: Artifact Table Layout

9.5.1 Inception

Setup Environment	**30**
Setup of work stations (*Ubuntu*, development environment)	10
Setup of robot operating systems (*Ubuntu*), production environment	5
Website, SVN repository, *SourceForce* Project Page	15

Project Plan	**10**
Concrete organization of project, definition of milestones and work sections	10

Requirements	**15**
Definition of use cases, definition of Remote Interface	15

Technology Research	**30**
Research in the robotics community, reading of relevant articles and publications	30

Total inception effort in hours: **85**

9.5.2 Implementation

Core	**37**
Improvement / refactoring of version 1.0	10
Creation of configuration files	10
Logging: save debug-information in data logs	2
Thread-safe programming of all classes	10
Implementation of Core Factory	5

Remote Interface	**10**
Implement Remote Interface (Listener, Sender)	10

Emulated COIL	**20**
Full implementation of COIL emulation	10

Splines	**15**
Realization of magnet-tracking	5
Improvements and additions to spline kernels	10

GUI	**40**
Improvements to *emss* Interface	10
Implementation of *emss* FingerprintCollector	10
Creation of RobotControlPanel, RobotSpeedGraph, MapOverview, WeightEditor, CameraView, TaskEditor, RemoteInterfaceView, HeapLoggerView, DockingStationView	10
Improvements to Viewport and include OpenGL support	10

Navigation	**20**
Implementation of SystemOfWeightsNavigation	20

Weights	**40**
Implementation of CollisionAvoidanceWeight	10
Implementation of WallFollowerWeight	10
Implementation of WallFollowerWeight	10
Implementation of supplemental weights such as JoystickWeight, RoamingWeight, FullSpeedWeight	10

Maps	**35**
Addition of PhysicalMap, support for KML files	10
Improvements to HeatMap	10
Creation of StructureMap	5
Creation of FadingCollisioMap	10

Controller	**20**
EmssController improvements	20

Tasks	**41**
Further developments to TaskManager	10
WallFollowerTask implementation	3
SplineDiscoveryTask implementation	3
RoamingTask implementation	3
TestMoveTask implementation	3
PauseTask implementation	2
UndockTask implementation	2
FingerprintNavigationTask implementation	5
FingerprintDiscoveryTask implementation	5
DiscoveryTask implementation	5

Watchdog	**20**
Watchdog implementation with actions	20

Tracker	**50**
SingleTracker, AveragedTracker	5
ExpectedTracker, FrenetTracker	20
RawMovementTracker	5
SelfCorrectingTracker	20

WPS	**30**
Implementation of KML file parser and GPS calculations	10

Tests	**40**
Unit tests	20
System tests	20

Total implementation effort in hours: **418**

9.5.3 Hardware

Purchasing and assembling	**35**
Purchase of components for the robot (chassis, sensors, et cetera)	5
Assembly of robots	20
Modification to docking stations	10

Total hardware effort in hours: **35**

9.5.4 Project Management

Documentation	**110**
Wiki	30
Documentation	80

Meetings	**60**
Weekly meetings with advisor and expert	60

Releases	**20**
Builds	10
Scripts	10

Buffer Time	**55**
Time from risk management (Chapter 9.4)	55

Total project management effort in hours: **254**. It is noteworthy to mention that the documentation requires the most time.

9.6 Comparison of Projected and Actual Time

The total projected time needed for completion of this project sums to **783** hours. However, in reality the time required for the project was underestimated and totaled **1190** hours. Closer inspection shows that the deviations in the projected time compared to the actual required time primarily arose in the implementation. Although the offending implementation components include nearly all artifacts, the worst underestimations include the Tracker, and Weights artifacts. This has been pin-pointed largely to the required fundamental analysis of mathematical methods and procedures which these artifacts required. The additional invested hours were fueled by the project member's passion for robotics and determination to accomplish the foreseen goals.

The diagram shown in Figure 9-1 shows an overview of the projected versus required time for the entire project. Figure 9-2 compares the projected to required hours specifically for the Implementation phase.

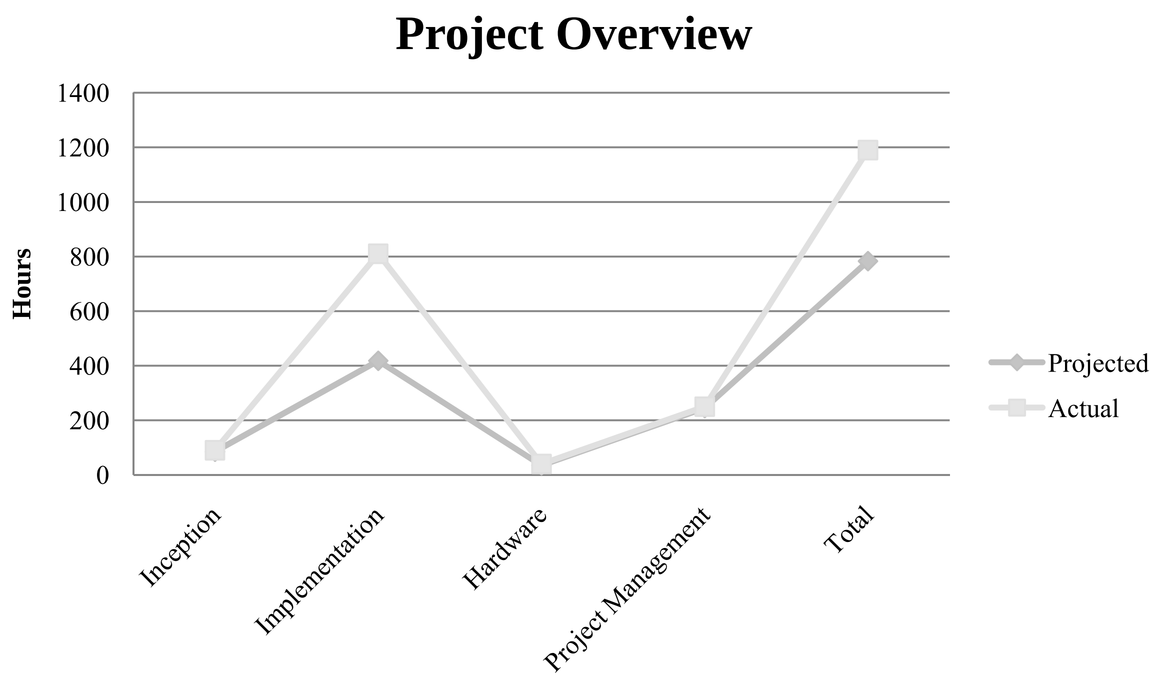


Figure 9-1: Overview of Projected versus Actual Time

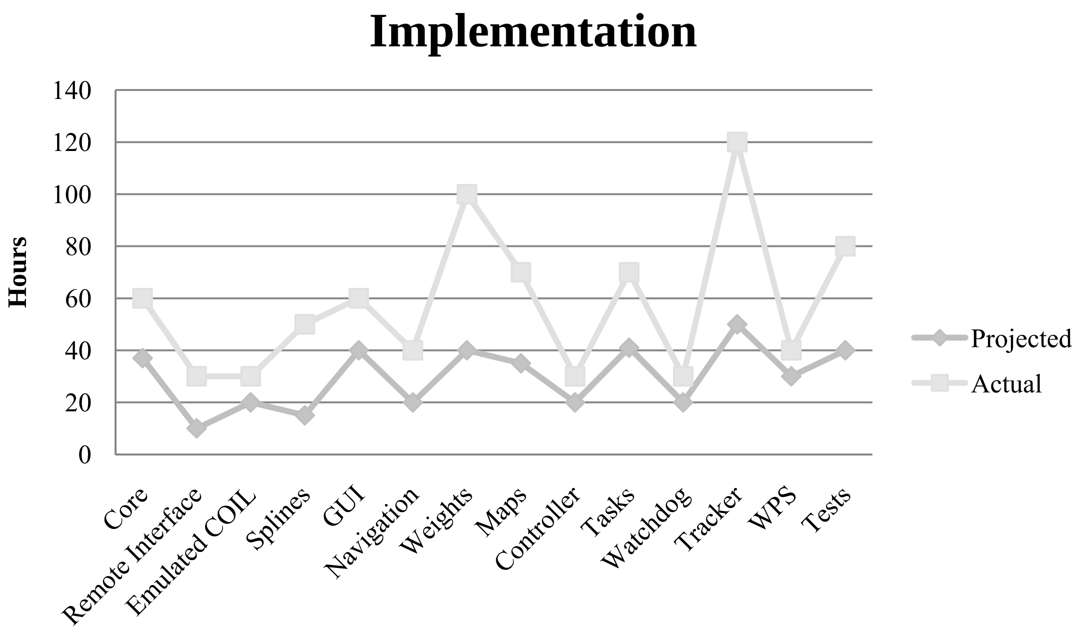


Figure 9-2: Comparison of Projected versus Required hours for Implementation

9.7 Metrics

To measure the code metrics of the *emss* project, the well known tool *SLOCCount* by David Wheeler was used. The total Source Lines of Code (SLOC) of all components is **19,971**, with the majority belonging to the *emss* Core, which totals 14,348. Compared with the previous work achieved in the Semester Project, the total SLOC has grown 96.7% from 10,138 SLOC, whereas the Core has grown 118.9% from 6,554 SLOC. It is worthwhile to mention that the current code base contains 8,776 comments – which is an accurate reflection of our efforts to create thoroughly documented source code.

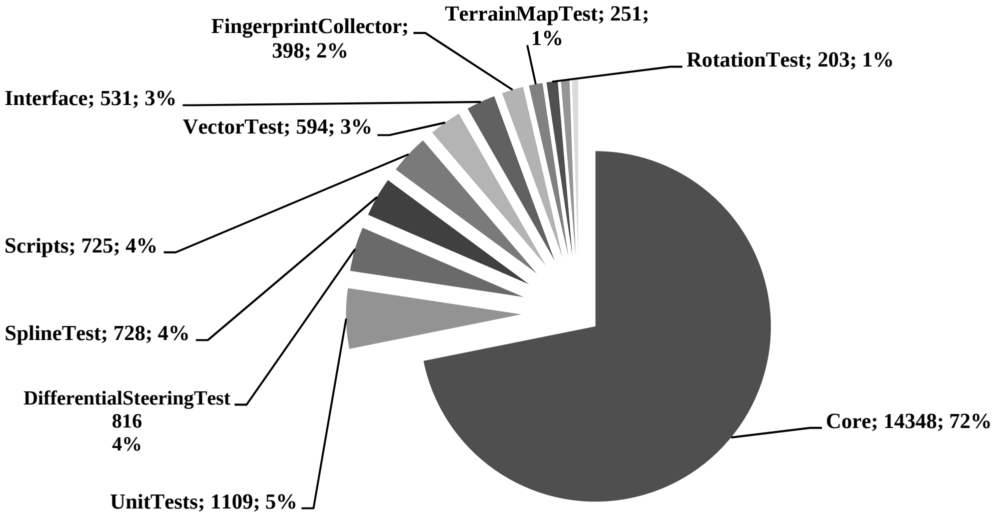


Figure 9-3: Source Lines of Code Distribution

9.8 Personal Report

9.8.1 Daniel Krüsi

Realizing this project has been a dream of mine for a long time. Since childhood I have been interested in robots, and since my teenage years I have been building them. The mix of theory, mathematics, programming, and tinkering with hardware throughout the project was really fascinating. While at many times the wide range of topics we touched was a little overwhelming, as was the entire scope of the project, I believe the values and lessons I learnt throughout the project are a invaluable experience. Not only were we pushed on an almost daily basis to extend our knowledge to new unfamiliar areas and fields, but we were also given the chance to realize different aspects of computer science which we had learnt throughout the course of our studies. Working with David Grob, Prof. Keller, and Dr. Wirth was very comfortable. We all supported each other with the resources and knowledge we had, and in total spent countless hours brainstorming problems and solutions. As students presenting our own project idea, I felt the interest and support from the university for the first time. At times the project was frustrating when after so much hard work specific areas would just continuously fail and remain unresolved, and constant new unexpected problems would arise. But, in hindsight, this is normal for any hardware-related project. All the long nights and weekends were definitely worth it. Many thanks to all who supported the project - I look forward to continue using the *emss* framework to build mobile two-wheeled robots.

9.8.2 David Grob

Dr. Joachim Wirth has unfortunately left the *HSR University of Applied Sciences* so that he could not advise our Bachelor Thesis. Nevertheless, we found Prof. Stefan Keller which was very interested and motivated to supervise our project. Hence we could build upon our Semester Project and achieved exciting new developments as well as improvements of our previous work. The entire project was very interesting and versatile. Many fields of Computer Science were covered, from accessing hardware to network programming to graphical user interfaces. Also, many theoretical and mathematical works was undertaken, as well as reading of relevant papers of the field. The project was so interesting that many times we forgot the time and worked too much. However, that wasn't a problem as we were happy to accomplish the different goals set before us. The teamwork with Daniel Krüsi was very agreeable, and I treasure the cooperativeness of Prof. Stefan Keller and Dr. Joachim Wirth which were always available for questions. I have learned much and I would do the work again. Robotics will remain an interest of mine most definitely.

9.9 Thanks

Special thanks to Prof. Stefan Keller and the *HSR Institute for Software* for their support in the project. We also especially thank Dr. Joachim Wirth for his continued support throughout the entire *emss* project.

10 Software Documentation

10.1 Installation

The entire *emss* framework restricts itself to a single root folder `<emss>`, so it is very simple to install. Binary releases are built statically and should be able to run on a standard *Linux*, *OS X*, or *Windows* installation without any additional libraries. The only setup required is for the script environment, described in detail in Chapter 0.

10.1.1 Linux and OS X

1. Download the latest source or binary tar from *irobotcreate.com*[15], such as `emssComplete-1.x-<source|<linux|osx>-x86>.tar.gz`.
2. Extract the tar contents: `mkdir ~/emss; tar -C ~/emss -xvvf emssComplete-1.x-<source|<linux|osx>-x86>.tar.gz`.
3. Set execute permissions on all scripts: `chmod u+x ~/emss/emss_1.x/Scripts/*.sh`
4. Run the setup script: `~/emss/emss_1.x/Scripts/setup.sh`.

10.1.2 Windows

1. Download the latest source or binary zip from *irobotcreate.com*[16], such as `emssComplete-1.x-<source|win-x86>.zip`.
2. Open the zip file and select "Extract all Contents" from the Folders Tasks menu. Extract the contents to a folder such as `C:\emss`.
3. If you would like to use the *emss* scripts in Windows, a bash/shell interpreter must be installed such as Cygwin[17]. Once installed, the script environment can be setup as follows: Set execution permissions on all scripts: `chmod u+x /cygdrive/c/emss/emss_1.x/Scripts/*.sh`.
4. Run the setup script: `/cygdrive/c/emss/emss_1.x/Scripts/setup.sh`.

The installation will have created default settings and configurations. To customize the settings for the script environment, modify the file `<emss>/Scripts/settings.sh;` which was automatically created by `setup.sh`. To customize any configuration for an *emss* component, modify the `<emss>/resources/emss<component>.config` or create a patch file `<emss>/resources/emss<component>.config.patch`. More information on patch files can be found in Section 10.6.5.3.

[15] The latest *Linux* and *OS X* downloads can be found at `http://irobotcreate.com/Downloads`.
[16] The latest *Windows* downloads can be found at `http://irobotcreate.com/Downloads`.
[17] *Cygwin* can be obtained from `http://www.cygwin.com`. A standard installation is sufficient to run all the *emss* scripts.

10.2 Build Instructions

10.2.1 Prerequisites

10.2.1.1 General

A significant effort has been maintained throughout the *emss* framework in order to keep the libraries and external resources at a minimum. The basic requirements for building the framework are the *GNU* compiler tool chain for *C++* and the *Qt* framework:

- *GNU g++* version 4.3 or newer
- *Qt* version 4.4.3 or newer

10.2.1.2 OS Specifics

10.2.1.2.1 Linux

The following *Debian* packages are required:

- subversion
- g++
- libqt4-dev
- libasound2-dev

These can be obtained through apt-get or aptitude as such:

```
sudo apt-get install subversion
sudo apt-get install g++
sudo apt-get install libqt4-dev
sudo apt-get install libasound2-dev
```

or

```
sudo apt-get install subversion g++ libqt4-dev libasound2-dev
```

10.2.1.2.2 OS X

In order to use the *Qt* framework on *OS X*, the *Apple X-Code* tools are required. These can be downloaded directly from apple at developer.apple.com[18].

The *Qt* framework can be downloaded from *Qt Software*[19].

[18] Apple developer tools are free of charge for users with a developer account. An account can be created at `http://developer.apple.com`.
[19] Visit `http://wwws.qtsoftware.com/downloads`, select the *LGPL* version and download the "Qt SDK for Mac" package.

10.2.1.2.3 Windows

The entire framework can be built by just installing the *Qt* framework, which can be downloaded from *Qt Software*[20]. If not already installed, *Qt* will automatically install the *MinGW* tool chain. In order to use the bash/shell scripts provided with the *emss* framework, we recommend *Cygwin*.

10.2.2 Environment

In order to build the *emss* framework using the *Qt* tools, the *Qt* bin folder must be in the `PATH` variable. Depending on how *Qt* was installed, the `PATH` variable might need to be updated to include the *Qt* bin folder.

10.2.2.1 Unix

On most systems one can change the `~/.bashrc` file by adding the following:

```
PATH="/path/to/Qt/bin:$PATH"
export PATH
```

10.2.2.2 Windows

Under “System”, “Advanced”, and then “Environment”, add the path to the *Qt* bin folder at the end of the `PATH` variable.

An easy way to check which *Qt* version is being used is to run the following command: `qmake --version`.

10.2.3 Building

10.2.3.1 Using build.sh

The easiest way to build any *emss* component is by using the included script `build.sh`. To build a component, just run `build.sh` followed by the component name, such as `build.sh Interface`. If you wish to build everything, just run `build.sh all`.

```
cd <emss>/Scripts
./build.sh Core
./build.sh Interface
```

The full documentation for this script can be found in Section 10.6.7.

A build can be customized by modifying the `settings.sh` file. Settings such as debug/release builds, target OS, platform et cetera can be set. The full documentation for these settings can be found in Section 10.6.3.

[20] Visit `http://wwws.qtsoftware.com/downloads`, select the *LGPL* version and download the “Qt SDK for Windows” package.

10.2.3.2 Manual Build

10.2.3.2.1 Calling Make

Each *emss* component has its own *Qt* project-file (`.pro`) which can be used for generating makefiles. This is done by calling the *Qt* tool `qmake`. After `qmake` is finished, calling `make` is sufficient for that component.

```
cd <emss>/Core
qmake
make
cd <emss>/Interface
qmake
make
```

It is worthwhile noting that some components might rely on others, notably Core (`libemssCore`), when linking. This is the case, for example, in the Interface component (`emssInterface`).

10.2.4 Output

All components are built to a common `bin` directory located directly in the *emss* home directory `<emss>`. Debug and release builds are not differentiated.

10.2.5 Debug Builds

In order to make a debug build `qmake` must generate the appropriate makefiles that link to the debug libraries of *Qt*. This can be easily done as demonstrated below:

```
cd <emss>/<component>
qmake -config debug_and_release
make <debug|release>
```

Alternatively, the script build.sh can be used to make debug builds when the debug setting is set. The full documentation for this script can be found in Section 10.6.7.

10.2.6 Example Script for Fresh Ubuntu Installation

The following downloads and installs all needed libraries, checks-out the *emss* Framework source code, configures the *emss* Scripts, builds the Core and Interface, and finally runs the emss Interface.

```
# Download and install libraries
sudo apt-get install subversion
sudo apt-get install g++
sudo apt-get install libqt4-dev
sudo apt-get install libasound2-dev

# Check out source code
```

```
svn co https://emssframework.svn.sourceforge.net/svnroot/emssframework/trunk
           emssframework

# Configure scripts
cd emssframework/Scripts
chmod u+x *.sh
./setup.sh

# Build and run the default component (Interface)
eb
er
```

Code 10-1: Example Environment Installation for Ubuntu

10.3 Core

Any application which wishes to make use of the *emss* framework must link against the *emss* Core library (`libemssCore.a`) and initialize a Core object. The Core object is the entry point into the entire *emss* framework, allowing one to connect to hardware and begin controlling a robot. Furthermore, the CoreFactory is also an essential player in quickly creating a user interface for an application using the *emss* framework. In this chapter a detailed set of instructions are described for setting up a *Qt 4.5* application which links against the *emss* Core library. Furthermore, a simple application is presented as an example how to setup and connect the *emss* Core. In Section 10.3.3 all the configuration settings for the *emss* Core are thoroughly described.

For more details and documentation on the Core, please see Chapter 6.3.1. For details on how to setup a working environment with *Eclipse*, see Section 11.5.3 in the Appendix.

10.3.1 Linking Against the Core Library

10.3.1.1 Qt Components

The *emss* framework makes use of, and therefore, requires the following *Qt* components: QtCore, QtGui, QtNetwork, QtOpengl, and QtXml. These must be added to the *Qt* Project File[21] (`.pro`) as such:

```
QT += core gui network opengl xml
```

10.3.1.2 Resources and Definitions

Some resources are required by the framework, such as icons and standard texts, and must also be specified in *Qt* Project File:

```
RESOURCES += <emss>/DefaultResources/Icons.qrc
RESOURCES += <emss>/DefaultResources/Texts.qrc
win32:RC_FILE = <emss>/DefaultResources/WinIcon.rc
```

[21] For more information on *Qt* Project Files, please see the official Qt documentation at http://doc.trolltech.com/4.5/qmake-project-files.html.

