D6.7

Smart warehouse micro-ROS use-case - initial

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Abstract	Report with detailed description for Smart warehouse use case.

Contents

1 Summary

Smart warehouse is complex use-case that intends to demonstrate how micro-ROS can be used in low power wireless network environment. In this use-case, robot mobile platform moves around the warehouse, doing scheduled tasks. This document is basis for use-case implementation, work on actual use-case will continue based on it and results of demonstrations will be documented in the next deliverable.

2 Acronyms and keywords

Term	Definition
ROS	Robot Operating System
GNSS	Global Navigation Satellite System
IMU	Inertial Measurement Unit
UWB	Ultra Wide Bandwidth
SLAM	Simulated Localisation And Mapping
RTOS	Real-Time Operating System
PTZ	Pan Tilt Zoom camera
6LoWPAN	IPv6 over Low -Power Wireless Personal Area Networks

3 Introduction

This document is based on use-case description that was created in D1.7 Reference Scenarios and Technical System Requirements Definition. In D1.7 all of project use-cases were described and requirements were drawn. This document will focus and expand further Smart Warehouse use-case and describes:

- hardware and software components,
- mechanical design,
- details of use-case operations.

This document is basis for use-case implementation, work on actual use-case will continue based on it and results of demonstrations will be documented in D6.8 Smart warehouse micro-ROS use-case release - Final.

Smart warehouse is a complex use-case that intends to demonstrate how micro-ROS can be used in low power wireless network environment. That is also a reason that scenario is both indoor and outdoor, so we can have enough space to have radios going out of range making the network not coherent. It is very important to check how micro-ROS can operate in such environments, as providing good quality network connection over wireless in industrial application is very difficult.

In this use-case, robots roams around smart warehouse, doing scheduled tasks. Those tasks will consist of move to and some interactions with radio controlled devices:

- door,
- lidar,
- light,
- sensor.

Those emulate interactions that warehouse robots encounter:

- open the door (door),
- check if passage is safe (lidar),
- activate machine (light),
- get data (sensor).

World model (global map, with sensor location, walls, doors) is known to robot and is a context for all executed tasks. However there is no real time communication between sensors and actuators - only robot communicates with them. An operator can task the robot if the latter is in range. When the robot was given a task, the mission will continue to be executed without communication with operator. Robot has to communicate with those devices on its own.

Details for use-case operations are described in chapter 7.

To execute this mission, an autonomous platform will be used. Its hardware and software components are described in following chapters.

4 Hardware components

Hardware architecture consists mostly of components that are reused from previous project. The Robot platform used will be customed with different systems. The *Systems* are the components/modules which the robot carries. Some mechanical elements will be created to assemble systems on robot as this exact configuration was never used on PIAP Scout base. Nonetheless, this is only for purpose of integration of existing systems. Newly developed systems are those related to 6LoWPAN network (sensor and actuator nodes) that are required to demonstrate micro-ROS capability. Smart warehouse architecure is shown on figure below.

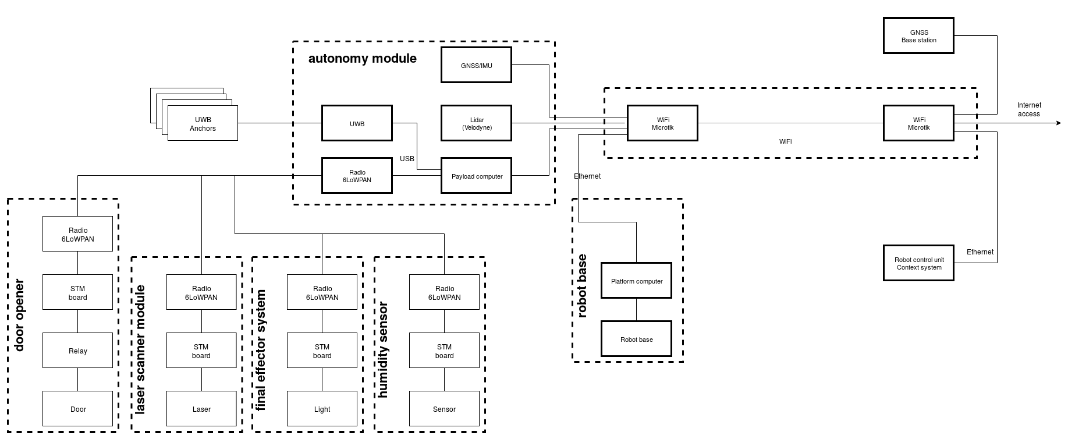

Figure 1: Hardware architecture

Specific components from this diagram are described on following subchapters.

4.1 Robot base

Robot base is a main part of PIAP Scout robot. Generally PIAP Scout is a robot designed for quick reconnaissance of field and hard-to-access places. Owing to its modular structure, it is possible to use it as a mobile platform for this use-case. Other robot features was listed in D1.7.

