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LEHRSTUHL FÜR PERVASIVE COMPUTING

Masterarbeit

ORIGNIAL FORMAT for the title of the work

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Zeitraum: 1.Januar 2010 - 1.Juni 2010

Inhaltsverzeichnis

Abstract

The function of the abstract is to summarize, in one or two paragraphs, the major aspects of the entire bachelor or master thesis. It is usually written after writing most of the chapters.

It should include the following:

- Definition of the problem (the question(s) that you want to answer) and its purpose (Introduction).
- Methods used and experiments designed to solve it. Try to describe it basically, without covering too many details.
- Quantitative results or conclusions. Talk about the final results in a general way and how they can solve the problem (how they answer the question(s)).

Even if the Title can be a reference of the work's meaning, the Abstract should help the reader to understand in a quick view, the full meaning of the work. The abstract length should be around 300 words.

Abstracts are protected under copyright law just as any other form of written speech is protected. However, publishers of scientific articles invariably make abstracts publicly available, even when the article itself is protected by a toll barrier. For example, articles in the biomedical literature are available publicly from MEDLINE which is accessible through PubMed. It is a common misconception that the abstracts in MEDLINE provide sufficient information for medical practitioners, students, scholars and patients[citation needed]. The abstract can convey the main results and conclusions of a scientific article but the full text article must be consulted for details of the methodology, the full experimental results, and a critical discussion of the interpretations and conclusions. Consulting the abstract alone is inadequate for scholarship and may lead to inappropriate medical decisions[2].

An abstract[IGM97, Lev65, MAdR02, Sal89] allows one to sift through copious amounts of papers for ones in which the researcher can have more confidence that they will be relevant to his research. Once papers are chosen based on the abstract, they must be read carefully to be evaluated for relevance. It is commonly surmised that one must not base reference citations on the abstract alone, but the entire merits of a paper.

Kapitel 1

Introduction

[You should answer the question: What is the problem?]

This paragraph should establish the context of the reported work. To do that, authors discuss over related literature (with citations[1]) and summarize the knowledge of the author in the investigated problem.

ToDo: how to make citations

An introduction should answer (most of) the following questions:

- What is the problem that I want to solve?
- Why is it a relevant question?
- What is known before the study?
- How can the study improve the current solutions?

To write it, use if possible active voice:

- We are going to watch a film tonight (Active voice).
- A film is going to be watched by us tonight (Passive voice).

The use of the first person is accepted.

1.1 Motivation

A good introduction usually starts presenting a general view of the topic and continues focusing on the problem studied. Begin it clarifying the subject area of interest and establishing the context (remember to support it with related bibliography).

[1] To cite a work in latex

1.2 Problem definition

Additionally, focuses the text on the relevant points of your investigation and problems that you want to solve, relating them with the first part.

1.3 Thesis/Diplom/Bachelor/Master Structure

Present your work to the reader giving a brief overview of what is going to cover every chapter. Write only general concepts, no more than one or two sentences per chapter should be necessary.

Kapitel 2

Materials and Methods

This section is to clarify the pre-existing tools, defining what was developed in this field until now, and why this tool was used instead of others.

The general structure is the following:

- Definition of the specific tool(s) studied (robots, sensor nodes, smart-phones). When relevant, pre-existing experiments.
- Definition of the context of use (indoor/outdoor, humans/animals/robots, with/without connection).
- Definition of used protocols (How the data are collected, when, etc.)

Kapitel 3

Approach

In our system there are a multiple robots that must handle various tasks. For example, visiting given rooms. To tackele this problem, a communication efficient task scheduling system is designed. This system allicate task according to system resources, including enviroment factors and robot available battery. Once these information is attained, the task scheduling system assign robot a set of task.