If you wish to use the HeapLogger feature (for testing purposes), you must define the following variable in the Project File:

```
DEFINES += ENABLE_HEAP_LOGGING
```

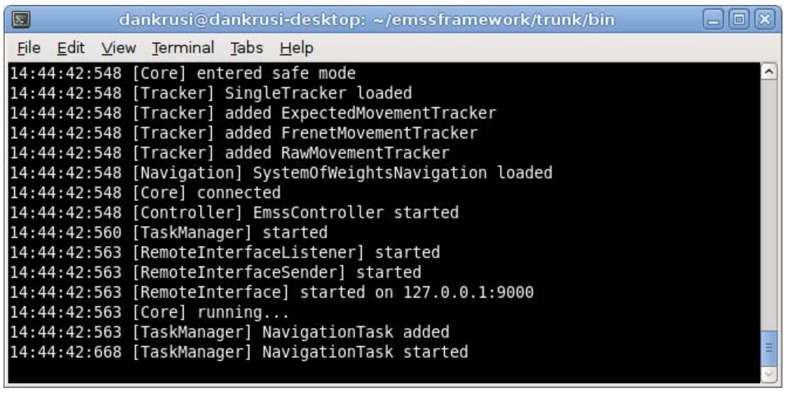
10.3.1.3 Libraries

On *Windows* and *OS X* the only required library is the *emss* Core library. However, on *Linux* better sound support is provided by the popular *asound* library (`libasound2`). This library is available on all Debian distributions and can easily be installed with the following command: `sudo apt-get install libasound2-dev`. The following is required in the *Qt* Project File to link against these libraries:

```
LIBPATH = <emss>/bin
LIBS += -lemssCore
unix:!macx:LIBS += -lasound
```

10.3.2 Example Application

The example application presented here shows how to use the *emss* Core to perform the simple task of navigating through three navigation points. It includes all the code necessary to instantiate and connects the Core, fire it up, respectively use it, and finally clean up. The application is made up of two files, `ExampleApplication.pro` and `main.cpp`, and can be found with any *emss* distribution as of version 1.3 in the `<emss>/ExampleApplication` folder.


dankrusi@dankrusi-desktop: ~/emssframework/trunk/bin
File Edit View Terminal Tabs Help

```
14:44:42:548 [Core] entered safe mode
14:44:42:548 [Tracker] SingleTracker loaded
14:44:42:548 [Tracker] added ExpectedMovementTracker
14:44:42:548 [Tracker] added FrenetMovementTracker
14:44:42:548 [Tracker] added RawMovementTracker
14:44:42:548 [Navigation] SystemOfWeightsNavigation loaded
14:44:42:548 [Core] connected
14:44:42:548 [Controller] EmssController started
14:44:42:560 [TaskManager] started
14:44:42:563 [RemoteInterfaceListener] started
14:44:42:563 [RemoteInterfaceSender] started
14:44:42:563 [RemoteInterface] started on 127.0.0.1:9000
14:44:42:563 [Core] running...
14:44:42:563 [TaskManager] NavigationTask added
14:44:42:668 [TaskManager] NavigationTask started
```

Figure 10-1: Test Application Running in the Console

The application does not provide a user interface, and runs strictly top-down without the use of additional signals and slots. For an example to see how to setup a custom user interface using the GUI components, see the source code for the *emss* Interface under `<emss>/Interface`.

10.3.2.1 Project File

The project file `ExampleApplication.pro` is defined exactly as the instructions provided in Section 10.3.1, with the additional standard keys `TEMPLATE`, `TARGET`, `CONFIG`, and `SOURCES`.

```
TEMPLATE = app ← defines this project to be a Qt Application
TARGET = emssExampleApplication ← sets the target name (-o flag) for the executable
CONFIG += console ← adds console output capability
QT += core gui network opengl xml
```

```
SOURCES += main.cpp ← adds our only source file to be included in the compiles input
HEADERS =
FORMS +=
LIBS += -lemssCore
DESTDIR = ../bin
LIBPATH = ../bin
unix:!macx:LIBS += -lasound
win32:RC_FILE = ../DefaultResources/WinIcon.rc
RESOURCES += ../DefaultResources/Icons.qrc
RESOURCES += ../DefaultResources/Texts.qrc
```

Code 10-2: Example *Qt* Project File

10.3.2.2 Source Code

The source file `main.cpp` consists of less than 20 lines-of-code. It is written to show how to use the *emss* Core and may not handle or catch every erroneous situation.

Additional comments have been added with the ← marker.

```
#include <QCoreApplication> ← the Example Application is solely a console application (QtCore)

#include "../Core/Core.h" ← header files must be included for each Core module used
#include "../Core/CoreFactory.h"
#include "../Core/Navigation/Navigation.h"
#include "../Core/Task/TaskManager.h"
#include "../Core/Tracker/Tracker.h"
#include "../Core/Controller/Controller.h"

int main(int argc, char *argv[])
{
     // Init the Qt Application environment
     QCoreApplication a(argc, argv); ← this must be called to setup a QEventHandler pipeline

     // Create a emss Core with settings specified in emssCore.config
     Core *core = new Core(); ← without any parameters, the Core constructor creates a default user Core

     // Connect the Core with the following configuration and start it:
     //     Controller:         EmssController
     //     Tracker:            SingleTracker
     //     Navigation:         SystemOfWeightsNavigation
     //     Serial Port:        /dev/TTYUSB0
     //     Safe Mode:          true
     //     Emulation:          true
     if(core->connect("EmssController", "SingleTracker",
"SystemOfWeightsNavigation", "/dev/TTYUSB0", true, true)) { ← make sure it connected
before continuing…
            core->start(); ← calling the start method will start all the appropriate internal threads

            // Set the Controller target speed
            core->controller->setTargetSpeed(150); // millimeters per second

            // Add some navigation points and its corresponding Task
            core->tracker->setPosition(1000,1000); // x/y-coordinates in
millimeters
            core->navigation->addNavPoint(2000,1000);
            core->navigation->addNavPoint(2000,2000);
            core->navigation->addNavPoint(3000,3000);
            core->addTask(CoreFactory::createTask(core, "NavigationTask"));

            // Wait for all Tasks to finish
            core->taskManager->waitForAllTasksToFinish(); ← this method will block the
current thread until all Tasks are finished

            // Shutdown the Core
            core->stop(); ← stopping a Core only "pauses" it – calling disconnect actually shuts down any
physical connections
            core->disconnect();
     }

     // Cleanup and finish
     delete core; ← the Core will clean up after itself – all Tasks, Messages, et cetera created through the
CoreFactory will automatically be deleted as long as they were passed to the Core at one point
    return 0;
}
```

Code 10-3: Example Application Source Code

10.3.2.3 Application Output

When executed, the application produces the following output on the console. First the Core is initialized and all the modules are loaded. After the Core is started, a simple NavigationTask is added and started. Once the Task is finished, the Core is stopped and disconnected.

Comments have been added with the ← marker.

```
14:17:59:125 [Core] initialized ← indicates that the Core could initialize and allocate all its data
14:17:59:125 [Core] using EmulatedCOIL ← indicates which COIL implementation is being used
14:17:59:125 [Core] started OI
14:17:59:125 [Core] entered safe mode
14:17:59:125 [Tracker] SingleTracker loaded ← shows which Tracker module was loaded
14:17:59:125 [Tracker] added ExpectedMovementTracker ← indicates that a MovementTracker was
added to the Tracker
14:17:59:126 [Tracker] added FrenetMovementTracker
14:17:59:126 [Tracker] added RawMovementTracker
14:17:59:126 [Navigation] SystemOfWeightsNavigation loaded ← indicates which Navigation
module was loaded
14:17:59:126 [Core] connected ← indicates the Core is connected and ready
14:17:59:126 [Controller] EmssController started ← when calling start on the Core, all
CoreThreads will report that they are now started
14:17:59:139 [TaskManager] started
14:17:59:142 [RemoteInterfaceListener] started
14:17:59:143 [RemoteInterfaceSender] started
14:17:59:143 [RemoteInterface] started on 127.0.0.1:9000
14:17:59:143 [Core] running... ← indicates that everything in the Core (specifically CoreThreads) is
running
```

```
14:17:59:143 [TaskManager] NavigationTask added ← indicates that a Task was added but has not necessarily been started
14:17:59:249 [TaskManager] NavigationTask started ← shows that a specific Task was started by the TaskManager
14:18:26:146 [TaskManager] NavigationTask finished ← indicates the Task has finished
14:18:26:261 [TaskManager] stopped ← when calling stop on the Core, all CoreThreads will report when they have stopped
14:18:26:312 [Controller] EmssController stopped
14:18:26:413 [RemoteInterfaceListener] stopped
14:18:26:515 [RemoteInterfaceSender] stopped
14:18:26:515 [RemoteInterface] stopped
14:18:26:515 [Core] stopped ← indicates that the Core is now stopped
14:18:26:515 [Core] disconnected ← indicates that the Core is now disconnected and may be deleted
```

Code 10-4: Example Application Output

10.3.3 Configuration

The settings below are used by the core application and can be located in the file `<emss>/resources/emssInterCore.config`. There are over 150 different configuration values throughout the Core and are split up over 12 sections. Each section corresponds to the first word in the configuration name. For further details on the different value types and configuration patches please see Section 11.5 in the glossary.

10.3.3.1 Camera

Camera_AutoRefreshInterval

Default	`1000`
Type	`ms`
Description	Specifies the rate at which the camera image should be refreshed in milliseconds.

Camera_CaptureToolCommand

Default	`v4l2src ! ffmpegcolorspace ! pngenc ! filesink location\\=$Camera_CaptureToolOutFile`
Type	`string`
Description	Specifies the command arguments to be executed for generating a camera snapshot. The variable `$Camera_CaptureToolOutFile` can be used to insert the output path specified in Camera_CaptureToolOutFile.

Camera_CaptureToolOutFile

Default	`camera.png`
Type	`string`
Description	The output filename or file path used when loading the output file of the capture tool.

Camera_CaptureToolPath

Default	`camera.png`
Type	`string`
Description	Specifies the capture tool to be executed when generating a camera snapshot. Arguments are specified in Camera_CaptureToolCommand.

Table 10-1: Core Configuration Values for Camera

10.3.3.2 COIL

COIL_EmulatedCOIL_SpecificMovementTrackerForSensorEmulation

Default	`RawMovementTracker`
Type	`string`
Description	This specifies which MovementTracker should be used for emulating the robot sensors when COIL_EmulatedCOIL_UseSpecificMovementTrackerForSensorEmulation is `true`. EmulatedCOIL will use this MovementTracker for emulating the various sensors. Specifically, the set MovementTracker's position is used for determining the local sensor position on the map. This can be useful when a localization error is wished to be emulated.

COIL_EmulatedCOIL_UseSpecificMovementTrackerForSensorEmulation

Default	`false`
Type	`bool`
Description	When true, enables a specific MovementTracker for emulating sensor data instead of using the Tracker data.

Table 10-2: Core Configuration Values for COIL

10.3.3.3 Controller

Controller_EmssController_EmergencyStopEnabled

Default	`true`
Type	`bool`
Description	When enabled, the EmssController will perform an emergency stop whenever a unsafe move is detected. When an emergency stop is triggererd, only backwards movements are allowed.

Controller_EmssController_Interval

Default	`10`
Type	`ms`
Description	The target interval at which the Controller process() method is called by the Controller CoreThread.

Controller_EmssController_Speed

Default	`400`
Type	`mmps`
Description	The maximum speed possible on the controller, in mmps.

Controller_EmssController_DebugInfoEnabled

Default	`false`
Type	`bool`
Description	Specifies whether debugging info, such as wheel speeds, should be printed to the console or not.

Controller_EmssController_DebugInfoInterval_ms

Default	`1000`
Type	`ms`
Description	Specifies the interval at which the controller debug info should be outputted when Controller_EmssController_DebugInfoEnabled is `true`.

Controller_StopRequestInterval

Default	`50`
Type	`ms`
Description	The interval at which a stop request should be performed on the Controller CoreThread when trying to stop the Controller.

Controller_Watchdog_Enabled

Default	`false`
Type	`bool`
Description	When true, adds a ThreadMonitorWatchdogAction for the Controller CoreThread. If the Controller CoreThread does not ping the Watchdog at its given interval (+- flexibility), the Watchdog will trigger the appropriate alarm or action.

Controller_Watchdog_Flexibility

Default	`2.5`
Type	`double`
Description	The flexibility to be used when registering the ThreadMonitorWatchdogAction.

Table 10-3: Core Configuration Values for Controller

10.3.3.4 Map

Map_GridMap_Color

Default	`150 150 150`
Type	`color`
Description	The color of the GridMap lines.

Map_GridMap_GridSize_mm

Default	`1000`
Type	`mm`
Description	The size of the GridMap grid squares in length and height.

Map_HeatMap_BumperCollisionOpacity

Default	`0.1`
Type	`double`
Description	The opacity of the heat-spot applied on the HeatMap when encountering a bumper collision. Must be a value between 0.0 to 1.0.

Map_HeatMap_BumperCollisionSize_mm

Default	`400`
Type	`mm`
Description	The size (in millimeters) of the heat-spot diameter when encountering a bumper collision.

Map_HeatMap_CliffCollisionOpacity

Default	`0.1`
Type	`double`
Description	The opacity of the heat-spot applied on the HeatMap when encountering a cliff collision. Must be a value between 0.0 to 1.0.

Map_HeatMap_CliffCollisionSize_mm

Default	`400`
Type	`mm`
Description	The size (in millimeters) of the heat-spot diameter when encountering a cliff collision.

Map_HeatMap_CollisionAreaColor

Default	`red`
Type	`string`
Description	The color which represents a collision, such as a bumper collision. This value must be either `red|green|blue`.

Map_HeatMap_HeatOpacity

Default	`0.2`
Type	`double`
Description	The opacity of a default heat-spot applied on the HeatMap. Must be a value between 0.0 to 1.0.

Map_HeatMap_HeatSize

Default	`400`
Type	`mm`
Description	The size (in millimeters) of a default heat-spot diameter.

Map_HeatMap_IRCollisionOpacity

Default	`0.1`
Type	`double`
Description	The opacity of the heat-spot applied on the HeatMap when encountering a IR collision (straight ahead collision). Must be a value between 0.0 to 1.0.

Map_HeatMap_IRCollisionSize_mm

Default	`200`
Type	`mm`
Description	The size (in millimeters) of the heat-spot diameter when encountering a IR sensor (straight ahead) collision.

Map_HeatMap_OpenAreaColor

Default	`green`
Type	`string`
Description	The color which represents a open area. This value must be either `red|green|blue`.

Map_HeatMap_OpenAreaOpacity

Default	`0.05`
Type	`double`
Description	The opacity of the heat-spot applied on the HeatMap when moving through an open-area space. Must be a value between 0.0 to 1.0.

Map_HeatMap_OpenAreaSize_mm

Default	`400`
Type	`mm`
Description	The size (in millimeters) of the heat-spot diameter when moving through an open-area space.

Map_HeatMap_WallCollisionOpacity

Default	`0.1`
Type	`double`
Description	The opacity of the heat-spot applied on the HeatMap when encountering a wall-sensor collision (to the right). Must be a value between 0.0 to 1.0.

Map_HeatMap_WallCollisionSize_mm

Default	`200`
Type	`mm`
Description	The size (in millimeters) of the heat-spot diameter when encountering a wall-sensor (to the right) collision.

Map_Height_mm

Default	`45000`
Type	`mm`
Description	The initial map height. Used by various Maps, such as the HeatMap, when pre-allocating memory.

Map_PhysicalMap_Color_Stairs

Default	`174 174 174`
Type	`color`
Description	The color which represents stairs (or drops) in the physical map. This is used by EmulatedCOIL (when in emulation mode) to determine when to trigger the cliff sensors. This value must be adjusted depending on how the physical map is saved. Finding a good value can be done by using the "Environment Info" tool in the emss Interface when the map is loaded and clicking on the different obstacles represented in the map. The color levels of the environment for that point is output to the emss Interface console. If needed, an alpha value can be added in the format of `R G B A`, such as `255 255 255 127` (50% gray).

Map_PhysicalMap_Color_Tolerance

Default	`20`
Type	`int`
Description	The level or tolerance used by the PhysicalMap when determining the area-type for a specific location together with Map_PhysicalMap_Color_Stairs and Map_PhysicalMap_Color_Wall. If a tolerance of 20 is specified, then the color `240 240 240` would register for a wall specified as `255 255 255`. Map_PhysicalMap_Color_Tolerance is used to allow maps to be aliased around the edges of obstacles, walls, or stairs (drops).

Map_PhysicalMap_Color_Wall

Default	`255 255 255`
Type	`color`
Description	The color which represents walls (or obstacles) in the physical map. This is used by EmulatedCOIL (when in emulation mode) to determine when to trigger the IR sensors or bump sensors. This value must be adjusted depending on how the physical map is saved. Finding a good value can be done by using the "Environment Info" tool in the emss Interface when the map is loaded and clicking on the different obstacles represented in the map. The color levels of the environment for that point is output to the emss Interface console. If needed, an alpha value can be added in the format of `R G B A`, such as `255 255 255 127` (50% gray).

Map_PhysicalMap_Description

Default	`ThisIsAMapDescription`
Type	`string`
Description	A custom description for the loaded PhysicalMap. This is used by external Tasks such as the FingerprintNavigationTask. Note that if a KML file is loaded, the Map_PhysicalMap_Description value is ignored.

Map_PhysicalMap_Filename

Default	`$ResourcesPath/PhysicalMap.png`
Type	`string`
Description	The full path to either an image file (`.jpg|.png|.bmp|.tiff`) or a KML file (`.kml`) which represents the PhysicalMap. If a KML file is specified, it must contain a `GroundOverlay` node. The variable `$ResourcesPath` may be used to specify the current emss Resources Path.

Map_PhysicalMap_Floor

Default	
Type	`string`
Description	A custom floor ID for the loaded PhysicalMap. This is used by external Tasks such as the FingerprintNavigationTask. Note that if a KML file is loaded, the Map_PhysicalMap_Floor value is ignored.

Map_PhysicalMap_GPSOffset

Default	`47.223611 15.146667`
Type	`gps`
Description	The GPS offset-coordinates used when translating the local map position to a global map position. These GPS coordinates must specify the local coordinates of 0.0,0.0 (bottom left) of the PhysicalMap. The translation is then calculated by the GPS Math Library Class. For further details on the calculation please see the documentation for the Core Math classes. If a KML file is loaded, the Map_PhysicalMap_GPSOffset value is ignored, as the KML describes the bounding GPS-box for the map

Map_PhysicalMap_Scale

Default	`1`
Type	`double`
Description	The pixel-to-mm scale of the PhysicalMap. This must be adjusted if the loaded map should represent a real-world map. Note that the Map_Scale value must also be calculated into this value. If a KML file is loaded, the Map_PhysicalMap_Scale value is automatically calculated, as the KML describes the bounding GPS-box for the map.

Map_Scale

Default	`10`
Type	`int`
Description	The pixel-to-mm scale of all Maps. This value defines the size of one pixel in millimeters. If a scale of 10 is defined, then a line of 20 mm will be drawn as 2 pixels. The same applies, for example, to any ColorMap, where the internal actual size of the map is Map_Width/Map_Scale.

Map_StructureMap_AutomaticallyAddStructurePoints_Enabled

Default	`true`
Type	`bool`
Description	When `true`, the StructureMap will automatically add points to the structure by reading the incoming sensor data (collisions).

Map_StructureMap_FinishTolerance_mm

Default	`500.0`
Type	`mm`
Description	The maximum distance of the most recent seen collision and the oldest seen collision when closing the StructureMap. This value must be less than the Map_StructureMap_MinimumDistanceBetweenCollision value for the StructureMap to function correctly. Map_StructureMap_FinishTolerance_mm allows the StructureMap to close even when the robot has not seen the original collision point.

Map_StructureMap_MinimumDistanceBetweenCollision

Default	`1000.0`
Type	`mm`
Description	The minimum distance required from the last StructureMap point before registering a new point. This is used to filter the StructureMap to a reduced set of point in real-time.

Map_TerrainMap_RaiseLowerIncrement

Default	`0.1`
Type	`double`
Description	The default amount to increment or decrement when raising or lowering the terrain level. The value must be between 0.0 and 1.0.

Map_TerrainMap_RaiseLowerSize_mm

Default	`400`
Type	`mm`
Description	The default length and width size of the terrain to raise or lower at a given point.

Map_Width_mm

Default	`45000`
Type	`mm`
Description	The initial map width. Used by various Maps, such as the HeatMap, when pre-allocating memory.

Table 10-4: Core Configuration Values for Map

10.3.3.5 Navigation

Navigation_AutomaticallyAddStartingNavPoints

Default	`false`
Type	`bool`
Description	When true, two navigation points will automatically be added upon starting the navigation. These two points are placed directly ahead of the robot and proves useful when navigating structures such as splines.

Navigation_InitialNavPointsListX_mm

Default	
Type	`string list`
Description	Specifies the x-coordinates (in millimeters) of the initial navigation points. The list must be separated by a `' '`.

Navigation_InitialNavPointsListY_mm

Default	
Type	`string list`
Description	Specifies the y-coordinates (in millimeters) of the initial navigation points. The list must be separated by a `' '`.

Navigation_MaxOpenAreaDistanceMaxRange_mm

Default	`2000`
Type	`mm`
Description	Specifies the maximum distance to check from the center of the robot when calculating the maximum open area available in a certain direction via the function `getMaxOpenAreaDistanceFromMap`.

Navigation_SplineNavigation_DynamicIntervalEnabled

Default	`true`
Type	`bool`
Description	When `true`, the SplineNavigation component will dynamically adjust itself to the current interval of `getWheelSpeed()`. This will ensure that the created splines remain accurate for the current execution environment of the robot. When the current interval is greater than the interval for which the spline was created plus `Navigation_SplineNavigation_DynamicIntervalFlexibility_ms`, the spline will be recalculated.

Navigation_SplineNavigation_DynamicIntervalFlexibility_ms

Default	`10`
Type	`ms`
Description	When `Navigation_SplineNavigation_DynamicIntervalEnabled` is true, this specifies the flexibility the interval of `getWheelSpeed()` is allowed before the spline is recalculated with the new interval.

Navigation_SplineNavigation_FixedInterval

Default	`100`
Type	`ms`
Description	When `Navigation_SplineNavigation_DynamicIntervalEnabled` is false, this value must match that of the Task interval which is executing the Navigation's `getWheelSpeed()`.

Navigation_SplineNavigation_MagnetTrackingEnabled

Default	`true`
Type	`bool`
Description	When `true`, the Magnet-Tracker feature for navigating splines is enabled. This allows the robot to peer back on track to the spline when for some reason it has peered off. Peering off-track can be the result of avoiding collision or because of the non-real-time nature of the emss Core.

Navigation_SplineNavigation_NavPointsSplineKernel

Default	`SplineKernelWirth`
Type	`string`
Description	Specifies which Spline Kernel shall be used when calculating the navigational splines. This value must be either "`SplineKernelBruenner|SplineKernelNRNatural|SplineKernelStoer|SplineKernelWirth`". The recommended kernel is the `SplineKernelWirth` kernel.

Navigation_SplineNavigation_ResetNavPointsWhenDone

Default	`true`
Type	`bool`
Description	When `true`, the navigation points will be reset (cleared) when the navigation spline has been traversed.

Navigation_SplineNavigation_SplineNodeAdjust

Default	`true`
Type	`bool`
Description	When `true`, the spline nodes which correspond to a navigation point will be adjusted when it is reached to better compensate for any error that might have occurred during the navigational execution. This means that the navigational spline might slightly differ over time from the original navigation points, but the navigation execution will be much more robust and exact in all.

Navigation_SplineNavigation_TargetSpeed_mmps

Default	`100.0`
Type	`mmps`
Description	The target speed when traversing splines.

Navigation_SplineNavigation_WheelSplineKernel

Default	`SplineKernelWirth`
Type	`string`
Description	Specifies which Spline Kernel shall be used when calculating the wheel splines. This value must be either "`SplineKernelBruenner|SplineKernelNRNatural|SplineKernelStoer|SplineKernelWirth`". The recommended kernel is the `SplineKernelWirth` kernel. It is recommended this value always be the same as `Navigation_SplineNavigation_NavPointsSplineKernel`.

Navigation_SystemOfWeightsNavigation_StopAtLastNavPoint

Default	`false`
Type	`bool`
Description	When `true`, the SystemOfWeightsNavigation component will stop the robot upon reaching the last navigation point.