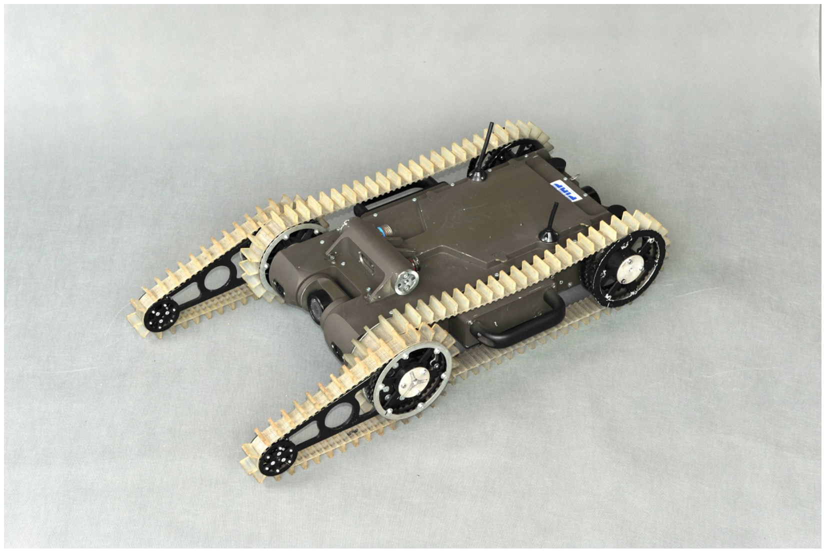

Figure 2: PIAP Scout base

Robot chassis has an integrated platform computer and can be controlled using Ethernet. Contains battery that is used to power all on board equipment. Base also has two integrated cameras (those will not be used in this use-case).

4.2 Autonomy module

The autonomy module consists of additional components mounted on robot chassis that are used to provide autonomous driving capabilities. Contains payload computer that is more powerful that platform computer integrated inside robot chassis and allow us to run mapping, localisation and path planning algorithms.

Localisation system consists of two absolute localisation systems:

- GNSS - satellite localisation system for outdoor use,
- UWB - radio localisation system based on beacons, intended to use indoors.

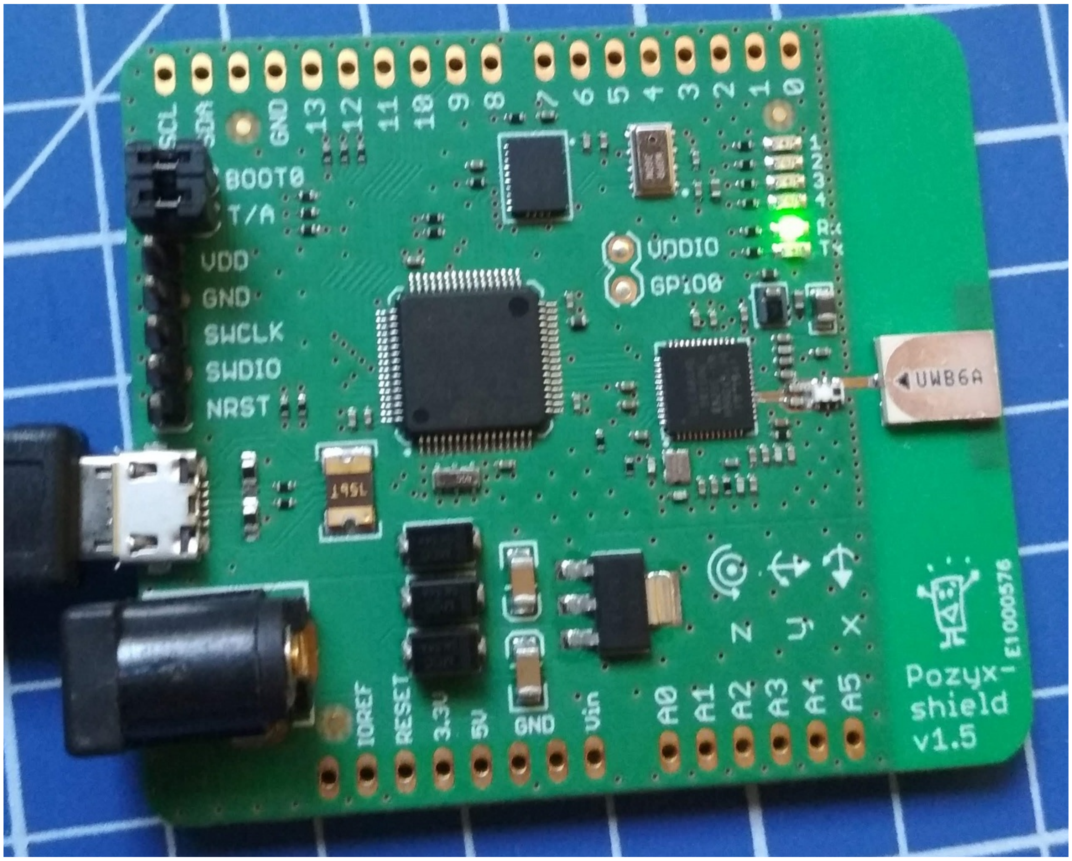

Figure 3: UWB anchor

There is also a Lidar for SLAM[1] or a visual odometry providing precise but relative positioning.

All of above sources are fused and filtered together with data from IMU. Thus from the results of the previous operations, the localisation system provides a coherent platform position and orientation for both indoor and outdoor.