- *Robot.* The robot is responssible for executing tasks as well as listen to sensors on its way. It has a rechargeable battery. Robot battery level drops as its moves and rotates.
- *Tasks.* The tasks include two part. The first part is moving to a given position and the second part is either finding a person or recharge itself.
- *Enviroment.* The enviroment is an office area that contains a corridor along the central x axis and 16 rooms located around the corridor. The enviroment model is shown in Figure 3.1. The enviroment factors, such as room location and occupancy possibility help task allocation.

3.1 Architecture Design

As shown in Figure 3.2, the architecture of the system consist of several parts: centralized pool, robot controller, navigation stack, charging station and system enviroment.

- *Centralized Pool.* A centralized pool consist of serveral modules: multi-robot task allocation module, system enviroment state, database, execution and mornitoring. The database contains the room information such as occupancy possible and the tasks. The multirobot task allocation module assign task to robots according to both robot status and system enviroment.

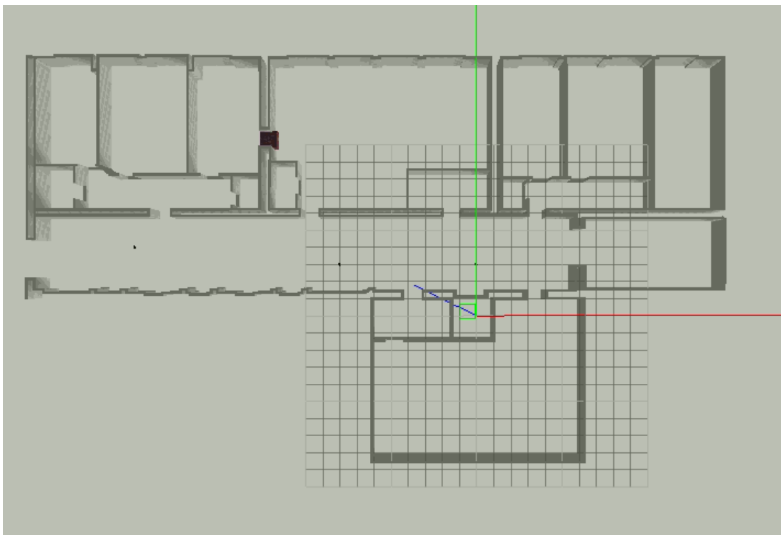

Abbildung 3.1: Gazebo Model

- *Robot Controller.* A robot controller contains serveral modules: execute module and robot action. The execute module receive commands from centralized pool and decide when and which task the robot should perform. During performing a task,a robot can send enviroment information to centralized pool.

- *Navigation stack.* The move_base node provides a ROS interface for configuring, running, and interacting with the navigation stack on a robot. It make robot move to desired positions using the navigation stack. Its advantages includes optionally performing recovery behaviors when the robot perceives itself as stuck.