Table 10-5: Core Configuration Values for Navigation

10.3.3.6 RemoteInterface

RemoteInterface_Enabled

Default	`true`
Type	`bool`
Description	When `true`, the RemoteInterface will be started upon Core connection and will accept subscriptions from remote users as well as send any significant messages.

RemoteInterface_IP

Default	`127.0.0.1`
Type	`string`
Description	The IP address for which the RemoteInterface shall bind itself to. The address must be given in the form of "`[0-255].[0-255].[0-255].[0-255]`".

RemoteInterface_ListenerInterval

Default	`100`
Type	`ms`
Description	The interval at which the RemoteInterfaceListener shall sleep-wait while there are no incoming messages. This is designed to allow a thread-switch to easily occur during the RemoteInterfaceListener's `process()`.

RemoteInterface_Port

Default	`9000`
Type	`string`
Description	The IP address for which the RemoteInterface shall bind itself to.

RemoteInterface_SenderInterval

Default	`100`
Type	`ms`
Description	The interval at which the RemoteInterfaceSender shall sleep-wait while there are no outgoing messages. This is designed to allow a thread-switch to easily occur during the RemoteInterfaceSender's `process()`.

Table 10-6: Core Configuration Values for RemoteInterface

10.3.3.7 Robot

Robot_BumperCollisionOffset_mm

Default	`130`
Type	`mm`
Description	The offset of a bumper collision from the center of the robot.

Robot_Diameter_mm

Default	`330`
Type	`mm`
Description	The diameter of the robot's chassis.

Robot_DockingStation_Enabled

Default	`true`
Type	`bool`
Description	Specifies whether the docking station is turned on or not. When `false`, all beams will be turned off.

Robot_DockingStation_StartingPositionX_mm

Default	`25000`
Type	`mm`
Description	The starting position x-coordinate of the docking station in millimeters.

Robot_DockingStation_StartingPositionY_mm

Default	`25000`
Type	`mm`
Description	The starting position y-coordinate of the docking station in millimeters.

Robot_DockingStation_StartingRotation_deg

Default	`0`
Type	`deg`
Description	The starting position rotation of the docking station in degrees.

Robot_DockingStation_RedBeamEnabled

Default	`true`
Type	`bool`
Description	Specifies whether the docking station red beam is on or off.

Robot_DockingStation_GreenBeamEnabled

Default	`true`
Type	`bool`
Description	Specifies whether the docking station green beam is on or off.

Robot_DockingStation_ForceFieldEnabled

Default	`true`
Type	`bool`
Description	Specifies whether the docking station force-field beam is on or off.

Robot_DockingStation_InterferenceEnabled

Default	`false`
Type	`bool`
Description	Specifies whether docking station interference is on or off. When `true`, all beams will be represented as the undocumented interference signal `242`.

Robot_DockingStation_Base_Size_mm

Default	`200`
Type	`mm`
Description	The base size of the docking station which represents its length.

Robot_DockingStation_ForceField_Radius_mm

Default	`1100`
Type	`mm`
Description	The radius of the docking station force-field signal from the center of the docking station emitter.

Robot_DockingStation_MinimumDockingPrecision_mm

Default	`30`
Type	`mm`
Description	The minimum docking station precision required for EmulatedCOIL to signal that it is docked/charging.

Robot_DockingStation_OffsetRotation_deg

Default	`0`
Type	`deg`
Description	The docking station offset rotation. This is used for placing the docking station underneath the robot, or likewise placing the robot on top of the docking station.

Robot_DockingStation_OffsetX_mm

Default	`0`
Type	`mm`
Description	The docking station offset position x-coordinate. This is used for placing the docking station underneath the robot, or likewise placing the robot on top of the docking station.

Robot_DockingStation_OffsetY_mm

Default	`160`
Type	`mm`
Description	The docking station offset position y-coordinate. This is used for placing the docking station underneath the robot, or likewise placing the robot on top of the docking station.

Robot_DockingStation_RedGreenBeam_Angle

Default	`4`
Type	`deg`
Description	The angle offset of the red and green beam from the center of the docking station emitter.

Robot_DockingStation_RedGreenBeam_Length_mm

Default	`4500`
Type	`mm`
Description	The length of the red and green beam ellipsoid from the center of the docking station emitter (plus offset).

Robot_DockingStation_RedGreenBeam_Offset_mm

Default	`60`
Type	`mm`
Description	The y-offset of the red and green beam from the center of the docking station emitter.

Robot_DockingStation_RedGreenBeam_Width_mm

Default	`500`
Type	`mm`
Description	The width of the red and green beam ellipsoid.

Robot_DockingStation_SnapToWall_Enabled

Default	`true`
Type	`bool`
Description	When `true`, placing the docking station close to a wall will automatically snap it to the side of the wall. This proves very useful when trying to position the docking station accurately.

Robot_FrontCliffSensorPositionAngle

Default	`13`
Type	`deg`
Description	The angle at which the front cliff sensors are offset from the forward center of the chassis.

Robot_SharpIRSensorCutoffValue

Default	`800`
Type	`mm`
Description	The cut-off value of the Sharp IR sensor mounted in the value. This is the cut-off value in millimeters, compared to a cut-off based on the analog signal. This cut-off value is used to ignore any sensor data that is not considered accurate. Typically, the sensor will deliver INT_MAX when the sensor does not recieve a valid signal, thus the cut-off value can be used in the fashion `if(irsensor < Robot_SharpIRSensorCutoffValue)` to validate it.

Robot_SideCliffSensorPositionAngle

Default	`62`
Type	`deg`
Description	The angle at which the side cliff sensors are offset from the forward center of the chassis.

Robot_StartingPositionX_mm

Default	`0.5`
Type	`mm|double`
Description	Defines the initial robot starting position x-coordinate in millimeters. If the value specified is between 0.0 and 1.0, the value represent the percent-position on the map (Map_Width * Robot_StartingPositionX_mm).

Robot_StartingPositionY_mm

Default	`0.5`
Type	`mm|double`
Description	Defines the initial robot starting position y-coordinate in millimeters. If the value specified is between 0.0 and 1.0, the value represent the percent-position on the map (Map_Height * Robot_StartingPositionY_mm).

Robot_StartingRotation_deg

Default	`0`
Type	`deg`
Description	Defines the initial robot starting rotation.

Robot_WallSensorRange_mm

Default	`210`
Type	`mm`
Description	The maximum wall-sensor range in millimeters.

Robot_WheelOffset_mm

Default	`131.25`
Type	`mm`
Description	The offset of the robot wheels from the center of the robot's chassis.

Table 10-7: Core Configuration Values for Robot

10.3.3.8 Task

Task_DefaultInterval

Default	`100`
Type	`ms`
Description	Defines the default process interval (in milliseconds) for any Task which does not define its own process interval. Typically, this interval should not be smaller than the Controller's interval.

Task_DiscoveryTask_ExplorationMapGridSize

Default	`100`
Type	`mm`
Description	Defines the grid size for dividing the map in a few points on the grid. The algorithm has much more performance.

Task_DiscoveryTask_Interval

Default	`100`
Type	`ms`
Description	The interval at which the DiscoveryTask runs.

Task_DiscoveryTask_RelativeExplorationHeight_mm

Default	`4000`
Type	`mm`
Description	Height of the local exploration map. That means the robot is centered and the local map is built around it.

Task_DiscoveryTask_RelativeExplorationWidth_mm

Default	`4000`
Type	`mm`
Description	Width of the local exploration map. That means the robot is centered and the local map is built around it.

Task_DiscoveryTask_TerrainCutLevel

Default	`15`
Type	`int`
Description	Defines the height of the terrain cut points.

Task_DiscoveryTask_TerrainCutPointDistance_mm

Default	`500`
Type	`mm`
Description	Defines the minimum distance between two terrain cut points.

Task_DiscoveryTask_TerrainMapMaxHeight

Default	`100`
Type	`int`
Description	Defines the maximum height of a terrain cut point.

Task_DiscoveryTask_TerrainMapUnknownHeight

Default	`101`
Type	`int`
Description	Defines the value of an unknown height.

Task_FingerprintNavigationTask_Fingerprint_Interval

Default	`6000`
Type	`ms`
Description	The default interval at which the robot halts and sends a `fingerprint` message over the RemoteInterface.

Task_FingerprintNavigationTask_Fingerprint_Waittime

Default	`2000`
Type	`ms`
Description	The default duration for which the robot halts after sending a `fingerprint` message over the RemoteInterface.

Task_FingerprintNavigationTask_GPSPrecision

Default	`14`
Type	`int`
Description	The depth of precision when representing GPS coordinates.

Task_FingerprintNavigationTask_Interval

Default	`100`
Type	`ms`
Description	The interval at which the FingerprintNavigationTask runs.

Task_FingerprintNavigationTask_PreTasks

Default	`PauseTask UndockTask`
Type	`string list`
Description	Defines the list of Tasks to add and execute before executing the FingerprintNavigationTask.

Task_JoystickNavigationTask_Interval

Default	`100`
Type	`ms`
Description	The interval at which the JoystickNavigationTask runs.

Task_NavigationTask_Interval

Default	`100`
Type	`ms`
Description	The interval at which the NavigationTask runs.

Task_NavigationTask_ResetNavPointsWhenDone

Default	`true`
Type	`bool`
Description	When true, the navigation points will be reset (cleared) when all navigation points have been reached.

Task_PauseTask_Timeout_ms

Default	`10000`
Type	`ms`
Description	The default timeout value when starting a PauseTask. When the timeout is reached, the PauseTask will automatically finish.

Task_ScriptedTask_TaskList

Default	`UndockTask WallFollowerTask DockAndChargeTask`
Type	`string list`
Description	Defines the list of Tasks to add when executing the ScriptedTask. All the ScriptedTask does is add each listed Task sequentially and finish.

Task_TestMoveTask_Interval

Default	`100`
Type	`ms`
Description	The interval at which the TestMoveTask runs.

Task_TestMoveTask_Circle_Radius_mm

Default	`1000`
Type	`mm`
Description	The radius of the test circle to be driven.

Task_TestMoveTask_TravelDistance_mm

Default	`1000`
Type	`mm`
Description	The standard travel distance for any test movement. For example, if the test move should be a square, each side of the square travelled shall be Task_TestMoveTask_TravelDistance_mm.

Task_TestMoveTask_WaitForEventIntervalDelay

Default	`10`
Type	`ms`
Description	The interval at which the MoveTask sleeps and waits for a specific event to occur (such as driving a given distance). Decreasing this value will make translations and rotations more accurate.

Task_UndockTask_Distance_mm

Default	`800`
Type	`mm`
Description	The distance to backup from the docking station when undocking.

Task_UndockTask_Speed

Default	`250`
Type	`int`
Description	The speed at which to backup from the docking station when undocking.

Task_DockAndChargeTask_Interval

Default	`100`
Type	`ms`
Description	The interval at which the DockAndChargeTask runs.

Table 10-8: Core Configuration Values for Task

10.3.3.9 TaskManager

TaskManager_Interval

Default	`100`
Type	`ms`
Description	The interval at which the TaskManager `process()` runs. This affects the speed at which scheduling/task-switching is performed, and does not affect the speed at which Task `process()` is called as this is defined by `Task_DefaultInterval` or where applicable by `Task_XXXXXXXXTask_Interval`.

TaskManager_Watchdog_Enabled

Default	`false`
Type	`bool`
Description	When `true`, the TaskManager will automatically register itself with the Watchdog if the Watchdog is enabled. The ping to the Watchdog is adjusted based on the currently running Task speed. If no task is running (and there is no idle task), the ping is adjusted to the TaskManager's interval.

TaskManager_Watchdog_Flexibility

Default	`2.5`
Type	`double`
Description	The flexibility for which the TaskManager must ping the Watchdog.

TaskManager_IdleTask

Default	`JoystickNavigationTask`
Type	`string`
Description	The idle task which is run when no other Task is in the waiting-queue. This value must specify the exact name of the Task which is to be instantiated via the CoreFactory. If the value is blank, no idle task will be registered with the TaskManager.

Table 10-9: Core Configuration Values for TaskManager

10.3.3.10 TextToSpeech

TextToSpeech_SpeakToolCommand

Default	`-v english_rp -a 60 -p 50 -s 150 $SpeechText`
Type	`string`
Description	Defines the arguments which will be passed to the `TextToSpeech_SpeakToolPath` application for executing the text to speech. The variable `$SpeechText` can be used to pass the text to be spoken. The defaults are setup for use with the Unix/Windows `espeak` application.

TextToSpeech_SpeakToolPath

Default	`espeak`
Type	`string`
Description	Defines path to the application which will execute the text to speech.

Table 10-10: Core Configuration Values for TextToSpeech

10.3.3.11 Tracker

Tracker_DefaultMovementTrackers

Default	`FrenetMovementTracker`
Type	`string list`
Description	List of MovementTrackers which are registered with the Tracker component upon Core connection. Each Tracker must be separated by a space `' '`. It is possible to add multiple Trackers of the same type.

Tracker_MovementLog_MinimumDistance_mm

Default	`100`
Type	`mm`
Description	The minimum distance required for the Tracker to translate before it can add a new position in the movement log. This is designed to prevent the movement log from becoming over-saturated with redundant data.

Tracker_SelfCorrectingTracker_CorrelationLog_MinimumDistance_mm

Default	`50`
Type	`mm`
Description	The minimum distance required between two correlation points in the SelfCorrectingTracker correlation log. This is designed to prevent the correlation log from becoming over-saturated with redundant data.

Tracker_SingleTracker_SelectedMovementTracker

Default	`FrenetMovementTracker`
Type	`string`
Description	The MovementTracker which is to be selected for retrieving the current transformation when using the SingleTracker component.

Tracker_CorrectedFrenetMovementTracker_vl

Default	`0.0`
Type	`double`
Description	The correction value in percent to be applied to any incoming `registerChangedWheelSpeed()` signal left wheel speed in the CorrectedFrenetMovementTracker. The value may be positive or negative. A positive value will make the MovementTracker peer right, while a negative value will make the MovementTracker peer left.

Tracker_CorrectedFrenetMovementTracker_vr

Default	`0.0`
Type	`double`
Description	The correction value in percent to be applied to any incoming `registerChangedWheelSpeed()` signal right wheel speed in the CorrectedFrenetMovementTracker. The value may be positive or negative. A positive value will make the MovementTracker peer left, while a negative value will make the MovementTracker peer right.

Tracker_CorrectedFrenetMovementTracker_dv

Default	`0`
Type	`double`
Description	When not 0, defines the minimum delta value between the left wheel speed and right wheel speed (`abs(vl-vr)`) in order to apply any correction. This is designed to prevent any tracking correction on values which the hardware may not be able to physically reflect.

Table 10-11: Core Configuration Values for Tracker

10.3.3.12 Watchdog

Watchdog_ActionInterval

Default	`2000`
Type	`ms`
Description	Defines the interval at which actions should be processed. For example, if this value is `2000`, then each registered WatchdogAction will be processed about every two seconds.

Watchdog_AddDefaultBeepAction

Default	`true`
Type	`bool`
Description	When `true`, a default BeepWatchdogAction is added to the Watchdog upon creation.

Watchdog_AddDefaultNetworkMonitorAction

Default	`false`
Type	`bool`
Description	When `true`, a default NetworkMonitorWatchdogAction is added to the Watchdog upon creation.

Watchdog_BeepWatchdogAction_BeepFile

Default	`beep.wav`
Type	`string`
Description	Defines which beep WAV-file to use for the BeepWatchdogAction. This file must be located in the emss Resources path (`<emss>/resources`).

Watchdog_Enabled

Default	`false`
Type	`bool`
Description	When true, the Watchdog is created and run upon Core connection.

Watchdog_Interval

Default	`100`
Type	`ms`
Description	Defines the interval at which the Watchdog's `process()` runs. This should be kept low in order to keep the Watchdog responsive to specific requests such as `stop()`.

Watchdog_NetworkMonitorWatchdogAction_WANIPs

Default	`152.96.`
Type	`string list`
Description	Defines the set of IP addresses (separated by a space `' '`) which are monitored for their presence upon the NetworkMonitorWatchdogAction `process()`. If none of the IP's are present on the machine, the NetworkMonitorWatchdogAction will trigger. Each IP can be specified by a either a full address or a prefix. For example, both `152.96.100.127` and `152.96.` will match the IP `152.96.100.127`.

Watchdog_StopRequestInterval

Default	`50`
Type	`ms`
Description	The interval at which a stop request should be performed on the Watchdog CoreThread when trying to stop the Watchdog.

Table 10-12: Core Configuration Values for Watchdog

10.3.3.13 Weight

Weight_AccelerationFilterWeight_MaxSpeedChange

Default	`0.25`
Type	`double`
Description	The maximum amount of speed change allowed in one process (based on max of 1.0).

Weight_CollisionAvoidanceWeight_AvoidanceFactor

Default	`1.0`
Type	`double`
Description	The factor for which how quickly the CollisionAvoidanceWeight should avoid an obstacle. If the value is less than `1.0`, the CollisionAvoidanceWeight will delay in avoiding the obstacle ahead of it. For example, with a value of `0.5`, the Weight will wait until it is 50% of the maximum sensing distance to the obstacle to avoid the obstacle.

Weight_CollisionAvoidanceWeight_DecisionBuffer_mm

Default	`100`
Type	`mm`
Description	Defines the distance buffer to wait before making a definite decision on which direction (left or right) to avoid an obstacle. A greater buffer will make the decision more accurate, however at the same time a too large buffer will result in a "last-minute" avoidance maneuver.

Weight_CollisionAvoidanceWeight_ReverseDistance_mm

Default	`200`
Type	`mm`
Description	Defines the distance to be reversed when encountering a collision if an obstacle was not avoided.

Weight_DockWeight_StartingMode

Default	`unknown`
Type	`string`
Description	Defines the starting mode of the DockWeight. This value can be either `unknown|homing|attack|search|retry|turnaround`.

Weight_DockWeight_MinimumAttackSpeed

Default	`320`
Type	`mmps`
Description	Defines the minimum speed required when in `attack` mode. If the current speed is less than this value, the speed is adjusted to at least the Weight_DockWeight_MinimumAttackSpeed.

Weight_DockWeight_DockIRHistory

Default	`200`
Type	`int`
Description	This size of the DockIR history log. A too large size might decrease performance, while a too small size might not produce good results when making decisions.

Weight_DockWeight_AttackAdjust_fx

Default	`1.5`
Type	`double`
Description	The wheel speed adjustment factor when in `attack` mode. 0.0 has no effect, 1.0 has stops the wheel, >1.0 puts the wheel in reverse...

Weight_DockWeight_HomingAdjust_fx

Default	`1.2`
Type	`double`
Description	The wheel speed adjustment factor when in `homing` mode. 0.0 has no effect, 1.0 has stops the wheel, >1.0 puts the wheel in reverse...

Weight_DockWeight_SearchAdjust_fx

Default	`0.9`
Type	`double`
Description	The wheel speed adjustment factor when in `search` mode. 0.0 has no effect, 1.0 has stops the wheel, >1.0 puts the wheel in reverse...

Weight_DockWeight_HomingAdjust_Time_ms

Default	`150`
Type	`ms`
Description	The amount of time spent adjusting the heading with hfx.

Weight_DockWeight_AttackAdjust_Time_ms

Default	`80`
Type	`ms`
Description	The amount of time spent adjusting the heading with afx.

Weight_DockWeight_JitterAmount

Default	`0.0`
Type	`double`
Description	When using EmulatedCOIL, the amount of random jitter for the beams. This is useful if you want to emulate the inacuraccy of beams. Set to 0 to turn of any jittering.

Weight_DockWeight_SearchTimeout_ms

Default	`5000`
Type	`ms`
Description	The amount of time before the `search` mode is abandoned.

Weight_DockWeight_DockExpectancyFactor

Default	`1.2`
Type	`double`
Description	The factor multiplied with the radius of the force-field when trying to dock in `attack` mode and determining by when the robot must be docked. If the distance travelled since sensing the force-field signal is greater than `Weight_DockWeight_DockExpectancyFactor * radius(force-field)` the docking is retried.

Weight_DockWeight_SearchTurnInterval_ms

Default	`5000`
Type	`ms`
Description	When in `search` mode, the interval at which a sharp turn should be executed.

Weight_DockWeight_SearchTurnAngle_deg

Default	`60`
Type	`deg`
Description	When in `search` mode, the angle to turn when executing a sharp turn.

Weight_DockWeight_RetryBackupDistance_mm

Default	`300`
Type	`mm`
Description	When in `attack` mode, the distance to backup after a failed attempt at docking.

Weight_DockWeight_TurnaroundAngle_deg

Default	`180`
Type	`deg`
Description	The angle to turn when turning around during a retry.

Weight_DockWeight_RetryMoveawayFactor

Default	`0.6`
Type	`double`
Description	When in `retry` mode, the factor multiplied with the radius of the force-field when trying to move away from the docking station.

Weight_WallFollowerWeight_NoWallTimer_Sec

Default	`5`
Type	`sec`
Description	The timeout value for resetting the `sensitivity` value in the WallFollowerWeight.

Weight_WallFollowerWeight_SearchWallTimer_Sec

Default	`15`
Type	`sec`
Description	The timeout value for abandoning the search wall mode. After this period of time has passed without finding a wall again, the WallFollowerWeight will no longer try to find the wall but will continue straight ahead until reaching a new wall.

Weight_WallFollowerWeight_Sensitivity

Default	`0.5`
Type	`double`
Description	The initial `sensitivity` value.

Weight_WallFollowerWeight_Sensitivity_Max

Default	`0.8`
Type	`double`
Description	The maximum `sensitivity` value allowed.

Weight_WallFollowerWeight_Sensitivity_Min

Default	`0.2`
Type	`ms`
Description	The minimum `sensitivity` value allowed.

Weight_WallFollowerWeight_StepSize

Default	`0.05`
Type	`double`
Description	The step size value used when increasing or decreasing the `sensitivity` value.

Table 10-13: Core Configuration Values for Weight

10.4 Interface

If the *emss* Core is the heart and soul of the *emss* framework, then the Interface application (`emssInterface`) is the body. The Interface smoothly integrates all the visual frontends from the GUI library to the Core modules, providing a useful user interface to the inner workings of the framework. All of the Core's functionality is exposed in the Interface in some manner or another. Operations such as setting navigation points, starting and stopping Tasks, swapping out module implementations, or moving objects such as the robot or docking station are offered by the Interface. The Interface allows a user to instantiate a *emss* Core and connect to it at ease. Common configurations and settings are replaced with drop-down menus and check-boxes, and windows can be freely placed around the desktop.

Events from the Core are connected to the different GUI elements via slots and signals, and in many cases, a one-to-many relationship has been used as to enable features such as multiple viewports. Events coming from the GUI thread are translated into the appropriate Tasks for the TaskManager to handle to ensure that the GUI always remains responsive.