4.3 GNSS Base station

Optionally more precise localisation with GNSS can be used, with real time kinematic correction from base station. In this use-case, this option might be used but only if localisations system will need it, as it requires additional setup.

4.4 Robot control unit & Context system

This is a regular computer connected to system. The operator will use it to provide robot with mission (or tasks). It will also provide robot with required context (world model) to execute the mission.

This is also the main place for monitoring system performance and mission execution status.

Figure 4: Example of robot control unit used in R5COP project (with Scout and MIR robots)

4.5 Radio link (WiFi)

Main communication is using WiFi to communicate with internet and also to send commands to robot (as well as receiving status). It consists of two Mikrotic routers (OmnitikG).

Optionally it can provide connectivity for real time kinematic corrections for GNSS localisation system.

4.6 Sensors and actuators

Below the list of sensors and actuators used in smart warehouse scenario:

- door opener,
- laser scanner module,
- final effector system,
- humidity sensor.

All of them use Olimex STM32-E407 board as it is the reference platform for running micro-ROS.

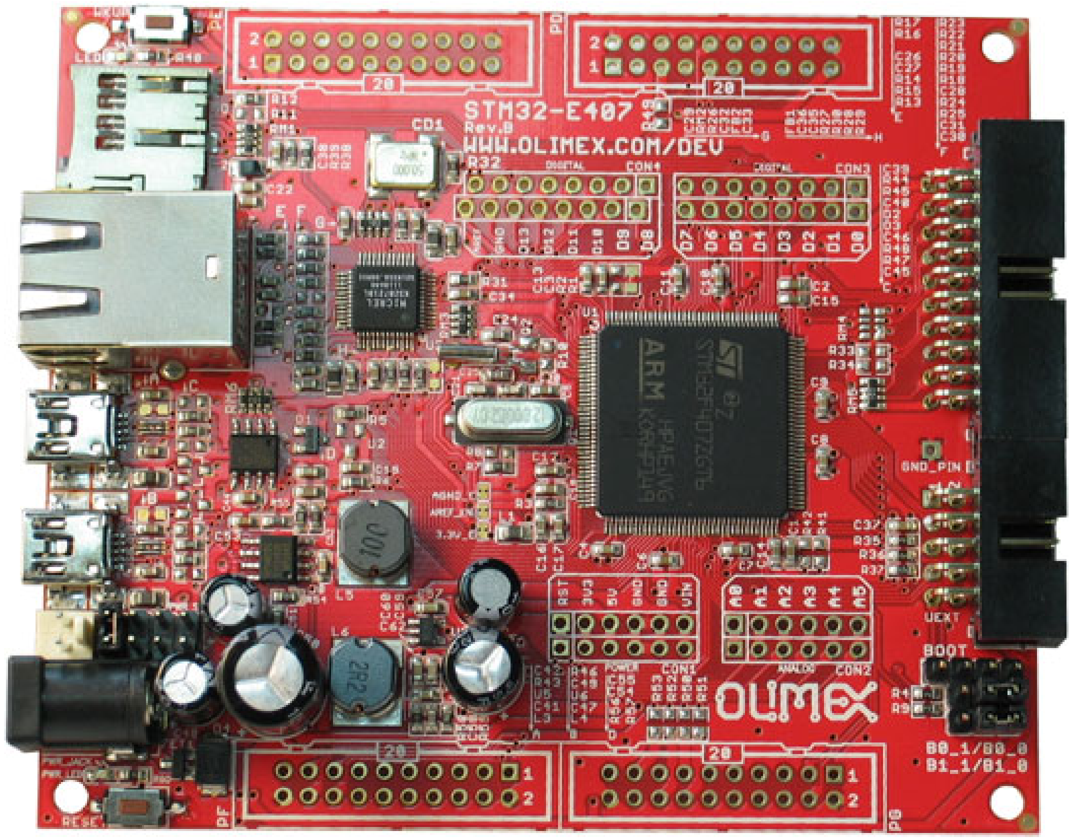

Figure 5: Olimex STM32-E407

Also all of them use Pmod RF2 module for low power wireless communication. The Pmod RF2 adds RF communication through the Microchip® MRF24J40 IEEE 802.15.4™ 2.4GHz RF transceiver module. By communicating with the device through SPI, users can transmit data at speeds up to 625 kbps over the air. Both boards are shown on picture below.

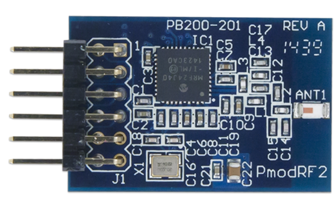

Figure 6: DIGILENT Pmod RF2

4.6.1 Door opener

The door opener is used as an actuator. The module is mounted close to the warehouse door and is used to control its opening and closing. In this case, it controls the original door driver. This module is powered from the mains through the power supply. The communication with robot mobile base will be done by the Pmod RF2 radio module.