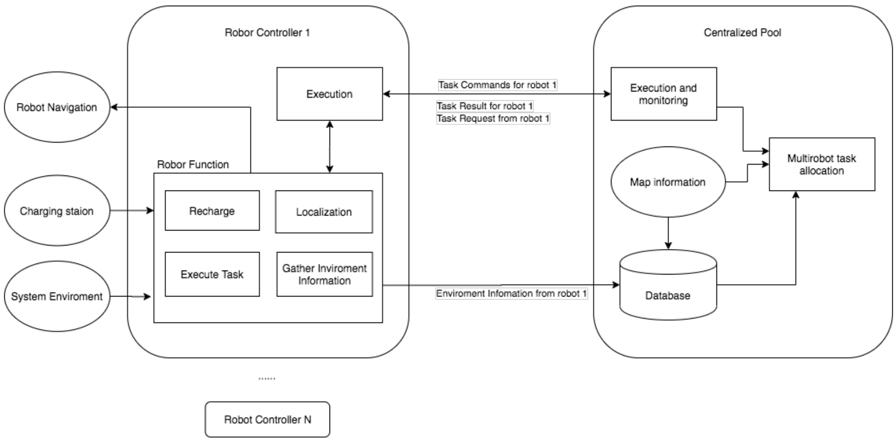

Abbildung 3.2: Multi-robot task allocation and execution system architecture

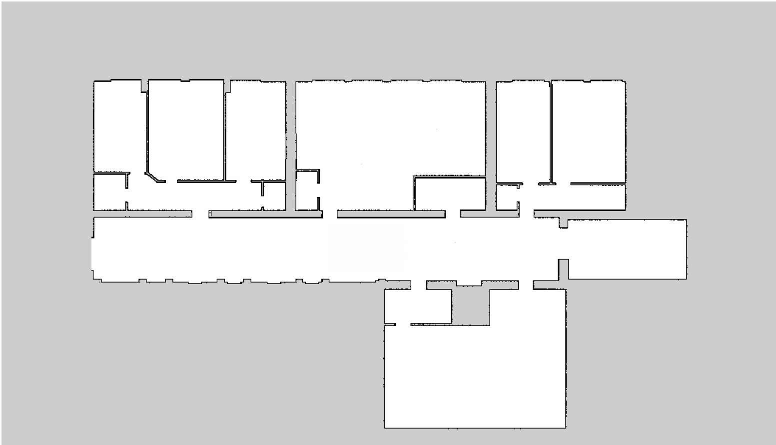

Abbildung 3.3: Enviroment occupancy grid

3.2 System Environment

The system enviroment is an office area. A 3D Gazebo module shown in 3.1, and an occupancy grid is shown in 3.3. The write area is unoccupied, which is the corridor and rooms. The black line is occuppied area, which is the wall. anything else is gray. Following are important objects in system enviroment that interact with robot.

- *Room.* As is shown in Fgure 3.4, the restrict area(the write area in Figure 3.4) is divided into rectangles. The rectangle is used to let the system clearly distinguish which room robot is in.

- *Door.* In 3D Model there are no original doors. However in order to simulate an enviroment, a few simulated sensors are created. Those coordinate of sensors are the same as corresponding doors positions (D1-D17 in Figure 3.5). Additionally one simulated door sensor is created on the door position. Each simulated door sensors brocasts door status periodically. The broadcast message are received by all robot within its range, including both robots enter the room and robots in corridor passing by the door. Figure 3.5 shows the distribution of doors.

- Charging Station. The battery decrease is also considered. Three simulated charging stations are located in the corridor. Figure 3.5 shows the distribution of charging stations. When robot get a charging task, it would move to one of the charging station and wait until fully charged. The details of robot charging is shown in Section . ToDo: Robot charging