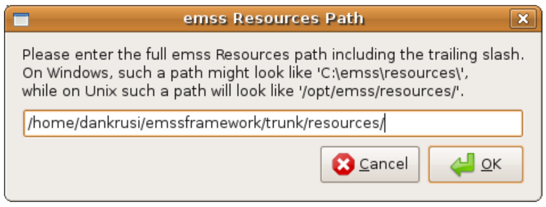
10.4.1First Usage

The *emss* Interface can be started by executing `<emss>/bin/<emssInterface|emssInterface.app|emssInterface.exe>`, depending on which platform is being used. If the *emss* scripts are installed, one can run the Interface by just entering the command `er`, or respectively `edr` for a *gdb* debugging session. For further information on these shortcut commands, see Section 10.6.5.4.

When the Interface is run for the first time, it might ask for the *emss* resources and logs path. These paths must be registered with the operating system for the Core to function properly[22]. You can create a resources directory manually by copying the `<emss>/DefaultResources` folder, or alternatively the resources and logs folders can be automatically created by either the `setup.sh` or

[22] Depending on which operating system is being used, the settings are saved in either the system registry or in the user's home folder (`~/.config/emss`).

`create_resources_and_logs.sh` script. The resources path must contain the Core configuration file `emssCore.config`. The Core cannot function properly without a valid configuration file.



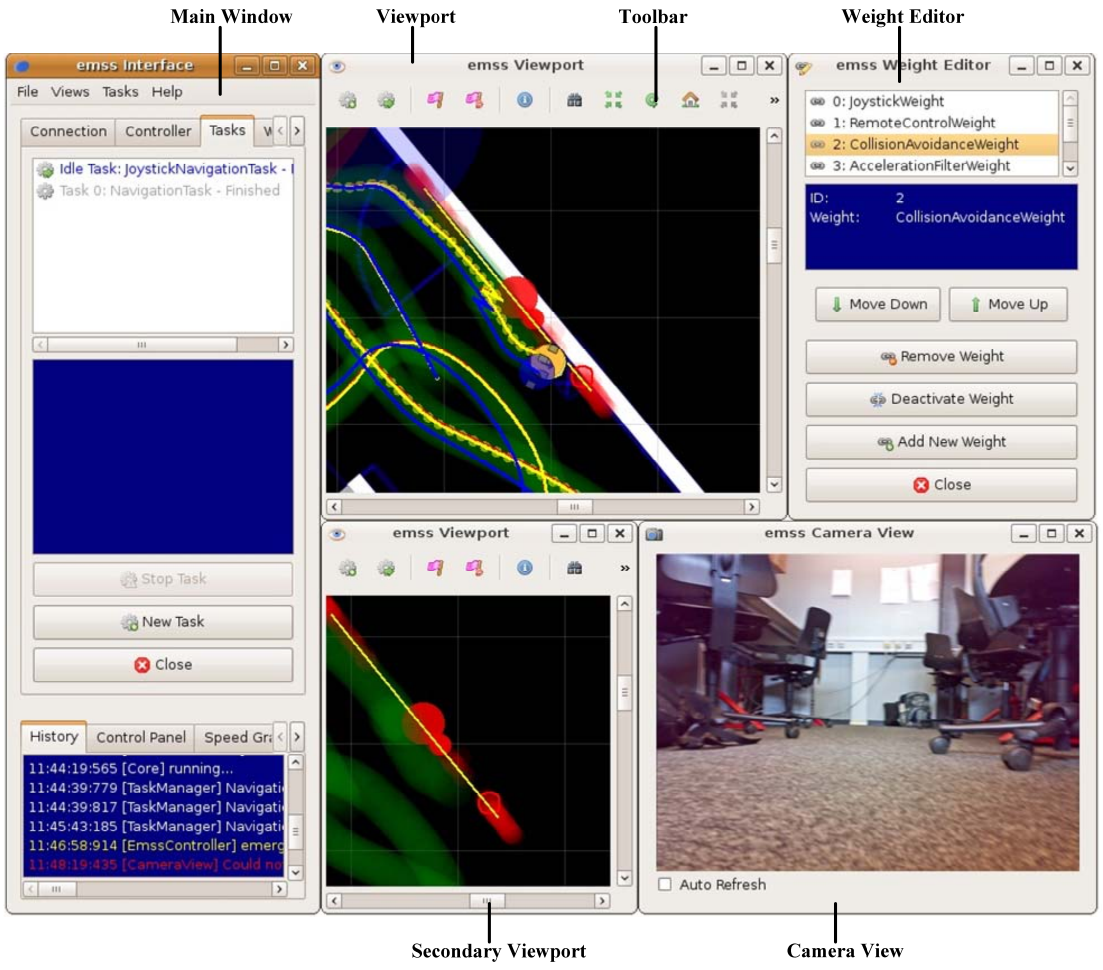
Please enter the full emss Resources path including the trailing slash.
On Windows, such a path might look like 'C:\emss\resources\',
while on Unix such a path will look like '/opt/emss/resources/'.

/home/dankrusi/emssframework/trunk/resources/

Figure 10-2: Resources Path Dialog Box

10.4.2 Graphical User Interface

Although there are more than ten different views available in the Interface application, the most important are the main window, titled „emss Interface“, and the Viewport –titled „emss Viewport“. Some views, such as the Task Editor and Weight Editor, are by default docked within the main window. These views can be undocked and also opened as separate dialogs. All the views can be resized – the contents will automatically adjust to fill the space efficiently. When the application first starts, only the main window is shown. Upon connecting the Core, a Viewport is automatically displayed next to the main window. An example layout of the emss Interface is shown below in Figure 6-32.



Idle Task: JoystickNavigationTask -
Task 0: NavigationTask - Finished

```
11:44:19:565 [Core] running...
11:44:39:779 [TaskManager] Navigati
11:44:39:817 [TaskManager] Navigati
11:45:43:185 [TaskManager] Navigati
11:46:58:914 [EmssController] emerg
11:48:19:435 [CameraView] Could no
```

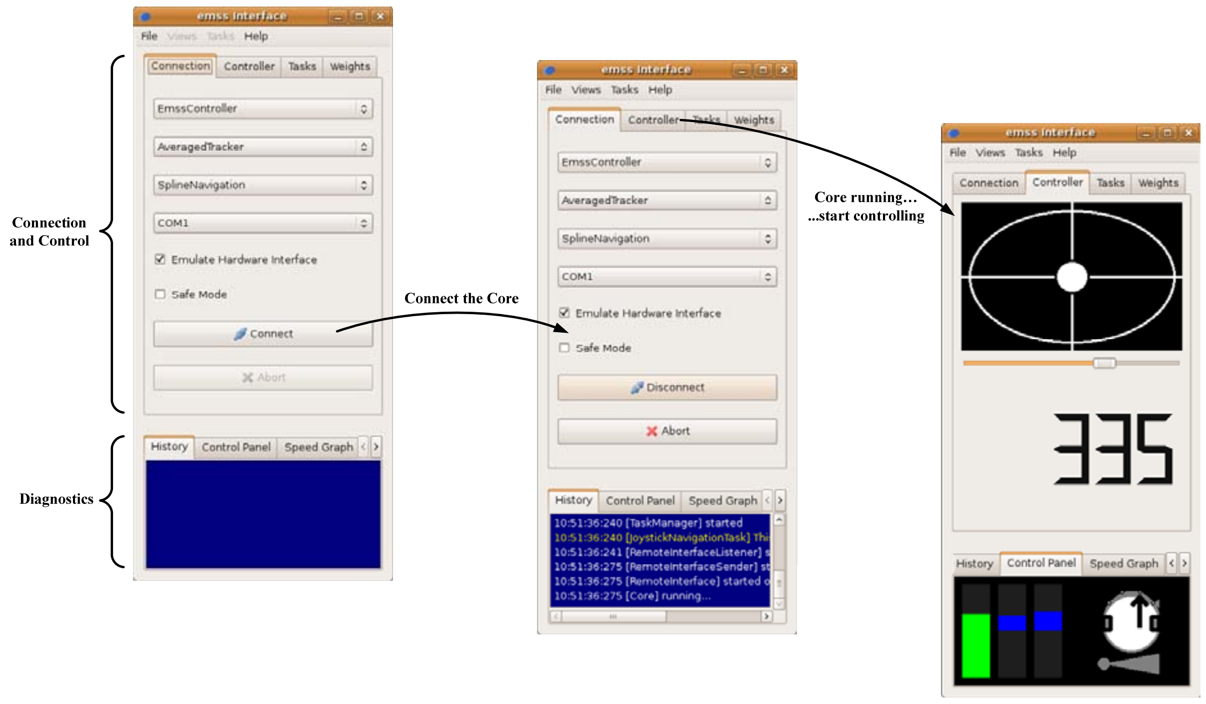
0: JoystickWeight
1: RemoteControlWeight
2: CollisionAvoidanceWeight
3: AccelerationFilterWeight

ID: 2
Weight: CollisionAvoidanceWeight

Figure 10-3: Example Interface Layout

The main window offers the functionality to setup a Core session and connect it. Connection settings such as which Navigation module, Controller module, Tracker module, serial port, et cetera, can be easily configured. In addition, the main window has some built in GUI views docked inside itself as tabs. There are two main widget groups in the main window (shown in Figure 10-4): *Connection and Control* and *Diagnostics*. Both groups are divided into different tabs which serve purposes related to the group.

Most widgets and views are not accessible or enabled when the Core is disconnected. Once connected, these "locked" widgets become alive (shown in Figure 10-4).



```
10:51:36:240 [TaskManager] started
10:51:36:240 [JoystickNavigationTask] Thi
10:51:36:241 [RemoteInterfaceListener] s
10:51:36:275 [RemoteInterfaceSender] st
10:51:36:275 [RemoteInterface] started o
10:51:36:275 [Core] running...
```

Figure 10-4: The Interface Main Window and its Different States

10.4.2.1 File Menu

The „File“ menu, shown in Figure 10-14, offers access to additional configuration settings related to the user interface and to the *emss* Core. Some menu items, such as *Reset*, are only available when a *emss* Core has been initialized and are marked with *Core required.*

Icon	Item	Description
🔄	Reset	The current world state is discarded and a new, default or saved, state is loaded. When connected, the reset functionality will automatically re-connect. *Core required*
💾	Save World State	The current state of the robot and docking station as well as navigation points are saved to the configuration file. This is useful when performing the same task multiple times. *Core required*
🔧	Core Settings…	Opens a Settings Editor for the currently loaded Core configuration file. The individual settings are described in detail in Section 10.3.3. *Core required*
🔧	Interface Settings…	Opens a Settings Editor for the currently loaded FingerprintCollector configuration file. The individual settings are described in detail in Section 10.5.3.
🔧	Reset File Paths…	Enables a user to reset the file paths to the *emss* resources and logs folders.
🚪	Exit	Closes the application after disconnecting (if necessary) the Core.

Table 10-14: Interface File Menu Entries

10.4.2.2 Views Menu

The „Views“ menu, shown in Figure 10-14, allows any GUI view to be created. These views will open into a separate window and are automatically connected to the currently loaded Core. This menu is only available when a *emss* Core has been initialized and connected.

10.4.2.3 Tasks Menu

The „Tasks“ menu, shown in Figure 10-14, allows any Core Task to be created and scheduled for running. This menu is independent of which Core it is linked against and will automatically populate itself with all the available Tasks in the connected Core. This menu is only available when a *emss* Core has been initialized and connected.

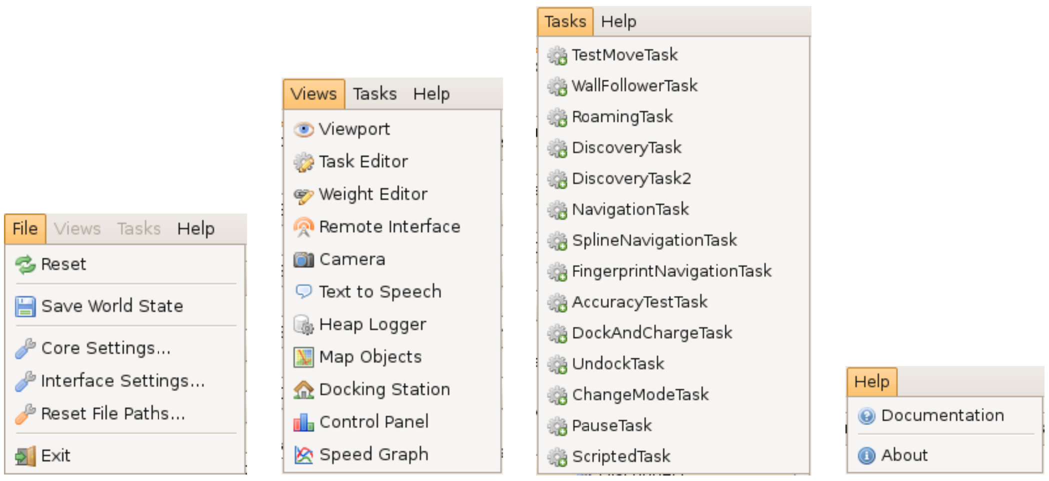


Figure 10-5: Various Main Window Menus

10.4.2.4 Connection and Control

The *Connection and Control* group offers everything to do with the Core connection settings and control of the robot, including a Joystick for the Controller, a Task Editor, and a Weight Editor for the SystemOfWeightsNavigation module.

The following describe the different settings available in the “Connection” tab:

Controller: Specifies which Controller implementation will be used.

Tracker: Specifies which Tracker implementation will be used.

Navigation: Specifies which Navigation implementation will be used.

Port: The serial port which represents the connection to the robot hardware from the laptop must be specified here. If the session should be emulated, then the checkbox „Emulate Hardware Interface“ must be checked and the port is no longer relevant.

Speed: Modifies the target speed of the controller and thus typically the average speed of the robot.

Button „Connect / Disconnect“: When pressed, the Core is either connected or disconnected, depending on which state the Core is in. A Core is automatically initialized if needed, however when disconnecting the Core is not discarded but kept for the next connection.

Button „Abort“: When pressed, a Core abort operation is performed. This attempts to interrupt all tasks and shutdown all CoreThreads.

10.4.2.5 Diagnostics

The Diagnostics group offers information related to software and hardware diagnostics. The most important is the „History“ tab. The History is the standard output for all Core modules. Important information related to the current state of the different modules are displayed in chronological order. Messages are always preceded by a timestamp and the module which created the message in the format of `hh:mm:ss:fff [Module]`. Messages are split into three categories:

Information: Output in white and display general information regarding connection states, Task execution, et cetera.

Warnings: Output in yellow and display more information related to improper configurations or minor errors which require the attention of the user.

Errors: Output in red and display information related to serious errors within the Core. At this point the Core is considered unstable and should be reconfigured and reset.

10.4.2.6 Viewport

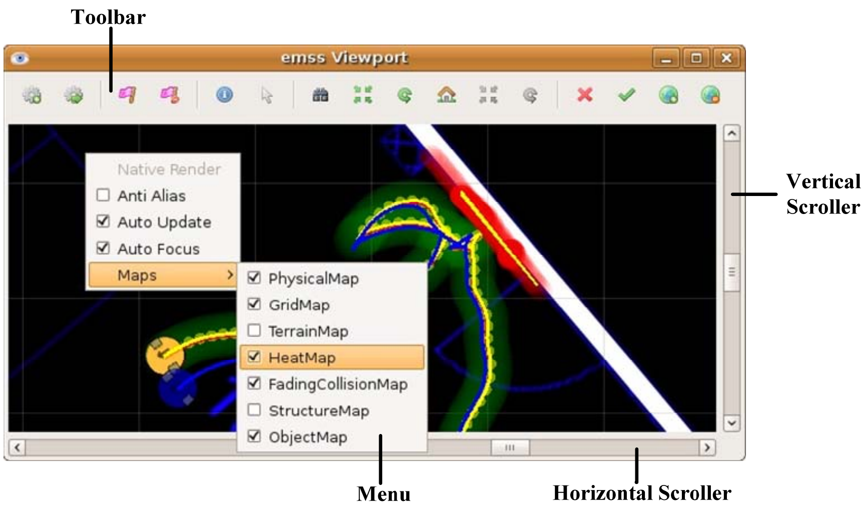


Figure 10-6: Viewport Displaying Toolbar and Menu

The Viewport displays the various Maps (PhysicalMap, HeatMap, etc) loaded in the Core. The Maps are described in further detail in Chapter 6.3.5. The main purpose of the Viewport is to represent the internal state of the Core in a visual fashion, as well as present an interface for interacting with the different Maps. The Viewport can be scrolled horizontally and vertically along its X and Y axis. When in *OpenGL* mode (see `Viewport_RenderMode` in Section 10.4.3), the Viewport can also be zoomed in and out using the zoom slider. Right-clicking the Viewport opens up a menu of different functionality.

It is worthwhile noting that multiple instances of the Viewport can be shown – each displaying its own set of Maps. This is useful if it is wished to so show, for example, the Physical Map and Robot on one Viewport, and just the HeatMap and StructureMap on a different Viewport. Furthermore, Viewports can be distributed onto different monitors or virtual desktops.

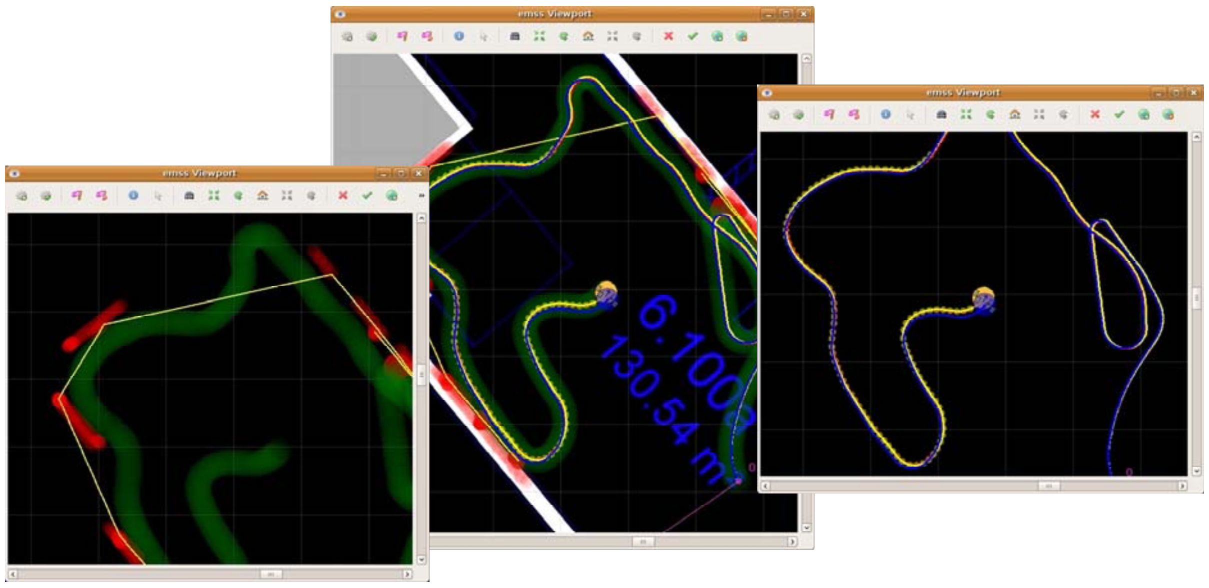


Figure 10-7: Multiple Viewports Displaying the Same Environment

10.4.2.6.1 Viewport Toolbar

The toolbar allows quick-access to various functionality within the *emss* Core. The toolbar actions range from finding out information about a point on the map to placing the robot docked on the home station.

Icon	Caption	Description
⚙	Add Task	Opens a dialog box in which a Task can be specified to be added for scheduling in the TaskManager.
⚙	Navigate	Adds a new NavigationTask for scheduling in the TaskManager.
⚑	Set NavPoint	Places a new navigation point at the clicked point on the map. *requires map click*
⚑	Reset NavPoints	Removes all navigation points.
ℹ	Map Info	Outputs information about the various maps for a specific point on the map: - Local Position (in Cartesian coordinates, millimeters) - Global Position (in GPS coordinates) - Whether or not the point is recognized as Collision Area - Whether or not the point is recognized as Open Area - Which color the PhysicalMap returns for the point (in RGB values) - The recognized area type for the point on the PhysicalMap (Wall, Stairs, Open) - The height of the TerrainMap - The signal of the DockingStation (if any). *requires map click*
↖	Focus on Point	Moves the center of focus of the Viewport window on the point clicked. *requires map click*
🤖	Find Robot	Moves the center of focus of the Viewport to the current position of the robot.
✥	Move Robot	Moves the robot to the clicked point on the map. *requires map click*
↻	Rotate Robot	Rotates or orientates the robot towards the direction of the clicked point on the map. *requires map click*
🏠	Set Robot Docked	Places the robot on top of the docking station in a docked position.
✥	Move Docking Station	Moves the docking station to the clicked point on the map. If the setting `Robot_DockingStation_SnapToWall_Enabled` is enabled (`true`) and the docking station is close to a wall, it is automatically aligned and snapped to the wall. *requires map click*
↻	Rotate Docking Station	Rotates or orientates the docking station towards the direction of the clicked point on the map. *requires map click*
✖	Mark as Collision Area	Marks the clicked point as Collision Area. Clicking multiple times will make the Collision Area stronger. *requires map click*
✔	Mark as Open Area	Marks the clicked point as Open Area. Clicking multiple times will make the Open Area stronger. *requires map click*
🌐	Raise Terrain	Raises the TerrainMap at the clicked point on the map. Clicking multiple times will raise the terrain more. *requires map click*
🌐	Lower Terrain	Lowers the TerrainMap at the clicked point on the map. Clicking multiple times will lower the terrain more. *requires map click*

Table 10-15: Viewport Toolbar Icons

Some tools instantly perform an action while others require a click on the map before undertaking an action. The tools which require a click are marked with *requires map click*. Such tools may be combined with others at the same time. For example, one could select both the „Focus On Point“ and „Set NavPoint“ tool, which upon clicking on the map would both set a new navigation point and focus the window on that point in the map.

10.4.2.6.2 Viewport Menu

When a right-click is performed on the Viewport, a small menu is shown. The following menu items are available for this menu:

Native Render / OpenGL Render: Displays whether the Viewport is being rendered natively using software or on the hardware using *OpenGL*. See `Viewport_RenderMode` in Section 10.5.3 on how to configure the render mode.