Components:

- Olimex STM32-E407
- Digilent Pmod RF2
- Power supply
- Relay module MOD-02170

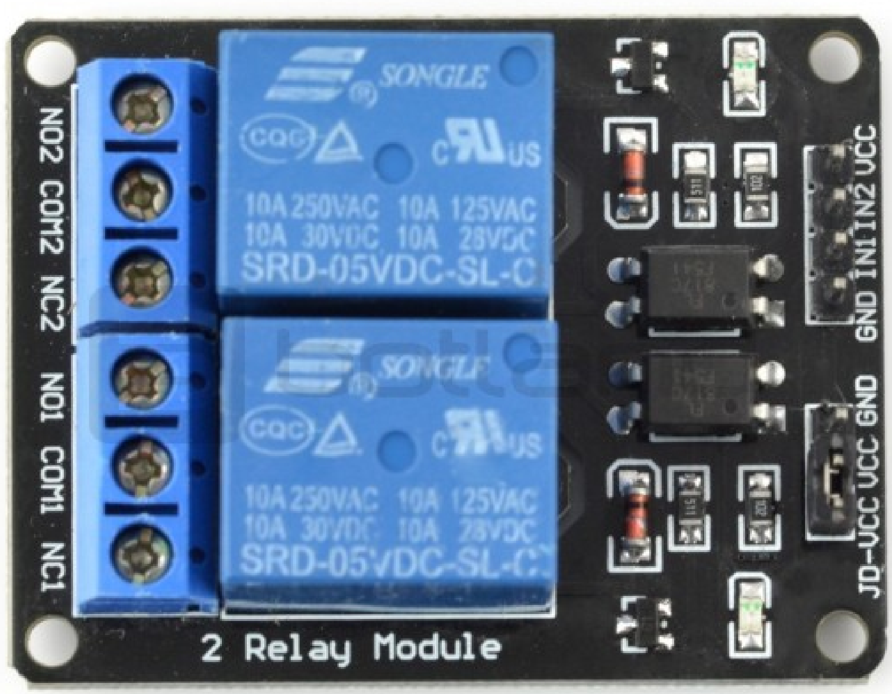

Figure 7: MOD-02170, source: https://botland.com.pl/pl/przekazniki/2170-modul-przekaznikow-2-kanaly-z-optoizolacja-styki-7a240vac-cewka-5v.html

Figure 8: Original door driver

4.6.2 Laser scanner module

Contrary to marketing, the TFMini is Time-of-Flight Infrared Rangefinder, not Lidar. It will be connected to STM32-E407 board and powered from it. Communication with robot mobile base will be done by Pmod RF2 radio module. Whole module will be powered from mains using power adapter. This is intended for checking if intersection is free.

Components:

- Olimex STM32-E407
- Digilent Pmod RF2
- Power supply
- TFMini Micro Lidar Module

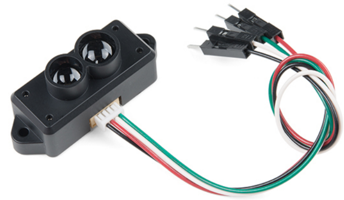

Figure 9: TFMini, source: https://www.sparkfun.com/products/14588

4.6.3 Final effector system

The module actuator is an amber warning light. It is turned on and off directly by Olimex STM32-E407 board and NMOS transistor circuit. Final effector will be powered from battery by default or optionally from mains and the power adapter. Light is used for indication of scenario status.

Components:

- Olimex STM32-E407
- Digilent Pmod RF2
- Battery or external supply
- NMOS transistor circuit instead of relay
- Amber warning light

Figure 10: LED amber warning light, source: http://www.strobos.pl/pl/produkt-p35.html

4.6.4 Humidity sensor

This module is used to measure the humidity and temperature in the warehouse. It is battery-powered. This module is suitable to test at the same time micro-ROS stack, microcontroller (STM32) sleep modes and low power communication. IT uses Honeywell HumidIcon Digital Humidity/Temperature Sensor HIH6130. Communication with the HIH6130 is achieved over I2C.

Components:

- Olimex STM32-E407
- SEN-11295 (HIH6130)
- Digilent Pmod RF2
- Battery

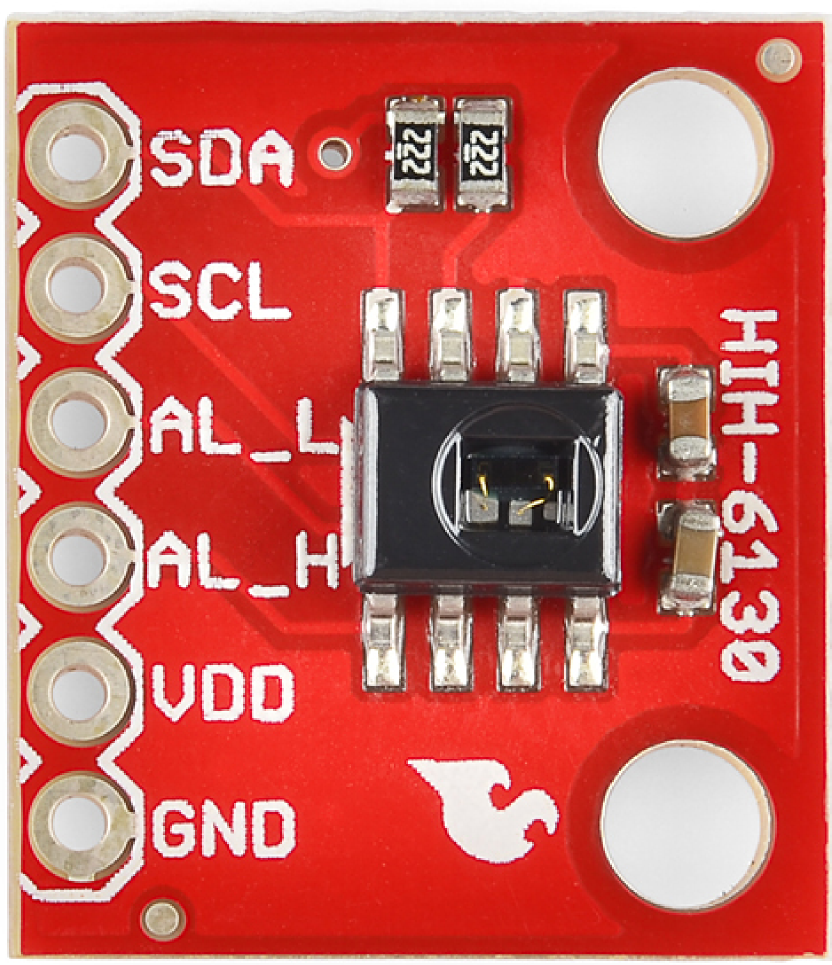

Figure 11: SEN-11295, source: https://www.sparkfun.com/products/11295

5 Mechanical design

5.1 Robot

On the visualisations a mobile base with payloads is shown. A robot manipulator as well as a PTZ camera are optional. The payload is mounted on a mobile platform in a way that ensures secure fixing and reliability. The robot mobile base and its payload modules were described in the chapters above.

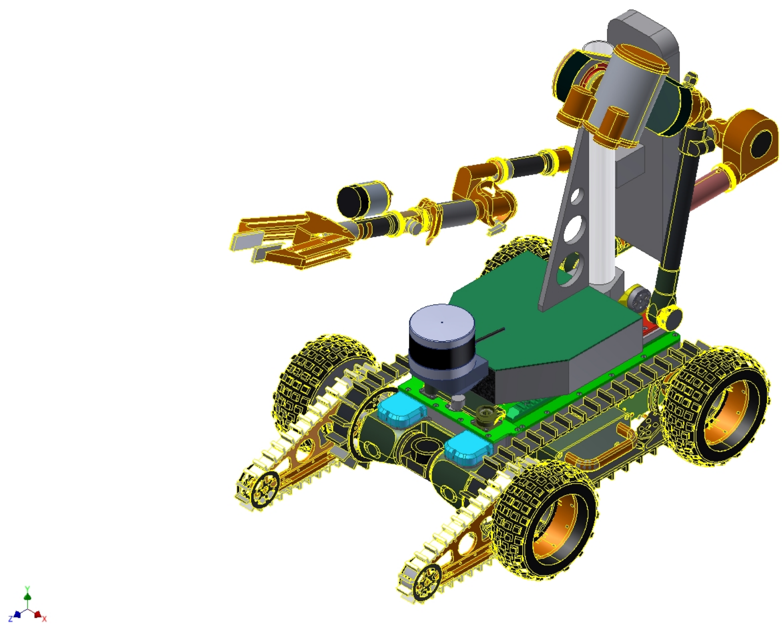

Figure 12: Mechanical design

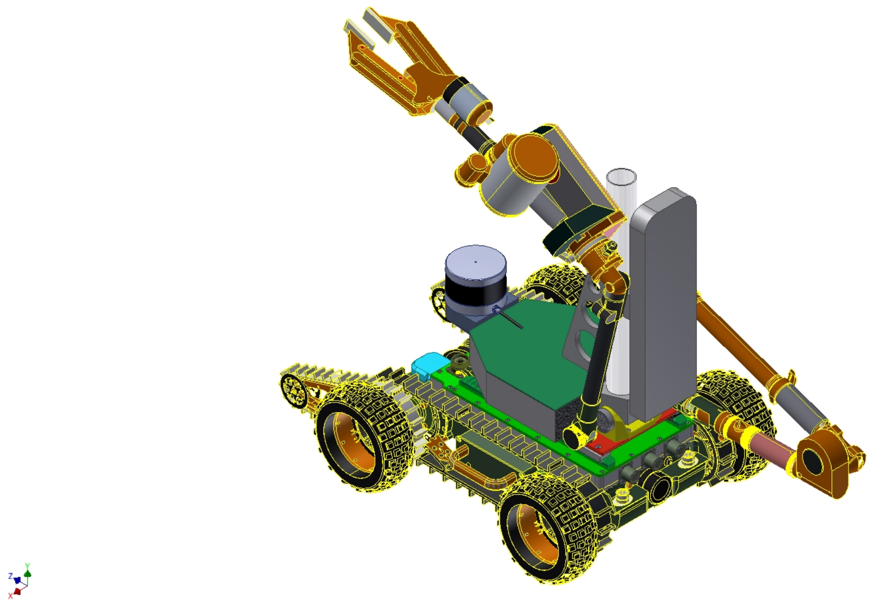

Figure 13: Mechanical design

5.2 Sensors

Each sensor component will be mounted inside a plastic box, for example: HAMMOND 1554V2GYSL.