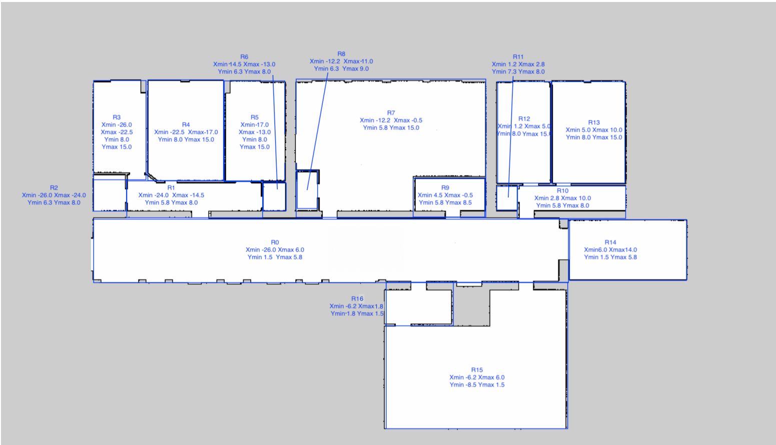

Abbildung 3.4: Room division

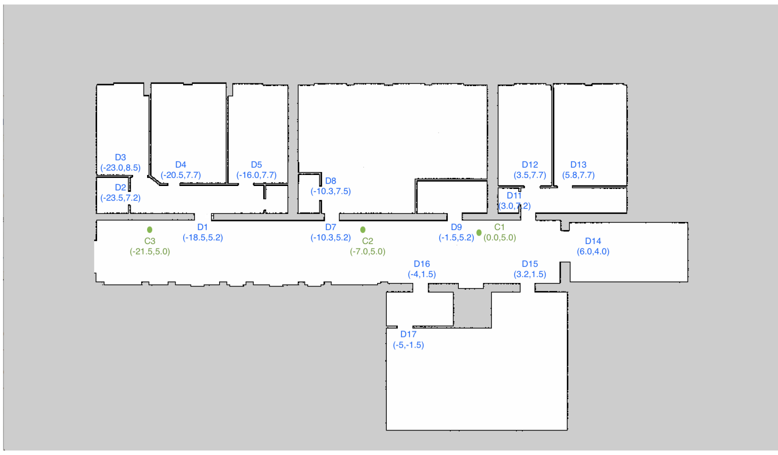

Abbildung 3.5: Doors and Charging Stations

3.3 Task Allocation

3.3.1 Task Explanation

In order to improving overall execution efficiency, one single robot can carry either small task, which make robot move to one position, or large task, which consist of multiple small task. On one hand, to make robot work long hours in office enviroment, recharging is necessary. On the other hand, a robot should gather enviroment information as much as possible, which centralized pool would learn from and make better decision. Therefore, three types of task are defined, which are shown in Table 3.1 and Table 3.2. Task attributes includes task type, target, size, dependency, priority, generator, the way of handle task, start time, finish time.

Task Arribute	Target	Dependency	Priority	Generator
GatherEnviromentInfo	Door	No	1	Centralized Pool
Execute task	Any point	Dependent on execute task	2,3,4	User
Charging	Charging station	No	5	Centralized Pool

Tabelle 3.1: Task arributes part 1

Task Arribute	Start time	Finish time
Explanation	The time when robot start moving	The time when robot finished interacting with the target

Tabelle 3.2: Task arributes part 2

Task Id	Task Type	Start Time	Target Id	Robot Id	Priority	Status	dependency	Finish Time	Description
1	2	10:00:00	10:59:59	0.80	2	RanToCompletion	0	2020-06-01 9:00:00	Succedded

Tabelle 3.3: Task Table in Database

- *Task size.* One single robot is able to carry out one charging task or gather inviroment information task, but can carry multiple execute task, thereby These tasks with dependencies also referred to as small task. The example of small task includes charging task and gather inviroment info task. Those small tasks form a dependency chain, also referred to as a large task. Execute task can be a large task which let the robot move to several positions continuesly.

- *Target.* Targets includes door, point and charging station. When a robot run an gather inviroment information task, it moves to the front of the door and interact with a sensor in door position, without entering the door. When robot run an execute task, the robot moves to a given point ether in corridor or in the room. When robot run a charging task, the robot moves to charging station and interact with charging station.

3.3.2 Execute Task Allocation

With robot information such as positions and avaliable battery provided by robot controller, the multi-robot task allocation module in the architecture should perform multi-robot task allocation. To select a execute task, the following decision variable are considered.

Door Id	Door Status	Date Time
1	1	2020-06-01 09:00:01

Tabelle 3.4: Measurement Result

Door id	Day Of Week	Start Time	End Time	Init Open Possibility	Open Possibility Statistic
1	2	10:00:00	10:59:59	0.80	0.80

Tabelle 3.5: Door Open Possibility

Decision variable

- *Task Priority.* Task priority. Task priority is an important factor that discribes task emergency level. The charging task has the highest priority of 5. The gather inviroment task has a lowest priority of 1. The execute task is determined by users but must be in the range of [2,4].

- *Product of Door Open Possibility.* Because of the limitation of simulation, the door open possibility is used to represent room occupancy. The door open possibility is based on the statistic of door measurement in a specific time period of each working day. The doors that the robot may pass through can be obtained from the map information module. An example of door measurement result is shown in Table 3.4 , an example of door open possibility table is shown in Table 3.5.