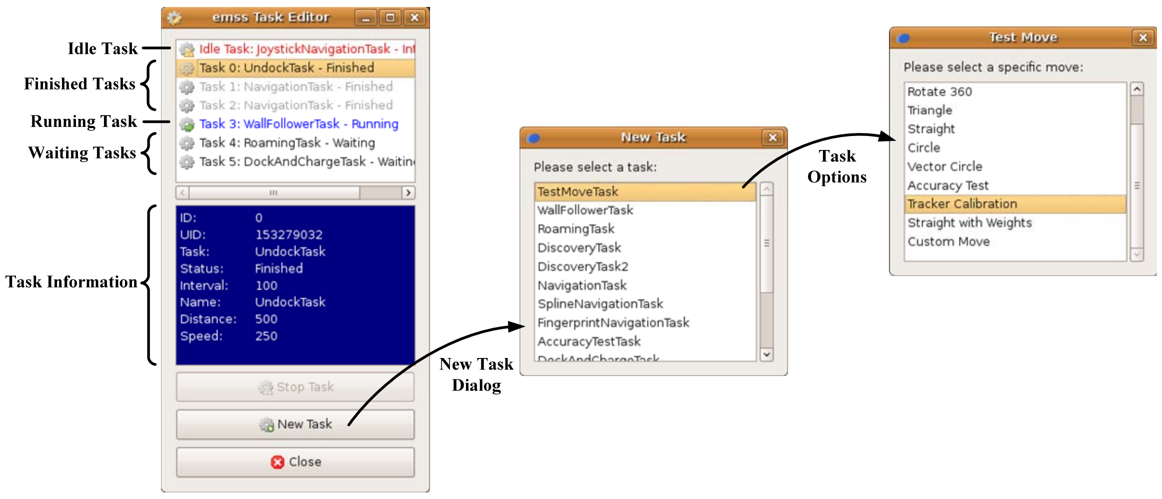
Anti Alias: When checked, MapObjects and other Map elements will be rendered using anti-aliasing. When in *OpenGL* render mode, the effect of the Anti Alias option might vary depending on what the hardware supports.

Auto Update: When checked, the Viewport will automatically refresh at the interval specified by the configuration setting `Viewport_AutoUpdateInterval`.

Auto Focus: When checked, the Viewport will automatically center its focus on the current position of the robot.

Maps: Individiual Maps can be hidden from being displayed unchecking the Map name under the „Maps“ menu.

10.4.2.7 Task Editor



ID:	0
UID:	153279032
Task:	UndockTask
Status:	Finished
Interval:	100
Name:	UndockTask
Distance:	500
Speed:	250

Figure 10-8: Task Editor with New Task Dialog

The Task Editor displays all the Tasks registered with the Core and their status. The top of the window features a chronological list of the Tasks. When a Task in the list is clicked, a more detailed set of information is displayed just below it. To make the interface more comfortable, Task statuses are assigned a specific color:

Red: Indicates the Task has been indefinitely interrupted by the TaskManager.

Gray: Indicates the Task has finished its execution.

Blue: Indicates that the Task is currently being executed by the TaskManager.

Black: Indicates that the Task is waiting to be scheduled by the TaskManager.

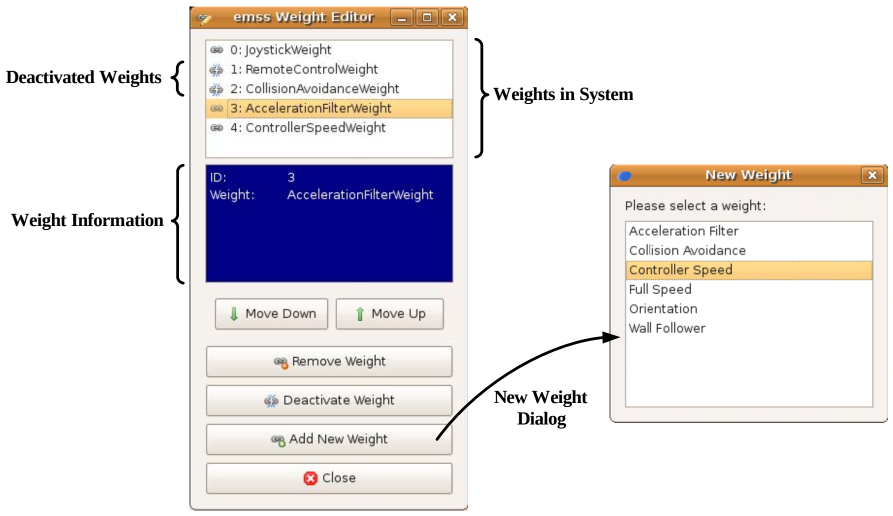
If an Idle Task is defined in the Core setting `TaskManager_IdleTask`, the TaskManager will automatically instantiate such a Task. The Idle Task always stays at the top of the list whether it is running or not. Typically the Idle Task has the status "Interrupted", however, when there are no Tasks waiting for execution the Idle Task kicks in, changing its status to "Running".

The buttons on the Task Editor perform the following actions:

Icon	Label	Description
⚠	Stop Task	Stops the currently selected Task if it is running. This is done by sending the `interrupt()` signal to it.
➕	New Task	Adds a new Task for scheduling by the TaskManager. Clicking the button will open a dialog in which the desired Task can be chosen. Some Tasks might require additional options and therefore display a second option dialog, as shown in Figure 10-8.
✖	Close	Closes the Task Editor window or tab.

Table 10-16: Task Editor Actions

10.4.2.8 Weight Editor



0: JoystickWeight
1: RemoteControlWeight
2: CollisionAvoidanceWeight
3: AccelerationFilterWeight
4: ControllerSpeedWeight

ID: 3
Weight: AccelerationFilterWeight

Please select a weight:
Acceleration Filter
Collision Avoidance
Controller Speed
Full Speed
Orientation
Wall Follower

Figure 10-9: Weight Editor Displaying Different Weights

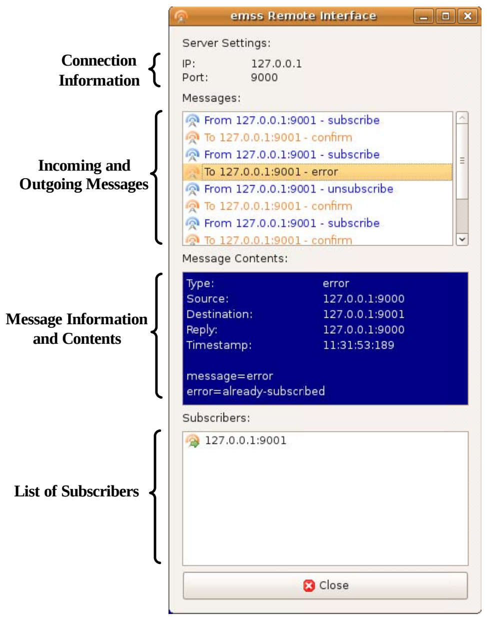
The Weight Editor displays all the Weight registered with the SystemOfWeightsNavigation module. The top of the window features a list of the Weights ordered by their priority. When a Weight in the list is clicked, a more detailed set of information is displayed just below it (if available).

The buttons on the Weight Editor perform the following actions:

Icon	Label	Description
⬇	Move Down	Moves the selected Weight down in the list, decreasing its priority.
⬆	Move Up	Moves the selected Weight up in the list, increasing its priority.
⊖	Remove Weight	Removes the selected Weight permanently from the SystemOfWeightsNavigation.
◉	Activate / Deactivate Weight	Temporarily activates or deactivates the currently selected Weight. When a Weight is deactivated, it will not serve any function during the `process()` of the SystemOfWeightsNavigation pipeline.
⊕	Add New Weight	Opens a dialog displaying a list of available Weights to be added to the SystemOfWeightsNavigation.
✖	Close	Closes the Weight Editor window or tab.

Table 10-17: Weight Editor Actions

10.4.2.9 Remote Interface



Server Settings:

```
IP:         127.0.0.1
Port:       9000
```

Messages:

```
From 127.0.0.1:9001 - subscribe
To 127.0.0.1:9001 - confirm
From 127.0.0.1:9001 - subscribe
To 127.0.0.1:9001 - error
From 127.0.0.1:9001 - unsubscribe
To 127.0.0.1:9001 - confirm
From 127.0.0.1:9001 - subscribe
To 127.0.0.1:9001 - confirm
```

Message Contents:

```
Type:               error
Source:             127.0.0.1:9000
Destination:        127.0.0.1:9001
Reply:              127.0.0.1:9000
Timestamp:          11:31:53:189

message=error
error=already-subscribed
```

Subscribers:

```
127.0.0.1:9001
```

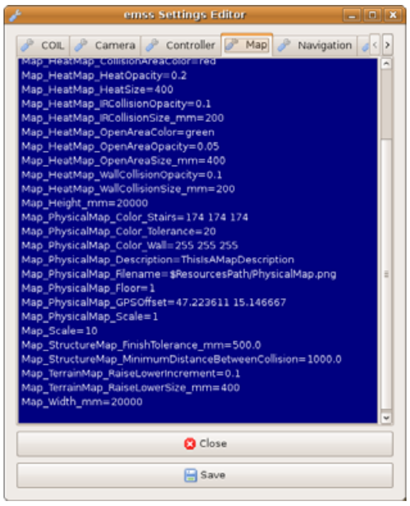
Figure 10-10: Remote Interface View with Incoming, Outgoing Messages, and Subscribers

The RemoteInterface view chronologically displays all the incoming and outgoing messages. In addition, a list of subscribers is presented at the bottom of the window. Clicking on a specific message will reveal all its standard properties, such as *Type*, *Source*, *Destination*, et cetera, and also outputs the entire message contents. The messages are displayed in different colors for convenient debugging:

Blue: Indicates the message was received (incoming).

Orange: Indicates the message was sent (outgoing).

10.4.2.10 Settings Editor



```
Map_HeatMap_CollisionAreaColor=red
Map_HeatMap_HeatOpacity=0.2
Map_HeatMap_HeatSize=400
Map_HeatMap_IRCollisionOpacity=0.1
Map_HeatMap_IRCollisionSize_mm=200
Map_HeatMap_OpenAreaColor=green
Map_HeatMap_OpenAreaOpacity=0.05
Map_HeatMap_OpenAreaSize_mm=400
Map_HeatMap_WallCollisionOpacity=0.1
Map_HeatMap_WallCollisionSize_mm=200
Map_Height_mm=20000
Map_PhysicalMap_Color_Stairs=174 174 174
Map_PhysicalMap_Color_Tolerance=20
Map_PhysicalMap_Color_Wall=255 255 255
Map_PhysicalMap_Description=ThisIsAMapDescription
Map_PhysicalMap_Filename=$ResourcesPath/PhysicalMap.png
Map_PhysicalMap_Floor=1
Map_PhysicalMap_GPSOffset=47.223611 15.146667
Map_PhysicalMap_Scale=1
Map_Scale=10
Map_StructureMap_FinishTolerance_mm=500.0
Map_StructureMap_MinimumDistanceBetweenCollision=1000.0
Map_TerrainMap_RaiseLowerIncrement=0.1
Map_TerrainMap_RaiseLowerSize_mm=400
Map_Width_mm=20000
```

Figure 10-11: Settings Editor Displayed With Group Tabs

The Settings Editor can be found by either clicking "File" then "Interface Settings…" or "File" then "Core Settings…" from the main window menu. The Settings Editor will load the corresponding configuration file (`.config`) and display its contents – grouped among several tabs. Pressing the "Save" button will write any changes made to disk.

10.4.2.11 Camera View

The Camera view, shown in Figure 10-12 (bottom right), allows the image of a camera device to be displayed within the *emss* Interface. This is achieved by sequentially executing a third-party application (see the Core settings `Camera_CaptureToolPath`, `Camera_CaptureToolCommand`, and `Camera_CaptureToolOutFile` in Section 10.3.3) which retrieves and saves the camera image. When "Auto Refresh" is checked, the image is automatically updated with the interval defined by `Camera_AutoRefreshInterval`.

10.4.2.12 Control Panel

The Control Panel, shown in Figure 10-12 and Figure 10-4, displays all the vital hardware information such as battery power, current wheel speeds, and all the physical sensors.

10.4.2.13 Speed Graph

The Speed Graph (shown in Figure 10-12, bottom left) maintains a chronological graph of both wheel speeds. This is useful when attempting to visually debug the results of an algorithm of Weight.

10.4.2.14 Docking Station

The Docking Station view, shown in Figure 10-12 (top left), allows easy manipulation of different signals within the virtual docking station. Unchecking "Enabled" will cause all the signals, or beams, to turn off. Individual signals can be turned on and off by using the "Red Beam", "Green Beam", and "Force Field" checkboxes. When checked, the "Interference" checkbox will cause the special undocumented signal `242` to be sent from the docking station – overriding all other signals.

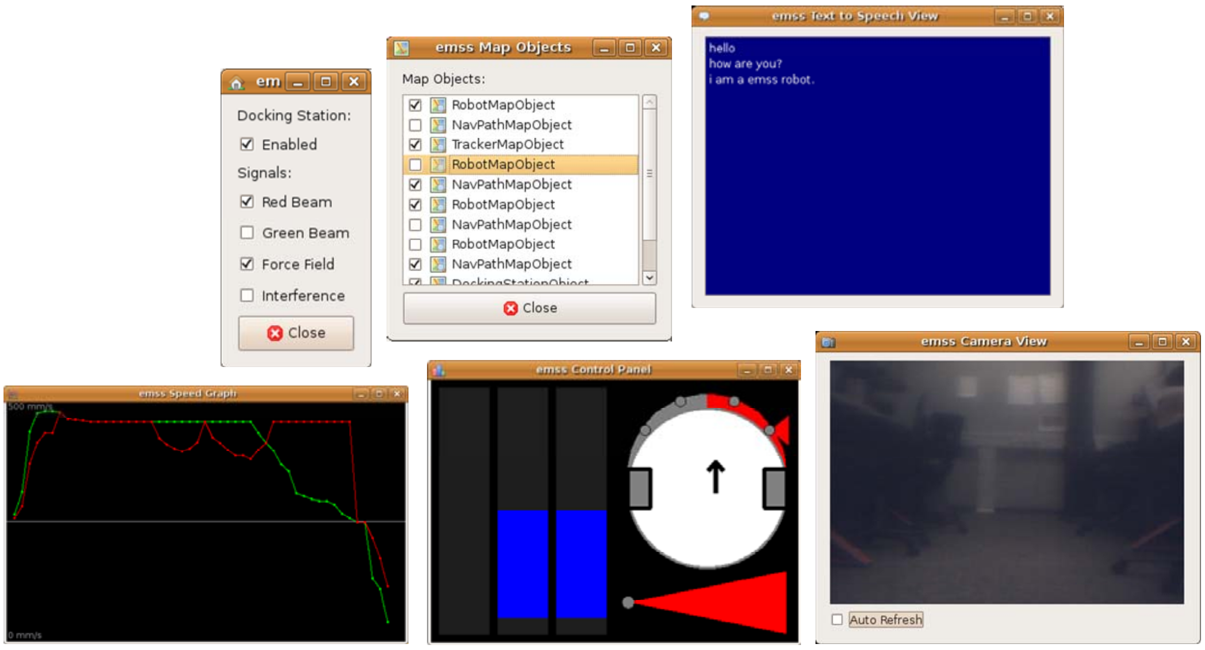
This view is essential when testing algorithms related to the Docking Station, such as the DockAndChargeTask or DockWeight.

10.4.2.15 Map Objects

The Map Objects view (shown in Figure 10-12, top center) allows individual MapObjects to be temporarily hidden. This is achieved via the checkbox next to the MapObject identifier name. This view is especially useful when trying to pin-down a specific Tracker.

10.4.2.16 Text to Speech

The Text to Speech View, shown below (top right), allows a single word or series of words to be output through the robot's speakers. This is achieved by executing a third-party application (see the Core settings `TextToSpeech_SpeakToolPath` and `TextToSpeech_SpeakToolCommand` in Section 10.3.3).



hello
how are you?
i am a emss robot.

Figure 10-12: Various Views Related to the Interface Application

10.4.3 Configuration

The settings below are used by the Interface application and can be located in the file `<emss>/resources/emssInterface.config`. The settings marked with *persistent* are saved with the current values automatically when the application closes. For further details on the different value types and configuration patches please see Section 11.5 in the glossary.

Connection_Controller *persistent*

Default	`0`
Type	`int`
Description	Defines the default Controller implementation to be used when the application is started.

Connection_Port *persistent*

Default	`5`
Type	`int`
Description	Defines the default port which is selected when the application is started.

Connection_Tracker *persistent*

Default	`1`
Type	`int`
Description	Defines the default Tracker implementation to be used when the application is started.

Connection_EmulateHardware *persistent*

Default	`true`
Type	`bool`
Description	Defines whether or not the „Emulate Hardware Interface“ should be checked when the application is started.

Connection_Navigation *persistent*

Default	`1`
Type	`int`
Description	Defines the default Navigation implementation to be used when the application is started.

Controller_TargetSpeed *persistent*

Default	`150`
Type	`int`
Description	Defines the default Controller target speed which is set when the application is started.

Connection_SafeMode *persistent*

Default	`false`
Type	`bool`
Description	When `true`, upon connection to the hardware COIL is set to enter Safe Mode instead of Full Mode. When in Safe Mode, the onboard controller prevents the robot from taking actions which may result in hardware damage.

Log_LogToFile

Default	`false`
Type	`bool`
Description	When `true`, all the messages output to the History panel or console are also saved to a log file in `<emss>/logs`.

Viewport_AutoUpdateInterval

Default	`500`
Type	`ms`
Description	Defines the interval at which the Viewport automatically redraws itself. If the application is run locally on the machine, an interval of 100 ms is sufficient for speedy rendering and feedback. If the application is run over SSH or a Remote Desktop Client, a higher interval (lower refresh rate) is recommended of 500 to 1000 ms.

Viewport_RenderMode

Default	`native`
Type	`string`
Description	Defines the render mode for the Viewport. This value must be either `native` or `opengl`. When in OpenGL mode, the Viewport supports zoom functionality. Note that to use the OpenGL render mode, a hardware accelerated graphics driver must be running with OpenGL support.

Window_X *persistent*

Default	`100`
Type	`int`
Description	Defines the X-coordinate of the main window position in pixels.

Window_Y *persistent*

Default	`100`
Type	`int`
Description	Defines the Y-coordinate of the main window position in pixels.

Window_Width *persistent*

Default	`350`
Type	`int`
Description	Defines the main window width in pixels.

Window_Height *persistent*

Default	`650`
Type	`int`
Description	Defines the main window height in pixels.

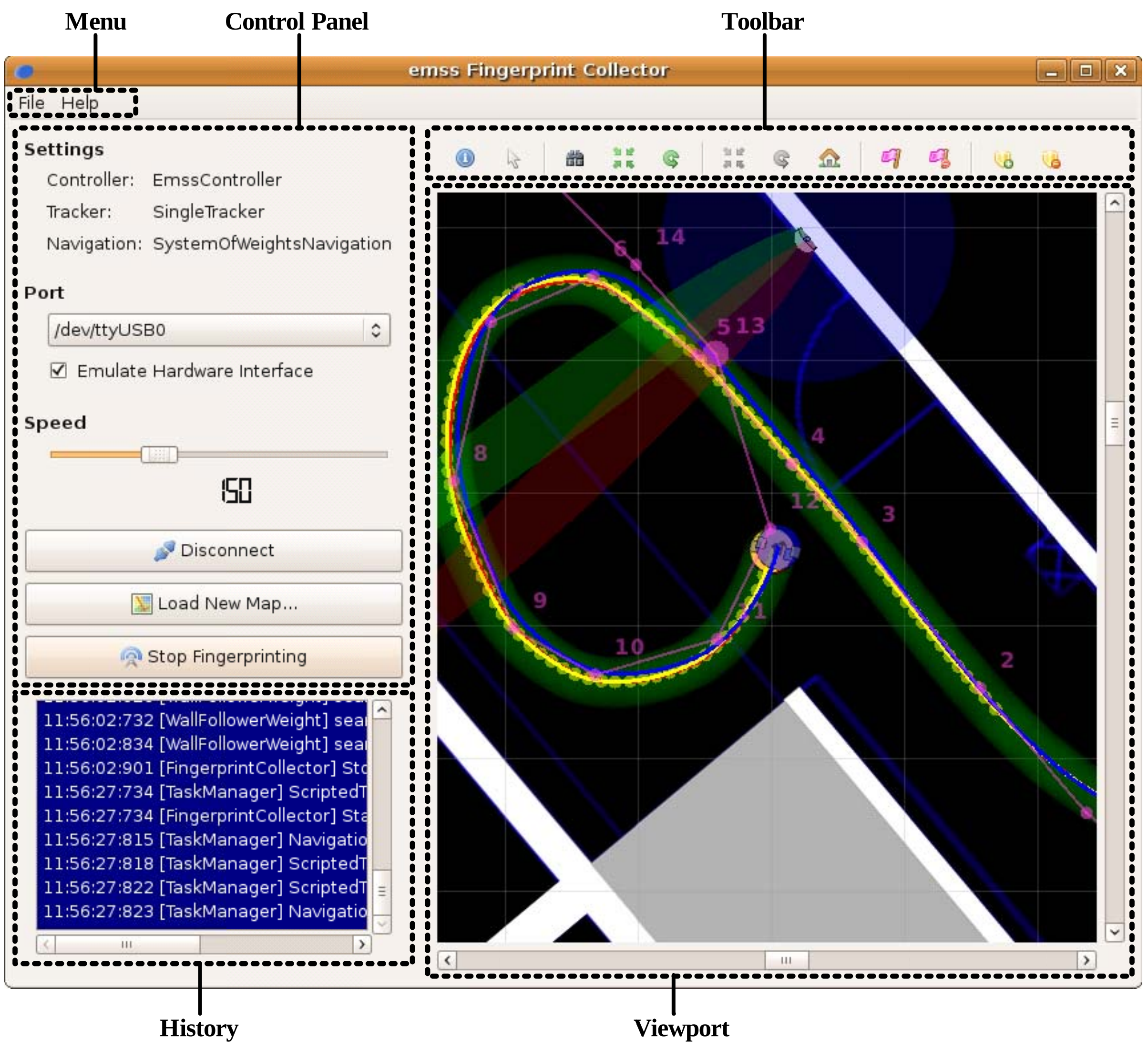
Table 10-18: Interface Configuration Values

10.5 FingerprintCollector

The FingerprintCollector application (`emssFingerprintCollector`) is the link between the robot and the WPS-Software. It instantiates an *emss* Core and provides the connection to the robot and the *emss* framework. The FingerprintCollecter is a simplified version of the *emss* Interface and provides only the functionality and settings for which its purpose serves: collecting fingerprints. In this Chapter both the graphical user interface and a use-case are described. In addition, the FingerprintCollector configuration settings are documented.

10.5.1 Graphical User Interface

The user interface is made up of a collection of widgets provided by the *emss* Core. It consists of three important areas: *Control Panel*, *Viewport*, and *History*. A typical presentation of the FingerprintCollector is shown below in Figure 10-13.



Settings

Controller: EmssController

Tracker: SingleTracker

Navigation: SystemOfWeightsNavigation

Port

/dev/ttyUSB0

☑ Emulate Hardware Interface

Speed

150

Disconnect

Load New Map...