Figure 14: HAMMOND 1554V2GYSL, Source: https://pl.mouser.com/ProductDetail/Hammond-Manufacturing

The box must provide protection against rain and other unfavorable weather conditions, especially for modules placed outside the warehouse. It has a transparent cover so that we can easily check the status of the device without having to disassemble it.

6 Software components

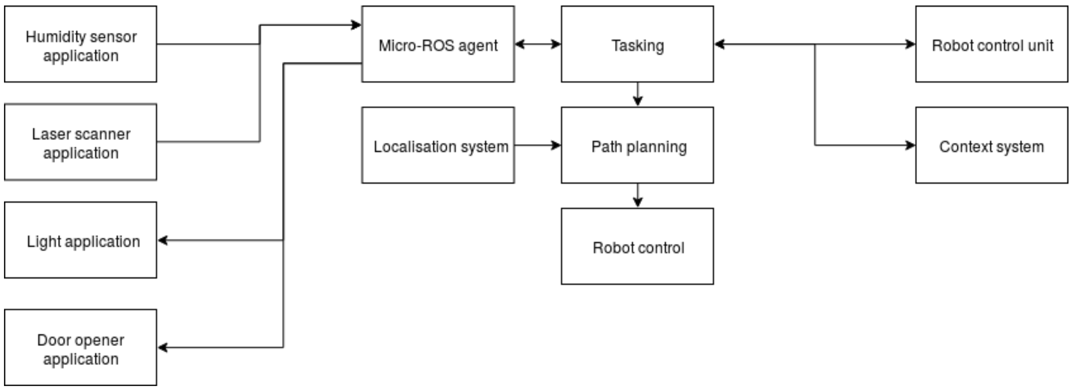

Figure 15: Software architecture

Similar to hardware components, most of software components will be reused. Including most complex ones like localisation and path planning.

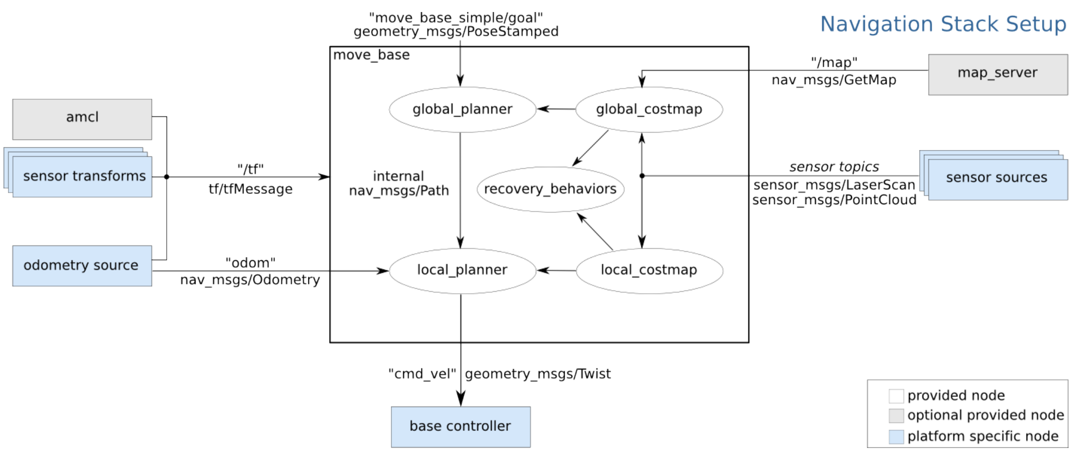

Figure 16: Navigation stack setup. Source: http://wiki.ros.org/move_base[2]

6.1 Component description

This section deals with the software components that will be used for the use-case and aren't reused (like autonomy module).

6.1.1 Humidity Sensors application

The Humidity sensor software component will be running on the embedded reference platform (Olimex STM32-E407). The driver for this software is available in the NuttX operating system and an example application is available to ease the development. The humidity sensor will be running on the reference hardware board. An additional 6LoWPAN device with its stack will be running on the same board.

A micro-ROS node will be available and publish information on a specific topic. This topic will be read by the Robot mobile platform.

6.1.2 Laser scanner application

As described earlier, there will be one laser scanner hardware components to detect if area is empty. The software will be similar except the topic's onto which the node will publish the information (to differentiate them).

The laser scanner driver is available in the NuttX tree. A software example application exists to ease the development. A laser module will is composed of 3 parts:

- laser scanner drivers
- 6LoWPAN stack to communicate
- micro-ROS node

The micro-ROS node will be in charge of publishing the information received from the laser scanner. The information from the laser scanner will be displayed on a specific topic.

6.1.3 Light application

The light application will be in charge to received information from outside. The driver to switch on the light is very simple to write in NuttX. It will just switch on/off a hardware relay. No application is available yet but the time to develop shall be very short.

The light application component consists in 3 software parts:

- driver to interact with the relay
- 6LoWPAN stack to communicate
- micro-ROS node that will subscribe to a specific topic and take action depending on the value received within the topic subscribed

The information is binary on/off.

6.1.4 Door opener application

The door opener software will be in charge to receive information from the mobile platform validate that information and interact with the door.