- *Waiting Time.* The waiting time is the difference of current system simulation time and start time of the first task to be execute. $T_{waiting} = T_{first\_task} - T_{now}$

- *Battery Consumption.* The Battery Consumption is related to robot trajectory. If a robot get a Large execute task that contains n small task, Equation 3.1 can be used to calculate battery consumption. The centralized pool will send the task with lowest cost to this robot.

$$
\begin{aligned}
&B : Battery\_ConsumptionW : Weight \\
B_{large\_task} &= \sum_{task_0}^{task_n} B_{trajectory} \\
&= \sum_{task_0}^{task_n} \sum_{point_0}^{pont_M} [W_{position} \times position\_variation + W_{angle} \times angle\_variation] \\
&= \sum_{t=task_0}^{task_n} \sum_{p=point_0}^{point_M} [W_{position} \times \sqrt{(x_p - x_{p-1})^2 + (y_p - y_{p-1})^2} \\
&+ W_{angle} \times 2 \times \arccos(w_p)]
\end{aligned}
\tag{3.1}
$$

In conclution, equation 3.2 can be used to calculate cost of a large execute task.

$$
\begin{aligned}
Cost_{Large\_execute\_task} = \frac{W_{battery} \times Battery\_consum}{n} + W_{waiting} \times Waiting\_time \\
+ W_{possibility} \times \prod_{i=1}^{n} Door\_open\_possibility + W_{priority} \times Priority
\end{aligned}
\tag{3.2}
$$

3.3.3 Enviroment Task Allocation

Once robot request a task, The task allocation module select only tasks with cost below the threshold. Once either no task in in database or all tasks cost above the threshold, the task allocation module should create a gather inviroment information task, in order to make more measurement result and forther more inprove the accuracy of door open possibility table. To create a gather inviroment information task, which door should robot visit must be considered. The following factor help task allocation module to select the door.

Decision variable

- *Door Last Update Time.* The last update time is decision variable related to gather inviroment information task.
- *Battery Consumption.* Similar to execute task allocation, the battery consumption is related to trajectory from robot to the door. Equation 3.1 can be used to calculate battery consumption.
- *Whether door is used.* If another robot is going to this door, the value is 0, otherwise the value is 1.

$$
\begin{aligned}
Cost_{door} = {} & \frac{W_{battery} \times Battery\_consum}{n} + W_{time} \times (T_{last\_update} - T_{now}) \\
& + W_{possibility} \times \prod_{i=1}^{n} Door\_open\_possibility + W_{is\_used} \times Is\_used
\end{aligned}
\tag{3.3}
$$

3.3.4 Charging Task Allocation

Once the robot send task request to the centralized pool, and the centralized pool figure out this robot need charging, it should create a charging task for robot. Since there are multiple charging station in the system enviroment (As is shown in Figure 3.5), the centralized pool select a charging station for this robot using the following decision variable.

Decision variable

- *Remain Time.* It describes how long the robot is charging now will take.
- *Battery Consumption.* Similar to execute task allocation, the battery consumption is related to trajectory from robot to the door. Equation 3.1 can be used to calculate battery consumption.

In conclution, equation 3.4 can be used to calculate cost of a charging station. The centealized pool will ganerate a charging task to charging station with lowest cost to robot which requests a task.

$$
Cost_{charging\_station} = \frac{W_{battery} \times Battery\_consum}{n} + W_{time} \times T_{remain} \tag{3.4}
$$

Kapitel 4

Implementation

4.1 Communication Protocols

Centralized pool and robots need to share task information with each other. There are some basic requirement for communication: firstly, robot should initiate the communication once it have finished all task in task queue and get free. This is solve by assigning robot controlller as ROS service client and centralized pool as ROS service server. This mothod unnecessary communication by continuesly broadcasting robot information to everybody including centralized pool. Secondly, robot should forward sensor data to centralized pool while processing a task. This is solved by assigning robot controlller as ROS action server and centralized pool as ROS action client. As is shown in 4.1, an efficent communication protocals is designed. Four types of message are defined: (1)Task request message(Table4.1); (2) Task goal messages(Table 4.2); (3) Task feedback message (Table 4.3); (4) Task result message (Table 4.4).