Stop Fingerprinting

```
11:56:02:732 [WallFollowerWeight] sea
11:56:02:834 [WallFollowerWeight] sea
11:56:02:901 [FingerprintCollector] Sto
11:56:27:734 [TaskManager] ScriptedT
11:56:27:734 [FingerprintCollector] Sta
11:56:27:815 [TaskManager] Navigatio
11:56:27:818 [TaskManager] ScriptedT
11:56:27:822 [TaskManager] ScriptedT
11:56:27:823 [TaskManager] Navigatio
```

Figure 10-13: FingerprintCollector Graphical User Interface

10.5.1.1 Menu

The menu, shown in Figure 10-14, offers access to additional configuration settings related to the user interface and to the *emss* Core. Some menu items, such as "Reset", are only available when an *emss* Core has been initialized and are marked with *Core required.*

Icon	Item	Description
🔄	Reset	The current world state is discarded and a new, default or saved, state is loaded. When connected, the reset functionality will automatically re-connect. *Core required*
💾	Save World State	The current state of the robot and docking station as well as navigation points are saved to the configuration file. This is useful when performing the same task multiple times. *Core required*
🔧	Core Settings…	Opens a Settings Editor for the currently loaded Core configuration file. The individual settings are described in detail in Section 10.3.3. *Core required*
🔧	FingerprintCollector Settings…	Opens a Settings Editor for the currently loaded FingerprintCollector configuration file. The individual settings are described in detail in Section 10.5.3.

	Reset File Paths…	Enables a user to reset the file paths to the *emss* resources and logs folders.
	Exit	Closes the application after disconnecting (if necessary) the Core.

Table 10-19: FingerprintCollector File Menu Entries

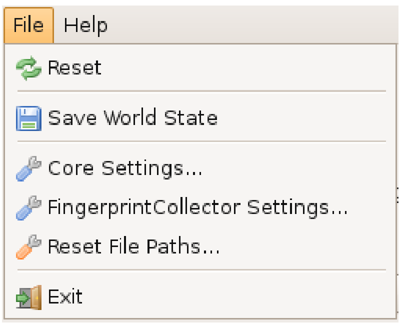


Figure 10-14: FingerprintCollector Menu

10.5.1.2 Control Panel

Settings: Displays the currently configured Controller, Tracker, and Navigation module. These modules can be swapped-out by modifying the Core settings.

Port: The serial port which represents the connection to the robot hardware from the laptop must be specified here. If the session should be emulated, then the checkbox „Emulate Hardware Interface“ must be checked and the port is no longer relevant.

Speed: Modifies the target speed of the controller and thus typically the average speed of the robot.

Button „Connect / Disconnect“: When pressed, the Core is either connected or disconnected, depending on which state the Core is in. A Core is automatically initialized if needed, however when disconnecting the Core is not discarded but kept for the next connection.

Button „Load New Map“: Opens a file-dialog and loads a new PhysicalMap from the specified file on the computer. This file may either be an image file (`.jpg`, `.png`, `.bmp`), or a KML file (`.kml`). It is recommened to load a KML file as these already contain the necessary GPS information. If a plain image was chosen, the GPS offset `Map_PhysicalMap_GPSOffset` must be specified in the Core configuration. In addition, the appropriate settings such as `Map_PhysicalMap_Description` and `Map_PhysicalMap_Floor` should be defined for 3rd-Party software.

Button „Start Fingerprinting / Stop Fingerprinting“: With this button the FingerprintNavigationTask is started. The settings for the fingerprint wait-time and interval are taken from the Core configuration file. If the FingerprintNavigationTask is already running, pushing the button will respectively stop the Task. Notice that if no navigation points are set, the FingerprintNavigationTask will attempt to follow the walls in the room until it has closed the structure of the room. If the Core setting `Task_FingerprintNavigationTask_PreTasks` contains one or more Tasks, these are executed first before the fingerprinting is started.

10.5.1.3 Toolbar

The toolbar allows quick-access to various functionality within the *emss* Core. The toolbar actions range from finding out information about a point on the map to placing the robot docked on the home station. Some tools instantly perform an action while others require a click on the map before undertaking an action. The tools which require a click are marked with *requires map click*. Such tools may be combined with others at the same time. For example, one could select both the „Focus On Point“ and „Set NavPoint“ tool, which upon clicking on the map would both set a new navigation point and focus the window on that point in the map.

Icon	Caption	Description
ⓘ	Map Info	Outputs information about the various maps for a specific point on the map: - Local Position (in Cartesian coordinates, millimeters) - Global Position (in GPS coordinates) - Whether or not the point is recognized as Collision Area - Whether or not the point is recognized as Open Area - Which color the PhysicalMap returns for the point (in RGB values) - The recognized area type for the point on the PhysicalMap (Wall, Stairs, Open) - The height of the TerrainMap - The signal of the DockingStation (if any). *requires map click*
↖	Focus On Point	Moves the center of focus of the Viewport window on the point clicked. *requires map click*
▣	Find Robot	Moves the center of focus of the Viewport to the current position of the robot.
✥	Move Robot	Moves the robot to the clicked point on the map. *requires map click*
↻	Rotate Robot	Rotates or orientates the robot towards the direction of the clicked point on the map. *requires map click*
✥	Move Docking Station	Moves the docking station to the clicked point on the map. If the setting `Robot_DockingStation_SnapToWall_Enabled` is enabled (`true`) and the docking station is close to a wall, it is automatically aligned and snapped to the wall. *requires map click*
↻	Rotate Docking Station	Rotates or orientates the docking station towards the direction of the clicked point on the map. *requires map click*
⌂	Set Robot Docked	Places the robot on top of the docking station in a docked position.
⚑	Set NavPoint	Places a new navigation point at the clicked point on the map. *requires map click*
⚑	Reset NavPoints	Removes all navigation points.
●	Set Border	Manually marks a border point in the StructureMap. *requires map click*
●	Reset Border	Removes all border points from the StructureMap.

Table 10-20: FingerprintCollector Toolbar Icons

10.5.1.4 History

The History is the standard output for all Core modules. Important information related to the current state of the different modules are displayed in chronological order. Messages are always preceded by a timestamp and the module which created the message in the format of `hh:mm:ss:fff [Module]`. Messages are split into three categories:

Information: Output in white and display general information regarding connection states, Task execution, et cetera.

Warnings: Output in yellow and display more information related to improper configurations or minor errors which require the attention of the user.

Errors: Output in red and display information related to serious errors within the Core. At this point the Core is considered unstable and should be reconfigured and reset.

10.5.1.5 Viewport

The Viewport displays the various Maps (PhysicalMap, HeatMap, etc) loaded in the Core. The Maps are described in further detail in Chapter 6.3.5. The main purpose of the Viewport is to represent the internal state of the Core in a visual fashion, as well as present an interface for interacting with the different Maps. The Viewport can be scrolled horizontally and vertically along its X and Y axis. When in *OpenGL* mode (see `Viewport_RenderMode` in Section 10.5.3), the Viewport can also be zoomed in and out using the zoom slider. Right-clicking the Viewport opens up a menu of different functionality. The following menu items are available for the Viewport:

Native Render / OpenGL Render: Displays whether the Viewport is being rendered natively using software or on the hardware using *OpenGL*. See `Viewport_RenderMode` in Section 10.5.3 on how to configure the render mode.

Anti Alias: When checked, MapObjects and other Map elements will be rendered using anti-aliasing. When in OpenGL render mode, the effect of the Anti Alias option might vary depending on what the hardware supports.

Auto Update: When checked, the Viewport will automatically refresh at the interval specified by the configuration setting `Viewport_AutoUpdateInterval`.

Auto Focus: When checked, the Viewport will automatically center its focus on the current position of the robot.

Maps: Individiual Maps can be hidden from being displayed unchecking the Map name under the „Maps“ menu.

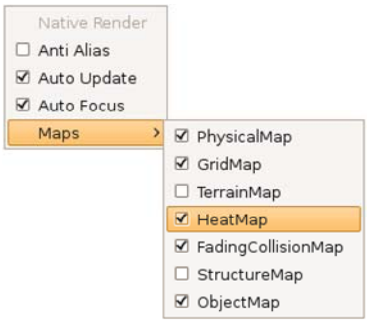

Native Render
☐ Anti Alias
☑ Auto Update
☑ Auto Focus
Maps
☑ PhysicalMap
☑ GridMap
☐ TerrainMap
☑ HeatMap
☑ FadingCollisionMap
☐ StructureMap
☑ ObjectMap

Figure 10-15: Viewport Menu Items

10.5.2 Fingerprinting Guide

In this section a step by step guide is presented on how fingerprints are collected with the help of the FingerprintCollector application, *WPS PointZero* software, and robot hardware. Pre-requisites for this guide are the installation of both the *emss* FingerprintCollector[23] and *WPS PointZero*[24].

1. The first step is to position the physical docking station. It is best to place the docking station at a location which is easy to spot on the floor plan or map. Use visual markers such as pillars or corners to choose a suitable location. In addition, if the robot is to be kept „at home“ on the docking station, it is advantageous to be near a power supply. In any case, the docking station should be placed solidly and tight against a wall or flat surface, with the robot placed exactly on top at the same angle as the docking station.

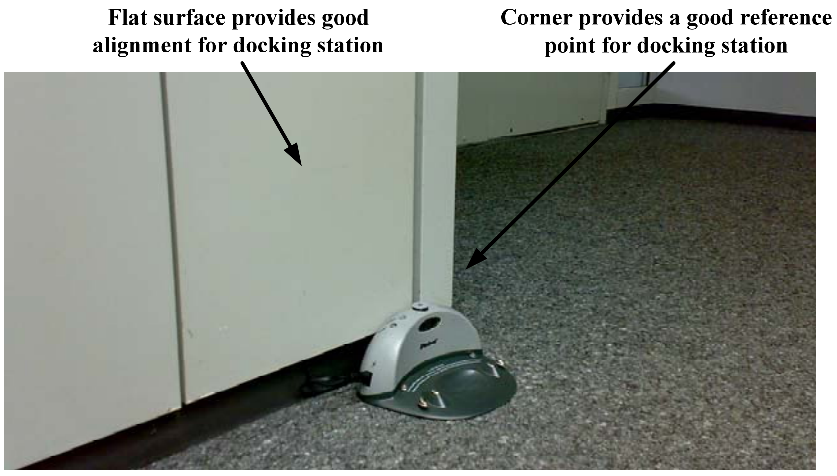

Flat surface provides good alignment for docking station
Corner provides a good reference point for docking station

Figure 10-16: Positioning the Physical Docking Station

2. Turn on the robot and laptop.

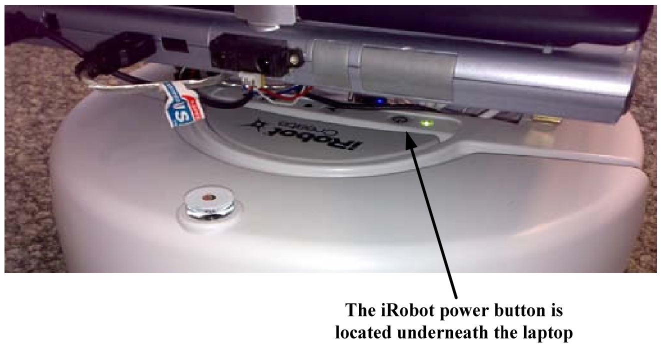


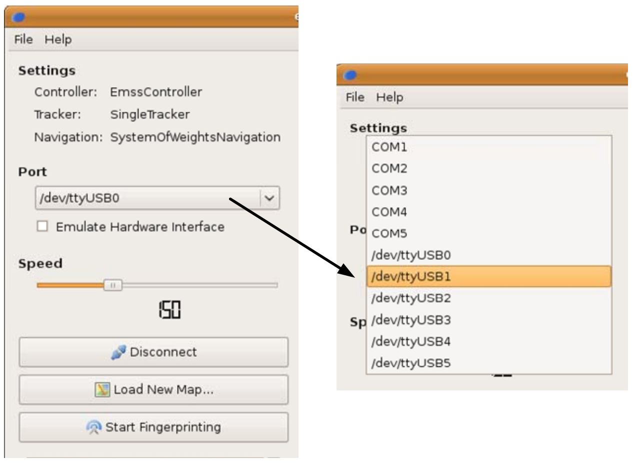
Figure 10-17: Powering on the iRobot Create

3. Start the FingerprintCollector application: `<emss>/bin/emssFingerprintCollector`.

---

[23] Instructions on the installation for the *emss* FingerprintCollector can be found in Chapter 10.1.
[24] Instructions on the installation for the *WPS PointZero* software can be found at `http://wiki.hsr.ch/StefanKeller/wiki.cgi?PointZero`.

4. Select the correct serial port[25] for communications with the hardware and press the „Connect“ button. Make sure the „Emulate Hardware Interface“ checkbox is not checked.



Settings
Controller: EmssController
Tracker: SingleTracker
Navigation: SystemOfWeightsNavigation

Port
/dev/ttyUSB0

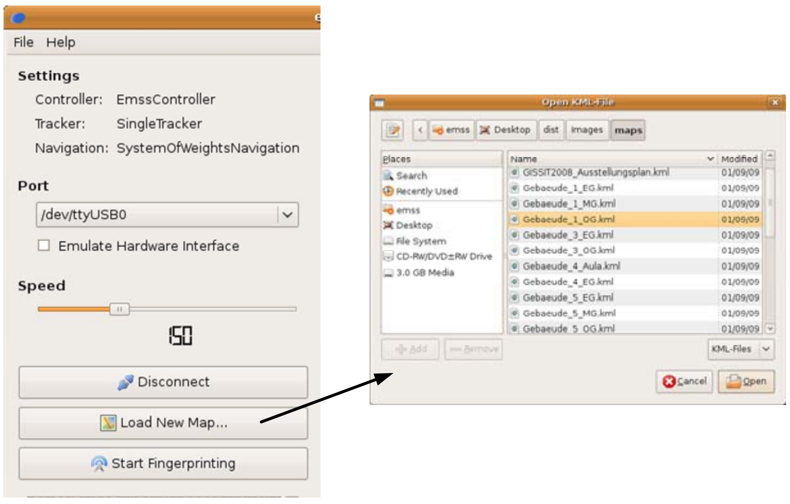
☐ Emulate Hardware Interface

Speed
150

Settings
COM1
COM2
COM3
COM4
COM5
/dev/ttyUSB0
/dev/ttyUSB1
/dev/ttyUSB2
/dev/ttyUSB3
/dev/ttyUSB4
/dev/ttyUSB5

Figure 10-18: Selecting the FingerprintCollector Port

5. If not already present, the correct map must be loaded. This can be done by pressing the „Load New Map...“ button, as documented in Section 10.5.1.2. It is recommended to load a KML file (`.kml`) as these already contain the necessary GPS information. If a plain image was chosen, the GPS offset `Map_PhysicalMap_GPSOffset` must be specified in the Core configuration. In addition, the appropriate settings such as `Map_PhysicalMap_Description` and `Map_PhysicalMap_Floor` should be defined for 3rd-Party software.[26]



Settings
Controller: EmssController
Tracker: SingleTracker
Navigation: SystemOfWeightsNavigation

Port
/dev/ttyUSB0

☐ Emulate Hardware Interface

Speed
150

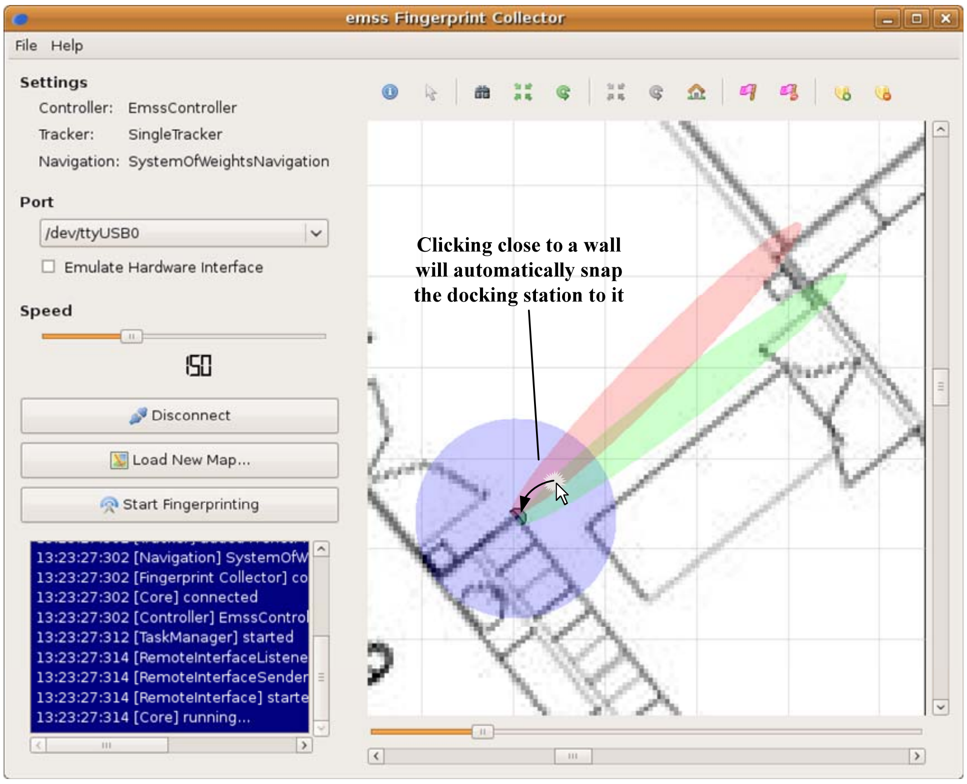
Name	Modified
GISSIT2008_Ausstellungsplan.kml	01/09/09
Gebaeude_1_EG.kml	01/09/09
Gebaeude_1_MG.kml	01/09/09
Gebaeude_1_OG.kml	01/09/09
Gebaeude_3_EG.kml	01/09/09
Gebaeude_3_OG.kml	01/09/09
Gebaeude_4_Aula.kml	01/09/09
Gebaeude_4_EG.kml	01/09/09
Gebaeude_5_EG.kml	01/09/09
Gebaeude_5_MG.kml	01/09/09
Gebaeude_5_OG.kml	01/09/09

Figure 10-19: Loading a New Map

[25] On *Unix* systems, the correct port can be easily determined with the following command: `ls /dev/ttyUSB*`. This command will list all the USB TTY devices (there should typically only be one). In most cases, the device to the robot hardware is called `/dev/ttyUSB0`.

[26] On some hardware too large image files might not be able to be properly displayed by *OpenGL*. If this occurs, try resizing the image to a smaller size, or setting the Core `Map_Scale` configuration value higher.

6. Next, the virtual docking station in the FingerprintCollector application must be placed as exactly as possible. This is a sensitive operation, as a slight difference in angle might affect the localization (or positioning) of the robot greatly over time. For this task the setting `Robot_DockingStation_SnapToWall_Enabled` helps by snapping and aligning the robot to the nearest wall. This is why it is advantageous to choose a remarkable flat surface, such as a wall, to place the physical docking station.


emss Fingerprint Collector
File
Help
Clicking close to a wall will automatically snap the docking station to it
Disconnect
Load New Map...
Start Fingerprinting

Settings
Controller: EmssController
Tracker: SingleTracker
Navigation: SystemOfWeightsNavigation

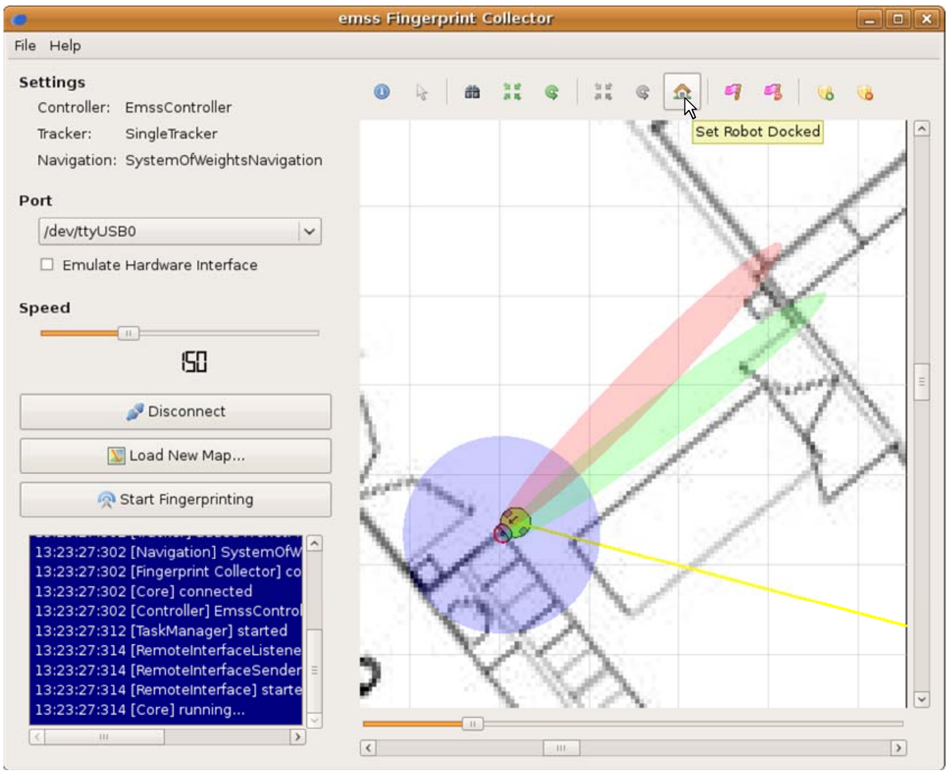
Port
/dev/ttyUSB0
Emulate Hardware Interface

Speed
150

```
13:23:27:302 [Navigation] SystemOfW
13:23:27:302 [Fingerprint Collector] co
13:23:27:302 [Core] connected
13:23:27:302 [Controller] EmssControl
13:23:27:312 [TaskManager] started
13:23:27:314 [RemoteInterfaceListene
13:23:27:314 [RemoteInterfaceSender
13:23:27:314 [RemoteInterface] starte
13:23:27:314 [Core] running...
```

Figure 10-20: Positioning the Virtual Docking Station

7. Using the toolbar action „Set Robot Docked" place the robot ontop of the docking station in a docked position.



Settings
Controller: EmssController
Tracker: SingleTracker
Navigation: SystemOfWeightsNavigation

Port
/dev/ttyUSB0
☐ Emulate Hardware Interface

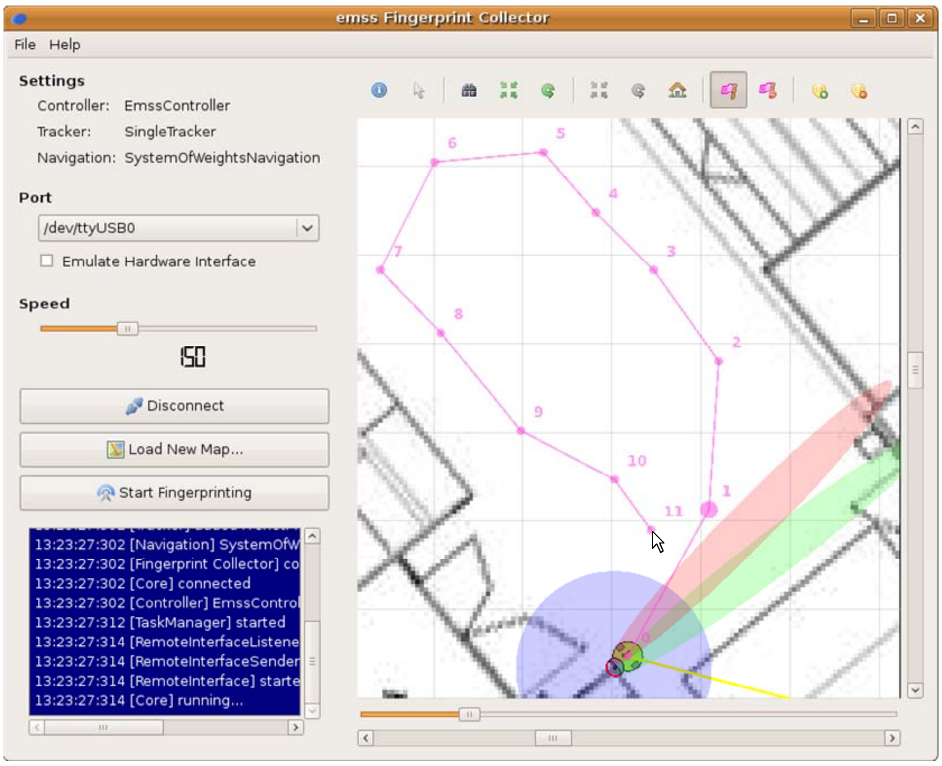
Speed
150

```
13:23:27:302 [Navigation] SystemOfW
13:23:27:302 [Fingerprint Collector] co
13:23:27:302 [Core] connected
13:23:27:302 [Controller] EmssControl
13:23:27:312 [TaskManager] started
13:23:27:314 [RemoteInterfaceListene
13:23:27:314 [RemoteInterfaceSender
13:23:27:314 [RemoteInterface] starte
13:23:27:314 [Core] running...
```

Figure 10-21: Placing the Robot on the Docking Station

8. Set all the desired navigation points on the map for the area which is to be covered by fingerprinting. Note that a navigation point does not define where a fingerprint is taken, just where the robot will drive through. The robot will decide by itself when it is time to take a fingerprint.[27]

[27] To avoid problems during navigation, make sure the path stays clear from obstacles or sharp corners. In general it is best to lay a path with at least 90 cm of space on both sides.