The door opener application component consists in 4 software parts:

- software driver will be interacting with the door's relay to open or close it
- in addition to the software driver, a 6LoWPAN stack to communicate

- software application to validate a token received from the mobile platform
- micro-ROS node

The micro-ROS node will subscribe to a topic where the token can be received. The received token must be validated. The token will be validated by the Fiware server by interacting with the context system, or locally by checking the signature against public certificates.

6.1.5 Scenario logic

Mission logic will be developed as state machine, and executed on robot payload computer. It will allow us to configure specific tasks order and dependencies into missions described in next chapter.

Operator will execute missions using robot control unit, or using connection to Fiware context broker. Mission status will be reported both to robot control unit and Fiware context broker.

7 Operation

In this chapter use-case scenarios are described. It is described here how the mobile base will move, with which sensors and actuators will communicate and what actions will be performed.

7.1 General scenario

A specially adapted laboratory hall will simulate the warehouse. In its corners, the nodes of the in-house location system based on UWB modules will be installed. The robot mobile platform can go to the warehouse door in the meantime collecting data from the sensors like humidity sensor and lidar according to planned tasks. After reaching the gate it can be opened using an actuator with which we also communicate using 6LoWPAN and a micro-ROS stack. To get the final effector robot mobile base has to cross the road, so it must check whether crossing the road is safe.

The warehouse plan can be found in the diagram below:

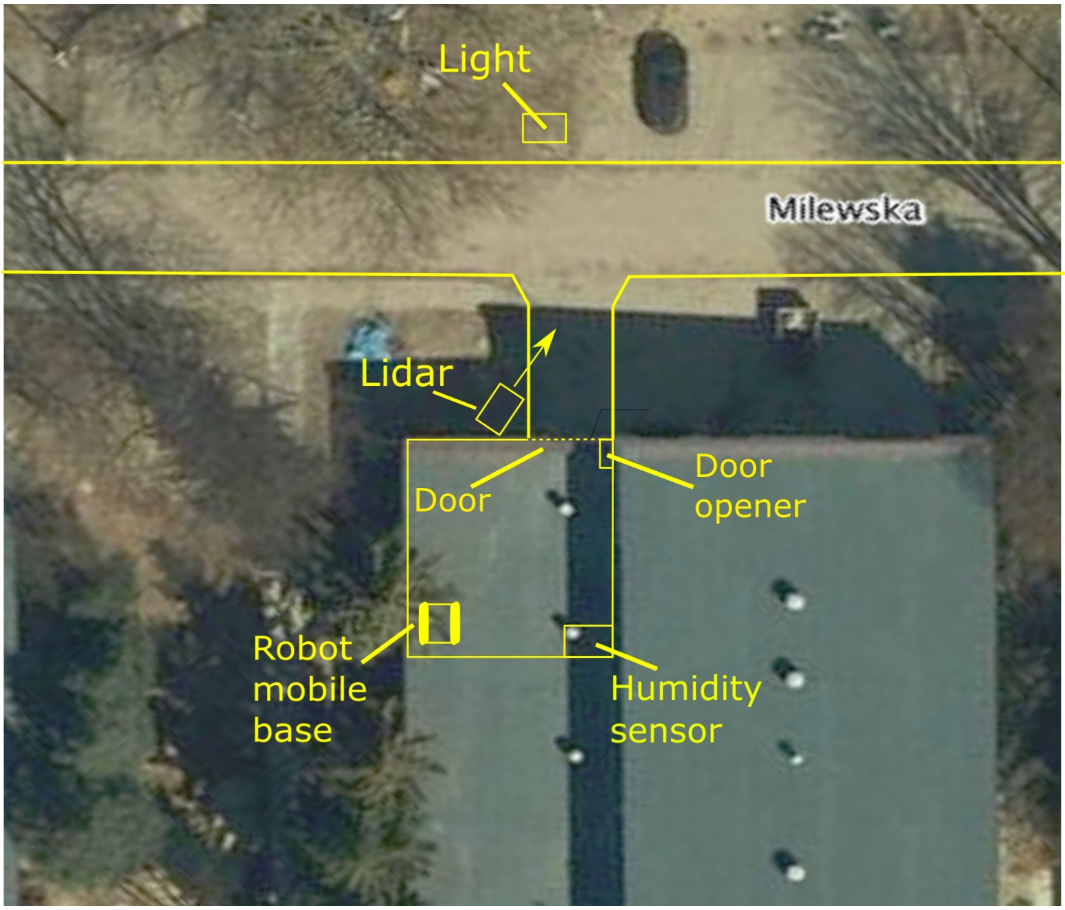

Figure 17: Warehouse plan

From outside warehouse looks like:

Figure 18: Warehouse door

The door is opened up.

Figure 19: Warehouse outside

In the picture you can see a temporary construction with scaffolding, which will not be used in the use-case.

7.2 Missions

The robot will perform specific missions according to the developed scenario. The task for the robot is set in the mission planner. Mission are focused on presentation of micro-ROS features. In the all missions, the micro-ROS stack will be used to communicate with the humidity sensor, door opener, lidar and lamp (final effector).

7.2.1 Mission 1

Mission 1 is performed according to the simplest scenario taking into account communication with all sensors and actuators used in the use-case.