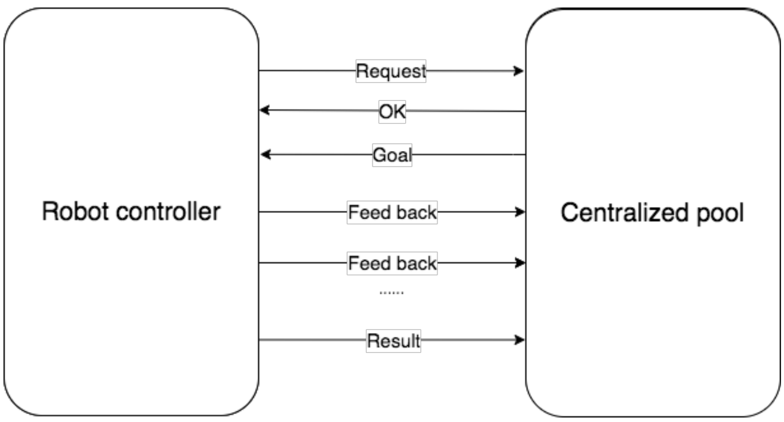

Abbildung 4.1: Communication between Robot and Centralized Pool

Battery	Pose	Robot id
93	(2,4)	1

Tabelle 4.1: Request Message Format and Example

Task id[]	Task type	Target id	Goal[]
1	Gather Enviroment Info	9	(-1.5,5.2) 2020-06-01 9:00:00
[3,4]	Execute task	21,22	(-24.0,12.0), 2020-06-01 9:02:00 (-21.0,12.0) 2020-06-01
5	Charging	17	(0.0,5.0), 2020-06-01 9:04:00

Tabelle 4.2: Action Goal Message Format and Example

4.2 Database structure

4.3 Procedure

Each robot autonomously request task from the centralized pool and centralized pool response with a set of suitable tasks.

4.3.1 Robot

Robor Component The robot component is shown in Figure 4.2. The following are explanations of some robot components.

- *Battery level.* Battery level drops as the robot moves and rotates.
- *Local task queue.* Local task queue keeps a list of tasks that a robot will run sequentially. Once a task is finished, it would be removed from task queue. Once this queue become empty, the robot send task result to centralized pool.
- *New task client.* Once all task are finished, the new task client send request to new task server.
- *Run task server.* The run task server receive tasks and send task feedback and task result.

Robor id	Door id	Measurement time	Measurement result
1	3	2020-06-01 9:00:03	Door open

Tabelle 4.3: Action Feedback Message Format and Example

Task id	Task type	Result
1	Gather Enviroment Info	Success

Tabelle 4.4: Action Result Message Format and Example

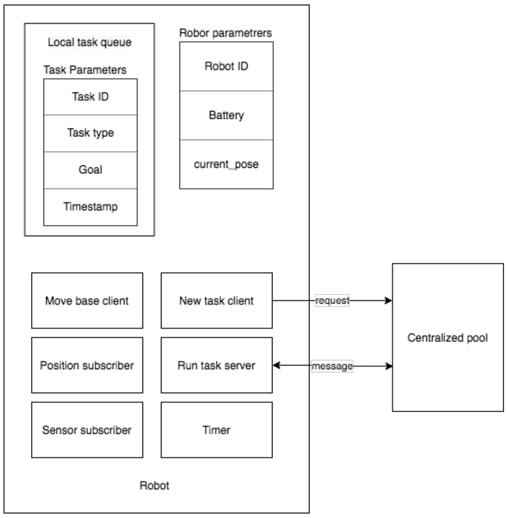

Abbildung 4.2: Robot Components

- *Timer.* To prevent robot to be hanged by one task forever, the timer check the robot moving state periodically.
- *Move base client.* The move_base node provides a ROS interface for configuring, running, and interacting with the navigation stack on a robot. The move_base client send a goal to move_base node to tracking their status
- *Position subscriber.* The position subscriber get robot current position from navigation stack. The robot send its current location to centralized pool to request a new task.
- *Sensor subscriber.* The Sensor subscriber listen to sensor data within the range.