Settings
Controller: EmssController
Tracker: SingleTracker
Navigation: SystemOfWeightsNavigation

Port
/dev/ttyUSB0
☐ Emulate Hardware Interface

Speed
150

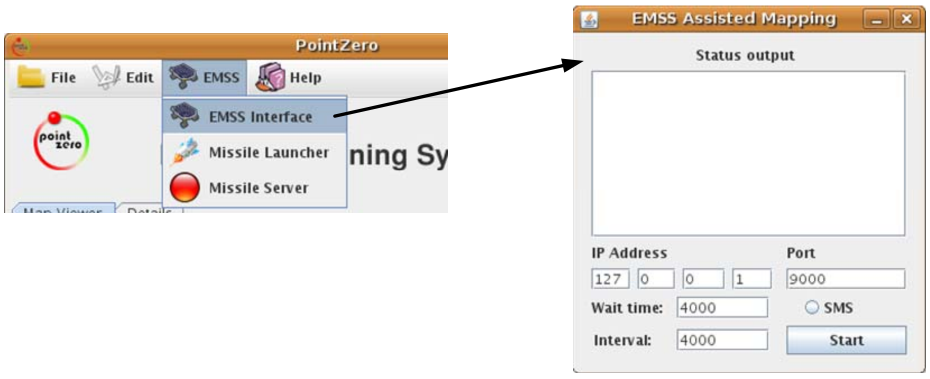
```
13:23:27:302 [Navigation] SystemOfW
13:23:27:302 [Fingerprint Collector] co
13:23:27:302 [Core] connected
13:23:27:302 [Controller] EmssControl
13:23:27:312 [TaskManager] started
13:23:27:314 [RemoteInterfaceListene
13:23:27:314 [RemoteInterfaceSender
13:23:27:314 [RemoteInterface] starte
13:23:27:314 [Core] running...
```

Figure 10-22: Setting Navigation Points for Fingerprinting

9. A this point the menu item „Save World State“ can optionally be selected from the „File“ menu. This will save the current configuration for when the software is restarted.
10. When everything is ready and setup, the *PointZero* software can be started using the follwoing command: `java -jar <pointzero>/PointZeroExtreme.jar`[28]. Once started, the software must register itself with the *emss* Core running inside of the FingerprintCollector application. This is done by selecting the menu „Emss“ then „Emss Interface“. The „EMSS Assisted Mapping“ dialog presents additional settings for the FingerprintNavigationTask, such as the fingerprint interval and wait-time. Clicking the „Start“ button will send a message to the *emss* RemoteInterface to begin fingerprinting.[29]

[28] As of version 1.2 certain *PointZero* features are disabled until the login procedure has been performed (“Edit” then “Log in…”).

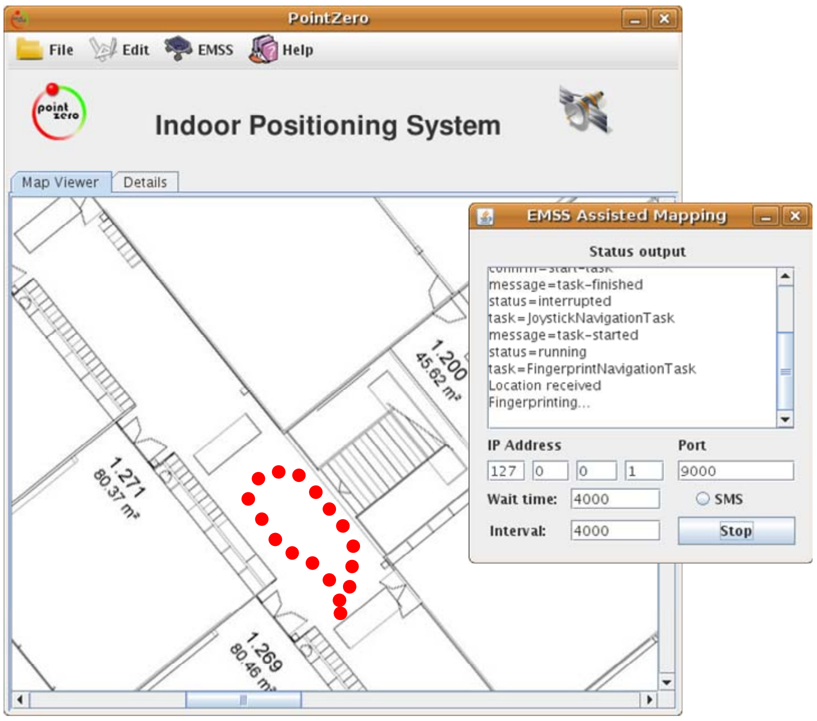
[29] Notice that if no navigation points are set, the FingerprintNavigationTask will attempt to follow the walls in the room until it has closed the structure of the room. If the Core setting `Task_FingerprintNavigationTask_PreTasks` contains one or more Tasks, these are executed first before the fingerprinting is started.



```
IP Address          Port
127 0 0 1           9000
Wait time: 4000     SMS
Interval:  4000
```

Figure 10-23: Starting Assisted Mapping in *PointZero*

11. Depending on the configuration, there will be a short pause (defined by `Task_PauseTask_Timeout_ms`) before the robot will undock itself and begin fingerprinting. At this time, close the laptop screen and stand back clear of the docking station (if not connected remotely).



```
message=task-finished
status=interrupted
task=JoystickNavigationTask
message=task-started
status=running
task=FingerprintNavigationTask
Location received
Fingerprinting...
```

```
IP Address          Port
127 0 0 1           9000
Wait time: 4000     SMS
Interval:  4000
```

Figure 10-24: *PointZero* Receiving Fingerprint Messages

10.5.3 Configuration

The settings below are used by the FingerprintCollector application and can be located in the file `<emss>/resources/emssFingerprintCollector.config`. The settings marked with *persistent* are saved with the current values automatically when the application closes. For further details on the different value types and configuration patches please see Section 11.5 in the glossary.

Connection_Controller *persistent*

Default	`EmssController`
Type	`string`
Description	Defines which Controller implementation to use.

Connection_Port *persistent*

Default	`5`
Type	`int`
Description	Defines the default port which is selected when the application is started.

Connection_Tracker *persistent*

Default	`SingleTracker`
Type	`string`
Description	Defines which Tracker implementation to use.

Connection_Navigation *persistent*

Default	`SystemOfWeightsNavigation`
Type	`string`
Description	Defines which Navigation implementation to use.

Controller_TargetSpeed *persistent*

Default	`150`
Type	`int`
Description	Defines the default Controller target speed which is set when the application is started.

Connection_SafeMode *persistent*

Default	`false`
Type	`bool`
Description	When `true`, upon connection to the hardware COIL is set to enter Safe Mode instead of Full Mode. When in Safe Mode, the onboard controller prevents the robot from taking actions which may result in hardware damage.

Connection_EmulateHardware *persistent*

Default	`true`
Type	`bool`
Description	Defines whether or not the „Emulate Hardware Interface“ should be checked when the application is started.

Log_LogToFile

Default	`false`
Type	`bool`
Description	When `true`, all the messages output to the History panel or console are also saved to a log file in `<emss>/logs`.

Viewport_AutoUpdateInterval

Default	`500`
Type	`ms`
Description	Defines the interval at which the Viewport automatically redraws itself. If the application is run locally on the machine, an interval of 100 ms is sufficient for speedy rendering and feedback. If the application is run over SSH or a Remote Desktop Client, a higher interval (lower refresh rate) is recommended of 500 to 1000 ms.

Viewport_RenderMode

Default	`native`
Type	`string`
Description	Defines the render mode for the Viewport. This value must be either `native` or `opengl`. When in OpenGL mode, the Viewport supports zoom functionality. Note that to use the OpenGL render mode, a hardware accelerated graphics driver must be running with OpenGL support.

Window_X *persistent*

Default	`100`
Type	`int`
Description	Defines the X-coordinate of the main window position in pixels.

Window_Y *persistent*

Default	`100`
Type	`int`
Description	Defines the Y-coordinate of the main window position in pixels.

Window_Width *persistent*

Default	`850`
Type	`int`
Description	Defines the main window width in pixels.

Window_Height *persistent*

Default	`650`
Type	`int`
Description	Defines the main window height in pixels.

Table 10-21: FingerprintCollector Configuration Values

10.6 Scripts

The *emss* framework comes with a full set of scripts which perform routine but tiring tasks such as dependency builds, resource file compilation, configuration patching, et cetera. The scripts are written to run on any *POSIX* compliant system[30], including *Cygwin* for *Windows*, and are found in `<emss>/Scripts`. When setup, shortcuts to specific scripts, such as `er`, `eubr`, and `ecc`, prove useful in a daily work environment.

10.6.1 Initialization

The `init.sh` script is used internally by other scripts to easily initialize all the settings and variables needed. In addition it includes all the common functions used across multiple scripts. If a splash has not already been shown, the script will display a splash screen with some environment information:

```
======================================
=           emss Framework           =
======================================
Location: /home/dankrusi/emssframework/trunk
SVN: https://emssframework.svn.sourceforge.net/svnroot/emssframework/trunk
Target: release
Version: 1.1
OS: linux
Architecture: x86
Verbose: true
Resources: /home/dankrusi/emssframework/trunk/resources
Logs: /home/dankrusi/emssframework/trunk/logs
Default Component: Interface$
```

Code 10-5: Script Splash Screen

10.6.2 Setup

The `setup.sh` script will setup the *emss* script environment by automatically creating settings, resource and logs folders, as well as shortcuts to various scripts. It is recommended to run this script when setting up a new *emss* workspace.

Usage: `setup.sh`

10.6.3 Script Settings

Each script typically requires at least one or more environment settings. These settings are stored in the file `settings.sh`, which is not provided in any of the *emss* packages. The settings.sh script must be created using the `create_settings.sh` or `setup.sh` script.

[30] Some versions of *OS X* require the *GNU Core Utils* to be installed as the tools are not implemented correctly by the operating system vendor.

It contains the following variables:

- `EMSS`: The full path to the *emss* root folder `<emss>`
- `SVN`: The full SVN path for which the `<emss>` is checked out from
- `TARGET`: The current target to build, either `target` or `release`
- `VERBOSE`: When true, scripts should output verbose information
- `VERSION`: The current *emss* version number, used for creating packages.
- `OS`: The current environment platform, used for creating packages. The value must be either `linux`, `win`, or `osx`.
- `ARC`: The current environment architecture, used for creating packages.
- `RESOURCES`: The resources folder within the `<emss>` folder.
- `LOGS`: The log-files folder within the `<emss>` folder.
- `DEFAULT_COMPONENT`: Defines the default *emss* component when none is specified.

A typical settings file might look like:

```
EMSS="/home/dankrusi/emssframework/trunk"
SVN="https://emssframework.svn.sourceforge.net/svnroot/emssframework/trunk"
TARGET="release"
VERBOSE=true
VERSION="1.3"
OS="linux"
ARC="x86"
RESOURCES="resources"
LOGS="logs"
DEFAULT_COMPONENT="Interface"
```

Code 10-6: Example Setting File

10.6.4 Environment

The script file `env.sh` will output as much environment information as possible. In addition to the standard information from the splash screen, environment information such as the current *Qt* version is shown.

Usage: `env.sh`

```
env.sh
======================================
Using Qt version 4.4.3 in /usr/lib
Using g++ version 4.3.2
Architecture: i486-linux-gnu
```

10.6.5 Creation

10.6.5.1 Creating Settings

Running this script will create a default `settings.sh` file and can automatically detect variables such as `EMSS`, `SVN`, and `OS`. Before using any scripts, either `create_settings.sh` or `setup.sh` must be run.

Usage: `create_settings.sh`

10.6.5.2 Creating Resources and Logs

This script creates a resources folder specified by `RESOURCES` containing the default *emss* resources (`<emss>/DefaultResources`) as well as a log-files folder specified by `LOGS`.

Usage: `create_settings.sh`

10.6.5.3 Creating and Patching Config Files

The `create_configs.sh` script will create a set of default configuration files (`.config`) in the `RESOURCES` folder. The newest version of the configurations is automatically retrieved from the SVN server. If specific files already exist, then they are overwritten.

You can specify custom settings and configurations by creating a patch file. Patch files must match the name of the configuration file but must include .patch at the end. For example, to patch the `emssCore.config` file, one would create a file `emssCore.config.patch` next to it. When `create_settings.sh` is called, the new `emssCore.config` is patched with all the settings in `emssCore.config.patch`. This proves especially useful when working collaboratively during development. In this environment there are typically many new Core configurations from different sources merged by SVN. Overwriting the config file is necessary, as to ensure all the required settings are present, but it is however very annoying if there are specific settings for a specific robot. This is where a patch file helps - it ensures the newest settings but forces a specific set of configurations.

Usage: `create_configs.sh` Shortcut: `ecc`

As an example, the following config file `emssTest.config`:

```
Test_SettingA=ValueA
Test_SettingB=ValueB
Test_SettingC=ValueC
Test_SettingD=ValueD
```

patched with this patch file `emssTest.config.patch`:

```
Test_SettingC=MyOwnValueC
```

will produce the following output config file `emssTest.config`:

```
Test_SettingA=ValueA
Test_SettingB=ValueB
Test_SettingC=MyOwnValueC
Test_SettingD=ValueD
```

10.6.5.4 Creating and Using Shortcuts

The `create_shortcuts.sh` script will create a series of shortcuts to commonly used scripts:

- `er` → `run.sh`
- `ebr` → `build_run.sh`
- `edr` → `debugrun.sh`
- `eubr` → `update_build_run.sh`
- `ecc` → `create_configs.sh`

To create the shortcuts, you might be asked for the root password (depending on the current platform).

Usage: `create_shortcuts.sh`

Once the shortcuts are installed, you can quickly run scripts from the console at any folder:

```
#ecc
#eubr
```

10.6.5.5 Creating Resource Files

Qt resource files for the *emss* framework, such as icons and texts, can be automatically be generated using the `create_qrcfiles.sh` script.

Usage: `create_qrcfiles.sh`

```
create_qrcfiles.sh
======================================
 * Writing /home/dankrusi/emssframework/trunk/DefaultResources/Icons.qrc...
 * Writing /home/dankrusi/emssframework/trunk/DefaultResources/Texts.qrc...
```

10.6.6 Updating Components

Any *emss* component can be updated with the script update.sh. To specify which component to update, provide the component name as the first argument. For example, to update the *emss* Core, enter the command `./update.sh Core`. If no argument is passed to the script, the default component is updated. You can update all the *emss* components by specifying `all` as the first argument: `./update.sh all`.

Usage: `update.sh <component|all>`

Shortcut: `eu <component|all>`

```
update.sh
======================================
Updating Core...
Updating Interface...
```

10.6.7 Building Components

An *emss* component can be built using the build.sh script. This script automatically generates makefiles from the Qt project files (`.pro`) and calls make. The target is defined by the `TARGET` setting. This script will automatically build any necessary components, such as the Core, if needed.

Usage: `build.sh <component|all>`

Shortcut: `eb <component|all>`

```
build.sh
======================================
Building Core...
Building Interface...
```

10.6.8 Running Applications

10.6.8.1 Normal Run

To execute an *emss* component that produces an executable binary, use the `run.sh` script. The component to be run must be specified in the first argument.

Usage: `run.sh <component|all>`

Shortcut: `er <component|all>`

```
run.sh
======================================
Running Interface...
```

10.6.8.2 Debug Run

If *gdb* is installed, a debug run can be performed with `debugrun.sh` on any *emss* component that produces an executable binary. The component to be run must be specified in the first argument. This script will automatically create a temporary *gdb* script for the debugger which kick-starts the program directly into execution. This is especially useful when debugging software errors on the hardware.

Usage: `debugrun.sh <component|all>`

Shortcut: `edr <component|all>`

```
debugrun.sh
======================================
Creating debug script...
Debug-run Interface...
This GDB was configured as "i486-linux-gnu"...
Breakpoint 1 at 0x8058213
[Thread debugging using libthread_db enabled]
[New Thread 0xb6a15b50 (LWP 21537)]
[Switching to Thread 0xb6a15b50 (LWP 21537)]
0x08058213 in main ()
Current language:  auto; currently asm
Program exited normally.
(gdb)
```

10.6.9 Cleaning Applications

If only the executables are to be cleaned, use the `clean_applications.sh` script. Cleaning the executables may be desired if, for example, the Core library has changed. Because the library is statically linked to the applications, one must re-link the applications to the new library - something that is not done automatically by make. For this reason `clean_applications.sh` is automatically called after building the Core component.

Usage: `clean_applications.sh`

10.6.10 Packaging

The most powerful *emss* scripts are the ones related to creating packages from source. To create a compiled package for a set of components use the `create_package.sh`. The following packages can be created:

- `Complete`: contains all components and resources
- `Core`: contains only the *emss* Core
- `Interface`: contains only the *emss* Interface
- `TestApplications`: contains all test applications

When executed, `create_package.sh` will automatically run `create_package_component.sh`. For each package created, the following files are generated in the `<emss>/Packages` folder.

- `emss<package>-<version>-source.tar.gz`: tar file containing the source
- `emss<package>-<version>-source.zip`: zip file containing the source
- `emss<package>-<version>-<os>-<arc>.<tar.gz|zip>`: tar or zip file containing the binaries and resources

When creating packages, the following steps are performed automatically:

1. Create temporary working directories
2. For each component:
    1. Source checkout from SVN
    2. Build component
    3. Patch `rpath` (Linux only)
3. Extract dependencies
4. Create source tar and zip files
5. Create binary file

If additional dependencies are needed for a release, they can be automatically added to the `bin` folder by creating a archive file containing the dependencies for each OS: `<emss>/Packages/Dependencies/<os>.tar.gz`.

Usage: `create_package.sh <Complete|Core|Interface|TestApplications|all>`

```
create_package_component.sh
======================================
Creating package component Interface...
Grabbing resources from SVN...
Creating source dir...
Building component...
Determining binary file...
Binary file is emssInterface
Creating binary dir...
Changing rpath to . for ELF binary...
Copying to package Interface...
Copying contents to structured dirs...
Copying dependencies to bin...
Creating source tars...
Creating binary tars...
Cleaning up...
```

11 Appendix

11.1 Glossary

Auxiliary Tower: Serves a platform for adding additional sensory equipment and other accessories.

Bumper: A buffer bar to recognize collisions in front of the robot.

CCW: Counter-clock-wise.

Cliff Sensors: Downward-pointing sensors disabling the robot from driving down stairs or other sudden drops.

COIL (Create Open Interface Library): This library opens a serial port and directly communicates with the *iRobot*.

Collision Area: Represents any sort of collision or obstacle, forming the environments boundary.

Controller: Sends movement commands to COIL and is also responsible for passing along sensor data to other Core components. The Controller is also a base class of fully functional Controllers.

CoreFactory: Serves as the factory for the entire Core.

Cut Level: Is used in the height map to cut the terrain at specific height.

Cut Level Points: Points in the map with the exact height of a cut level.

Differential steering: Each wheel is controlled independently of the other.

DiscoveryTask: A Task with the goal to explore an unknown area.

Docking Station: The docking station provides the recharging hardware for both the robot and laptop battery.

***emss* (Environment-Mapping Self Sustainable) Robot**: A robot which interacts autonomously and explores an unknown area.

***emss* Fingerprint Collector**: The FingerprintCollector application is the link between the robot and the WPS-Software.

EmssController: The main Controller of the *emss* software.

***emss* Interface**: A graphical interface to control the robot and create Tasks.

EmulatedCOIL: Emulates the *COIL* so that no physical robot is needed for executing tests.

Environment mapping: Building a map representing the environment using sensor data.

FadingCollisionMap: Slowly fades away the detected collisions over time, only remembering the local collisions

Fingerprint: Used in association with WPS, which needs reference points of wireless signals (fingerprints) to determine its position.

FingerprintNavigationTask: Navigates the robot through a room while pausing regularly at fixed intervals, allowing third-party software to collect data and use the robots current position.

Framework: A framework is an extensible structure for describing a set of concepts, methods and technologies.

FrenetMovementTracker: Implements a mathematically sound tracker for the differential steering system of the robot.

GPS (Global Positioning System): Satellite based system for positioning.

HeatMap: A Heat Map is built to visualize the discovered environment of the robot with different colors.

HeightMap: A map which visualizes a terrain.

IR Range Finder: A device used for detecting distant objects using infra-red waves.

iRobot Create: The *iRobot Create* is a robust, rugged and versatile robot base kit that can be used for various hobby and research robotics applications.

LIDAR: Common range finder which stands for Light Detection and Ranging.

LocalHeightMap: A local height map is a fixed size map with the robot in its center. It is used by the height map algorithm.

Localization: The act of determining the local position within a global frame based on external sources. Also known as positioning.

Map: A visual representation of an environment.

MovementTracker: Responsible for tracking movements of the robot, and in turn performing the localization, a Movement Tracker accepts signals from the active Controller and translates them accordingly.

Navigation: The Navigation class holds the information of the navigation points, or way points, for the robot. Other data structures, such as splines, are also included in this class.

Open Area: No collision is at this point and portrays the robots path through the environment.

OpenGL (Open Graphics Library): Specification of a cross platform programming interface for Computer Graphics.

PauseTask: Task which just waits the defined period of time.

PhysicalMap: The *emss* Physical Map represents the real world environment in its physical state.

Positioning: The act of determining the current position in a given frame. Usually positioning is related to a global scope. See also localization.

***Qt* Framework**: *Qt* is a cross-platform application framework produced by *Qt Software* (formerly *Trolltech*).

RawMovementTracker: The Raw Movement Tracker tracks the robot's movement by geometrically interpreting the sensor data sent back from the robot.

RemoteInterface: Enables third-party software to make use of the *emss* framework, including access to its Maps and Tracker, and the ability to start and stop Tasks.

RoamingTask: Task which executes randomly movements.

Self-Sustainable: The ability to provide ones own resources and needs without external help.

SLOC: Source Lines of Code.

Spline: Smooth, piecewise defined function of polynomials.

StructureMap: Represents the structure of a room as the robot sees it.

SystemOfWeights: Completely dynamic navigation system which reacts solely on the current perception on the state of the environment at that moment of time with the aid of weights.

TaskManager: The Task Manager receives a Task, appends it to the Task List, and to schedules it for execution.

TerrainMap: Visualizes the exploration map together with a heat map with the aim of calculating a navigational terrain.

TestMoveTask: Performs different test movements. These movements are used for diagnostic purposes, such as calibration, accuracy observation, and general research.

Tracker: Is responsible for providing other modules information about the localization, or positioning data, of the robot.

Transformation matrix: A description of the position and alignment of an object.

UndockTask: Releases the robot from the docking station.

Vector: Objects in a vector space.

Vector space: A vector space is a set of objects (called vectors) that can be scaled and added.

VGA: A resolution of 640x480.

Viewport: A Viewport has the ability to display any *emss* Map as well as the Map Objects.

WallFollowerTask: Follows walls and investigates the structure of the room

Watchdog: Runs in a separate thread and monitors different aspects of the *emss* Core during its runtime. It responsible for reporting any detected fatal errors, such as a deadlock, or taking action when certain situations come about.

WPS (Wireless Positioning System): A system to locate a position based on wireless signals.

11.2 List of Figures

11.3 List of Tables

11.4 List of Code

11.5 Configuration Files

All configurations and settings for the *emss* Core and other *emss* applications are contained within different `.config` files in the *emss* resources folder. The names for these files adhere by the naming scheme of `emss<component>.config` such as `emssCore.config`.

11.5.1File Format

Each configuration file consists of a series of key-value pairs. Each pair is separated by a new line character `\n` and each key-value is separated by an equal character `=`. The first line of the file must begin with a `[General]` tag, commonly found in `.ini` files, in order to stay compatible with Windows systems.

Keys can be grouped and sub-grouped by adding a _ character. For example, if there is a set of configurations for a Camera module, one would add configuration keys starting with `Camera_`, such as `Camera_RefreshRate`.

To include the reseverved equal character `=` in the value, one must escape it using the following: `\=`.

11.5.2Value Types

The following values types are used in configuration files:

Data Type	Description
`ms`	milliseconds, given as a positive integer
`sec`	seconds, given as a positive integer
`mm`	millimeters, given as a integer or double
`mmps`	millimeters-per-second, given as a integer or double
`string`	string value, given without spaces or special characters
`string list`	space-separated ( ) list of strings, given without special characters
`int`	integer value, given as a integer
`double`	double value, given as a integer or double
`bool`	boolean value, given as either `true` or `false`
`color`	RGB value, given as a space-separated ( ) byte-triplet such as `255 200 243`
`GPS`	GPS coordinates, given as a space-separated ( ) latitude/longitude-pair such as `43.2234 7.8883`

11.5.3Patch Files

Configuration Files can be automatically patched with a patch file. See 10.6.5.3 for more information on how to create and apply patch files.

11.6 Eclipse Tutorial

For development of the *emss* software it can be helpful to use the open-source *Eclipse CDT*[31] with *Qt Eclipse Plugin*[32]. This combination provides a comfortable and well-supported programming environment for both *C++* and the *Qt* framework.

The following steps describe how to import a *Qt* project file into *Eclipse* when the *Qt Eclipse Plugin* has been installed.

1. After downloading the source code via *SVN*, start *Eclipse CDT* and choose a workspace.
2. Right Click on Project Explorer and choose “Import...”.

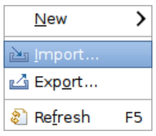


Figure 11-1: Import Menu

3. Then choose “Qt Project” from the “Qt” menu.

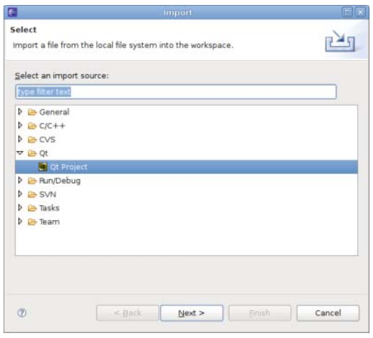
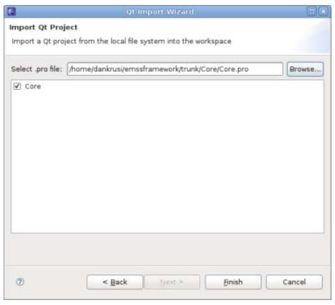


Figure 11-2: Import Menu

4. Browse the file system for the SVN checkout directory and choose, for example, `<emss>\Core\Core.cpp`. Click “Finish” to import the project.



Select .pro file: /home/dankrusi/emssframework/trunk/Core/Core.pro

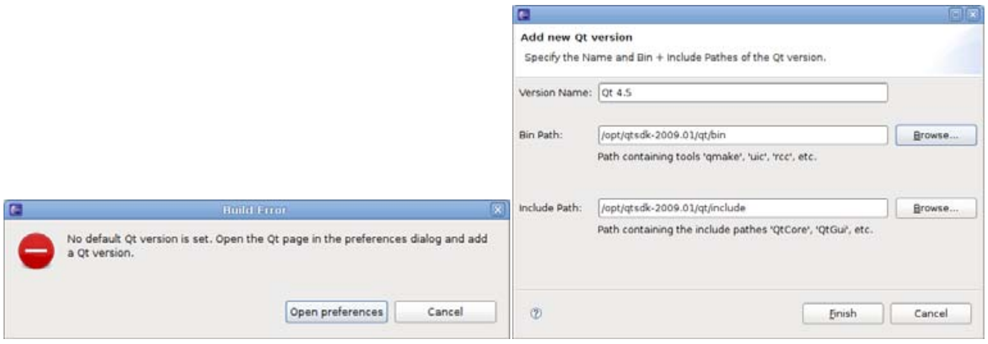
[✓] Core

Figure 11-3: Import Qt Project File

[31] The *C/C++ Development Tooling* can be found at `http://www.eclipse.org/cdt`.

[32] The *Qt Eclipse Integration for C++* provided by *Qt Software* can be found at `http://www.qtsoftware.com/developer/eclipse-integration`.

5. If the *QT Eclipse Plugin* is used the first time, a warning appears and requests to configure the preferred *Qt* version and its bin and include path.



No default Qt version is set. Open the Qt page in the preferences dialog and add a Qt version.

Add new Qt version
Specify the Name and Bin + Include Pathes of the Qt version.

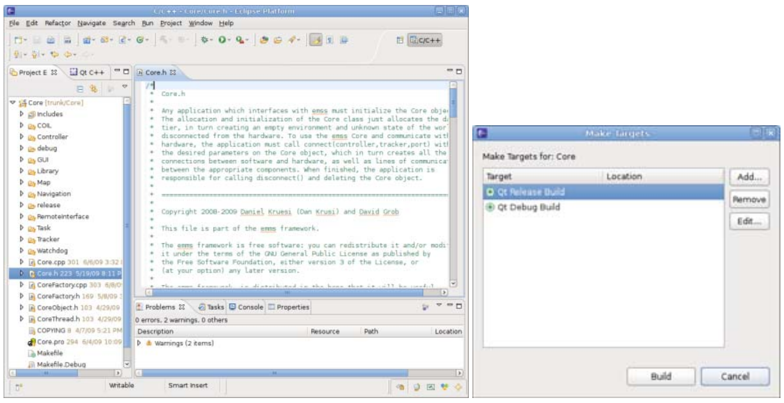
Version Name: Qt 4.5

Bin Path: /opt/qtsdk-2009.01/qt/bin
Path containing tools 'qmake', 'uic', 'rcc', etc.

Include Path: /opt/qtsdk-2009.01/qt/include
Path containing the include pathes 'QtCore', 'QtGui', etc.

Figure 11-4: Add New Qt Version

6. Now the source code is ready to compile. The new project will automatically update the *Qt* project file (`.pro`) and run *qmake* when necessary.



```
/*
 *  Core.h
 *
 *  Any application which interfaces with emss must initialize the Core obje
 *  The allocation and initialization of the Core class just allocates the d
 *  tier, in turn creating an empty environment and unknown state of the wor
 *  disconnected from the hardware. To use the emss Core and communicate wit
 *  hardware, the application must call connect(controller,tracker,port) wit
 *  the desired parameters on the Core object, which in turn creates all the
 *  connections between software and hardware, as well as lines of communica
 *  between the appropriate components. When finished, the application is
 *  responsible for calling disconnect() and deleting the Core object.
 *
 *  ========================================================================
 *
 *  Copyright 2008-2009 Daniel Kruesi (Dan Krusi) and David Grob
 *
 *  This file is part of the emss framework.
 *
 *  The emss framework is free software: you can redistribute it and/or modi
 *  it under the terms of the GNU General Public License as published by
 *  the Free Software Foundation, either version 3 of the License, or
 *  (at your option) any later version.
 *
```

0 errors, 2 warnings, 0 others

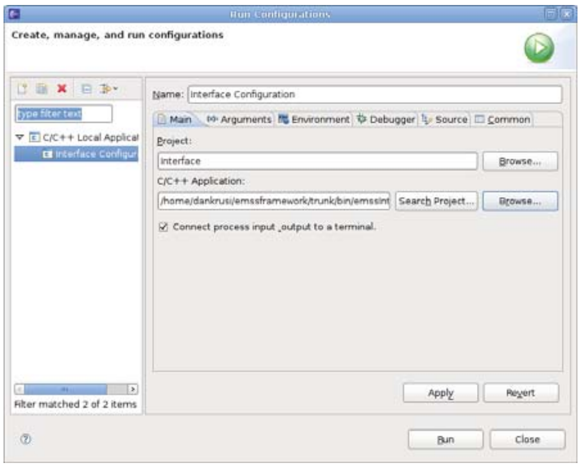
Description	Resource	Path	Location
Warnings (2 items)			

Make Targets for: Core

Target	Location
Qt Release Build	
Qt Debug Build	

Figure 11-5: Import is Complete

The *emss* `.pro` files the binary location defined as `<emss>/bin`. To start an *emss* application after it has been compiled select to "Run" and then "Run Configurations..." from the menu. Create a new Configuration and set the "C/C++ Application" value to the compiled binary file from the `<emss>/bin` directory.



Create, manage, and run configurations

Name: Interface Configuration

Project:
Interface

C/C++ Application:
/home/dankrusi/emssframework/trunk/bin/emssInt

☑ Connect process input ,output to a terminal.

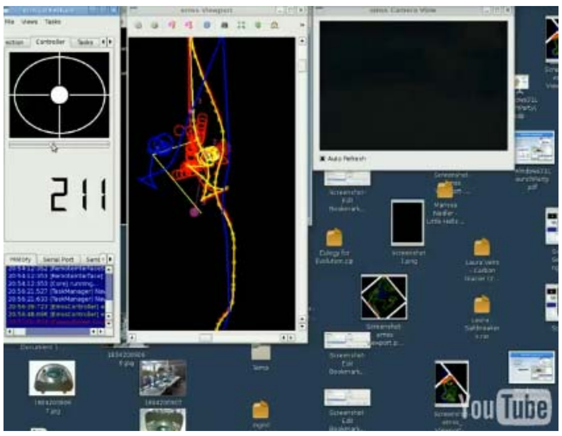
Filter matched 2 of 2 items

Figure 11-6: Create Configuration to run the application

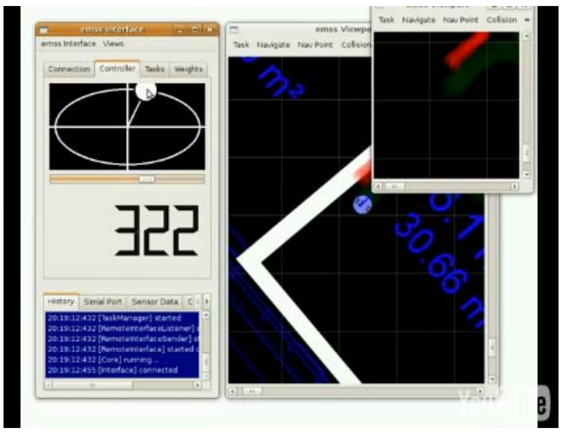
11.7 List of Videos

There are over twenty published videos available of both the *emss* software and hardware in action. These videos are listed here and can be viewed directly at `http://irobotcreate.com/Videos`.

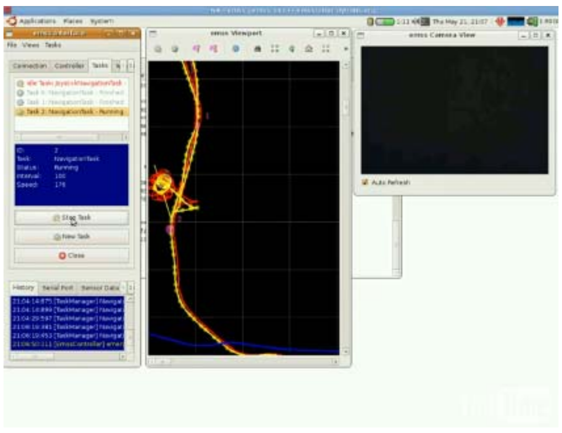
11.7.1 Software



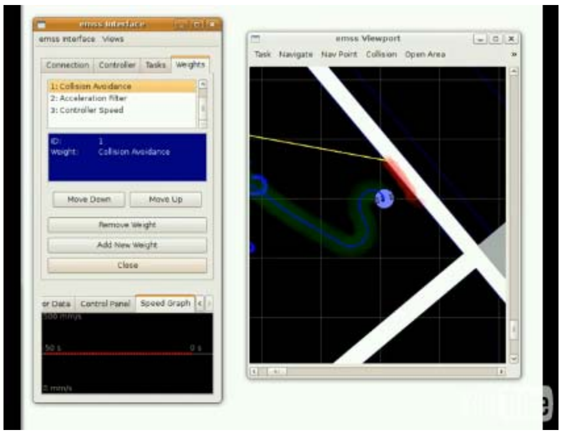
Video 11-1: Roaming around the Hallway via Remote Interface



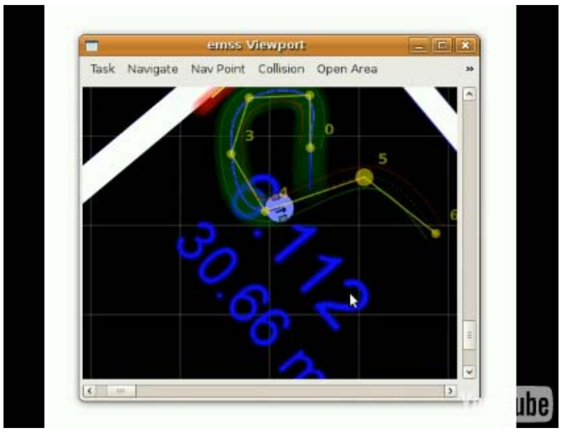
Video 11-3: Using Different Maps And Viewports



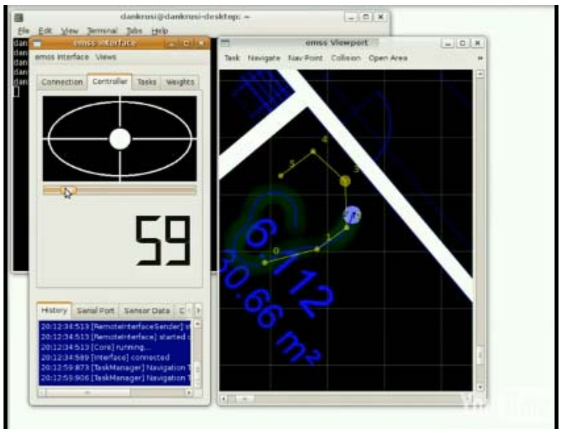
Video 11-2: Roaming around the Cafeteria



Video 11-4: Using And Editing Weights



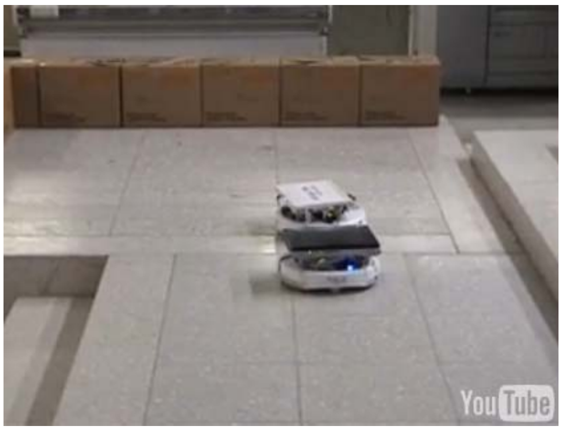
Video 11-5: Navigating By Splines



```
20:12:34:513 [RemoteInterfaceSender]
20:12:34:513 [RemoteInterface] started
20:12:34:513 [Core] running...
20:12:34:589 [Interface] connected
20:12:59:873 [TaskManager] Navigation
20:12:59:906 [TaskManager] Navigation
```

Video 11-6: Driving Around And Setting Nav Point

11.7.2 Hardware



Video 11-7: Two Robots

Video 11-9: Wall-Following

Video 11-8: Driving along Navigation Points

Video 11-10: Presentation Scenario

Video 11-11 Docking Algorithm in Action

Video 11-13: Driving around Outside

Video 11-12: WallFollowerTask followed by Discovery2Task

Video 11-14: Roaming around Outside

11.8 References

Aprile, M., & Denzler, P. (2008). *Diplomarbiet, Indoor WPS.* Rapperswil: Hochschule für Technik.

Bartels, R. H., Beatty, J. C., & and Barsky, B. A. (1998). *An Introduction to Splines for Use in Computer Graphics and Geometric Modelling.* San Francisco: Morgan Kaufmann.

Binder, O. O. (1957, January). You'll own Slaves by 1965. *Mechanix Illustrated* .

Boor, C. d. (1978). *A Practical Guide to Splines.* Springer-Verlag.

Čapek, K. (1921). *Rossum's Universal Robots.* Prague.

Carmo, M. P. (1976). *Differential Geometry of Curves and Surfaces.* Rio de Janeiro: Prentice-Hall.

Catmull, E. a. (1974). *Computer Aided Geometric Design.* New York: Eds. Academic Press.

Chan, C. (n.d.). *Averatec 2100 Series Review.* Retrieved 2008, from Notebook Review: http://www.notebookreview.com/default.asp?newsID=2991

Conte, S., & deBoor, C. (1972). *Elementary Numerical Analysis.* New York: McGraw-Hill.

Fowler, C. B. (1967). The Museum of Music: A History of Mechanical Instruments. *Music Educators Journal* .

Frenet, J. F. (1847). Sur les courbes à double courbure. *Journal de Math* .

Handy, J. (Director). (1940). *Leave It To Roll-Oh* [Motion Picture].

iRobot Corporation. (2006). *iRobot® Create Open Interface.*

iRobot Corporation. (2006). *iRobot® Create Owners Manual.*

Jonathan, K., Jonathan, B., Arvind, P., Omair, K., & Sukhatme, G. S. (2008). *Just Add Wheels: Leveraging Commodity Laptop Hardware for Robotics and AI Education.* Los Angeles: University of Southern California.

Kelly, J., Binney, J., Pereira, A., Khan, O., & Sukhatme, G. S. (2008). *Just Add Wheels: Leveraging Commodity Laptop Hardware for Robotics and AI Education.* Los Angeles: University of Southern California.

Kimberling, C. (1998). *Triangle Centers and Central Triangles.*

Kostandov, M., Schwertfeger, J., & Jenkins, O. C. *Toward Real-time Human Detection and Tracking in Diverse.* Providence: Brown University.

Kostandov, M., Schwertfeger, J., Jenkins, O. C., Jianu, R., Buller, M., Hartmann, D., et al. (2007). *Robot Gaming and Learning using Augmented Reality.* Brown University.

Kostandov, M., Schwertfeger, J., Jenkins, O. C., Jianu, R., Buller, M., Hartmann, D., et al. (2007). *Robot Gaming and Learning using Augmented Reality.* Brown University.

Krüsi, D., & Grob, D. (2008). *Environment Mapping Self-Sustainable Robot.* Rapperswil.

Krusi, D., & Grob, D. (2008). *Environment Mapping Self-Sustainable Robot Proposal.* Zurich.

Krusi, S. (2008). *Modeling Forward Trajectories of a Robot.* College Station: Texas A&M University.

Logitech. (2006). *QuickCam Connect Manual.*

Martinez, D. M., Haverinen, J., & Roning, J. (2008). *Sensor and Connectivity Board (SCB) for Mobile.* Oulu: University of Oulu.

Martınez, D. M., Haverinen, J., & Roning, J. (2008). *Sensor and Connectivity Board (SCB) for Mobile Robots.* Oulu.

Mataric, M. J., Koenig, N., & Feil-Seifer, D. (2007). *Materials for Enabling Hands-On Robotics.* Los Angeles.

Nathan, K. (2007). *Toward Real-time Human Detection and Tracking in Diverse.* iRobot Corporation.

Olson, L. (2008). *Cubic Splines, Bezier Curves.* Urbana-Champaign: University of Illinois.

Runge, C. (1901). Über empirische Funktionen und die Interpolation zwischen äquidistanten Ordinaten. *Zeitschrift für Mathematik und Physik* .

Serret, J. A. (1851). Sur quelques formules relatives à la théorie des courbes à double courbure. *Journal De Math* .

Sharp. (2002). *Sharp GP2D12 IR Range Finder.* Sharp Publishing.

Takacs, B., & Hanak, D. (2008). *Home Robots and Ambient Facial Interfaces.* Budapest.

Thorpe, C., Clatz, O., Duggins, D., Gowdy, J., MacLachlan, R., & Ryan, J. (2001). *Dependable Perception for Robots.* Carnegie Mellon University.

Veblen, O. (1905). Theory on plane curves in non-metrical analysis situs. *Transactions of the American Mathematical Society 6* .

Webb, B. (2001). *Can robots make good models of biological behaviour?* Stirling: Cambridge University Press.

Weisstein, E. W. (1999). Vector. *MathWorld* .

Wood, G. (2002). *Living Dolls: A Magical History Of The Quest For Mechanical Life.*

Yen-Chun, L., Yen-Ting, C., Szu-Yin, L., & Jen-Hua, W. (2008). *Visual Tag-based Location-Aware System for Household Robots.*