Robor Task Processing

4.3.2 Centralized Pool

- *Map Information.* Map information contains information such as the door list that the robot will pass through when moving to target position.

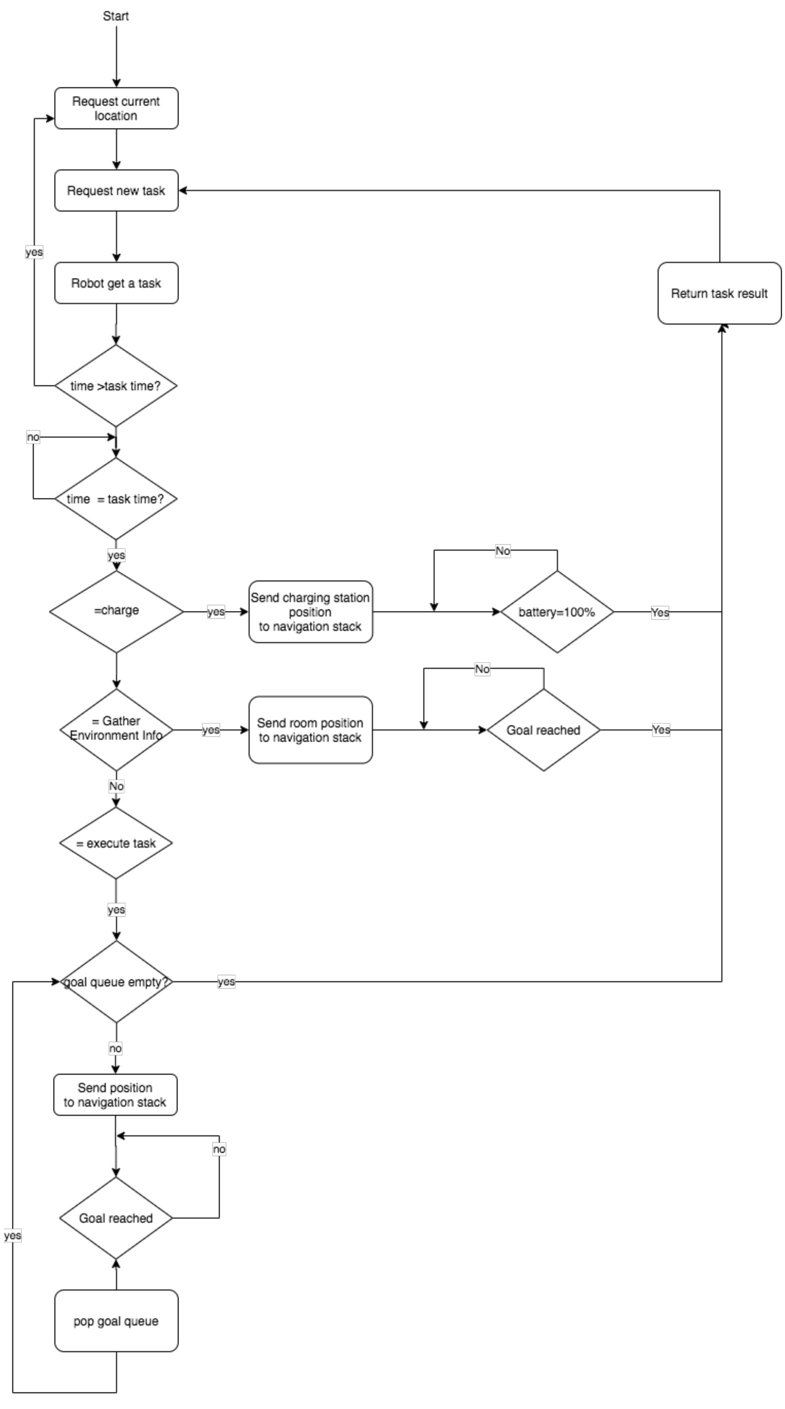

Abbildung 4.3: Robot Task Processing Flowchart

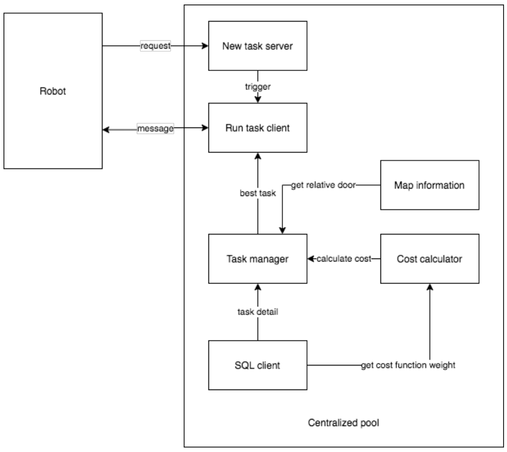

Abbildung 4.4: Centralized Pool Components

- *Cost calculator.* Cost calculator calculate the cost for doors, rooms and charging stations.
- *Task manager.* Task manager can construct, sort and allocate tasks.

4.3.3 Charging Station

Kapitel 5

Evaluation

In this chapter you should describe the previous (if possible) and final experiments performed on the implementation.

Every single experiment should be explained individually, providing to the reader information about the meaning of the experiment, the expected (theoretical) results, the final results, the comparison between them and others (if possible) and the conclusions.

Each experiment should include a description, covering (when possible) the following information:

- Significant physical features (obstacles present on the environment, human presence, temperature, humidity, possible noise sources, computational speed of the machine, etc.)
- The precise location of the experiment (latitude and longitude, room number or citation to a description of the used laboratory).
- Sampling design (variable(s) measured, transformation performed to the data, samples collected, replication, comparative with a Ground Truth system, collecting data protocol).
- Analysis design (how the data are processed, statistical procedures used, statistical level to determine significance).

The provided information should be sufficient to allow other scientists to repeat your experiment in the same conditions. Thus, the use of standard and well-known equipment could only be represented by a simple sentence, but the non-standard equipment should be described in detail, citing the source (vendor) and most important characteristics.

To write it, try to use the third person when describing the experiments and results. Avoid to use first person. Past tense should be the dominant conjugation (the work is done and was performed in the past).

Note: Graphics represent really well data, use them! (Matlab or Octave could be useful for that).

Kapitel 6

Discussion

The meaning of this paragraph is to interpret the results of the performed work. It will always connect the introduction, the postulated hypothesis and the results of the thesis/bachelor/master.

It should answer the following questions:

- Could your results answer your initial questions?
- Did your results agree with your initial hypothesis?
- Did you close your problem, or there are still things to be solved? If yes, what will you do to solve them?

Kapitel 7

Acknowledgements

(This part is optional, and it could be completely excluded by deleting
\include {content/chapters/chapter7}
from the Firstname_Lastname_Diplom_Master_arbeit.tex file)

This paragraph could mention people or institutions that supported you to some extent with your work or friends and relatives that supported you during your study period.

Literaturverzeichnis

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English

I hereby declare that I have written this Bachelor (Master) thesis - except for the guidance of the supervisor - independently, using no other than the specified sources and resources, and that all quotations have been indicated. I declare that I have reported to the best of my knowledge all the relevant information, that it is true and that I concealed nothing. I am aware that a false declaration will be punished according to §156 and §163 par. 1 of the criminal code with a prison sentence or a monetary penalty.

Essen, 22. September 2020
(Ort, Datum)

First Name Second Name