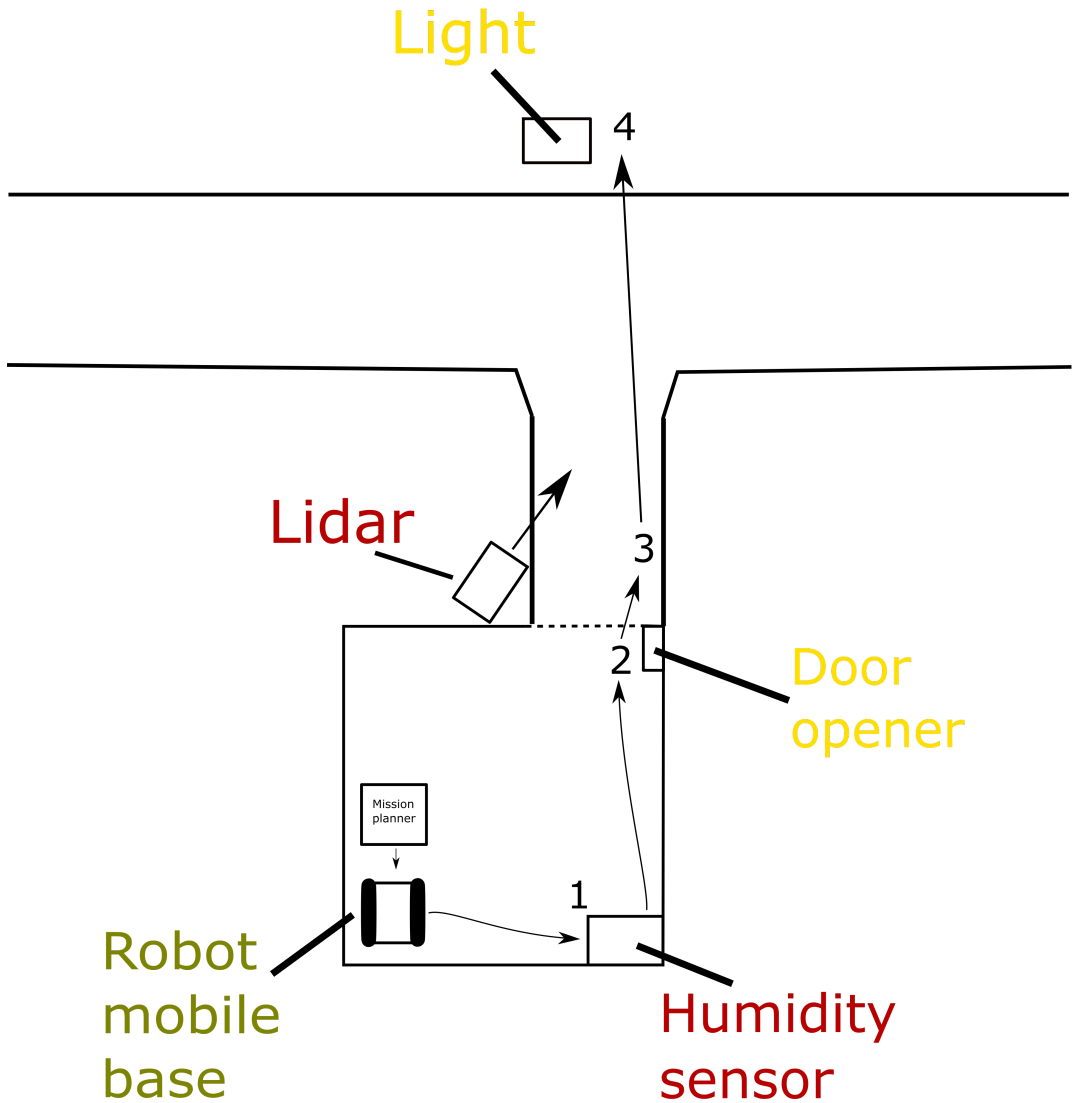

Figure 20: Mission 1

Mission 1 consists of the following steps:

- approach the humidity sensor (1) and obtain the measurement,
- go towards the warehouse gate (2) and after communication with the door opener and their opening, the platform moves towards the road,
- the lidar next to the road provide information (3) to the platform whether the road is empty and we can go,
- after crossing the road and reaching the lamp, the platform sends command to the lamp to switch it on,
- stop and wait for the next task.

This mission is focused on evaluating the communication and the correct operation of sensors and actuators. Also, the correct operation of sleep modes will also be checked.

In the first task (approaching the humidity sensor) robot mobile base moves near to the humidity sensor and try to connect to it. After obtaining the connection, the measurement results are sent from the sensor to robot. Then robot mobile base goes towards the door. Like before connection is established with the door opener. Door opening procedure is additionally secured, so only after confirming that the robot is authorized to open these door the gate is opened. After door opening we have to ensure that exit is clear and there is no obstacles. This is checked by lidar placed outside the warehouse. Now robot mobile base can go to the lamp - final effector. After approaching final effector, it remotely lights the lamp.

7.2.2 Mission 2

Mission 2 is an extension of Mission 1 and takes into account a more realistic scenario that could happen in a real warehouse.

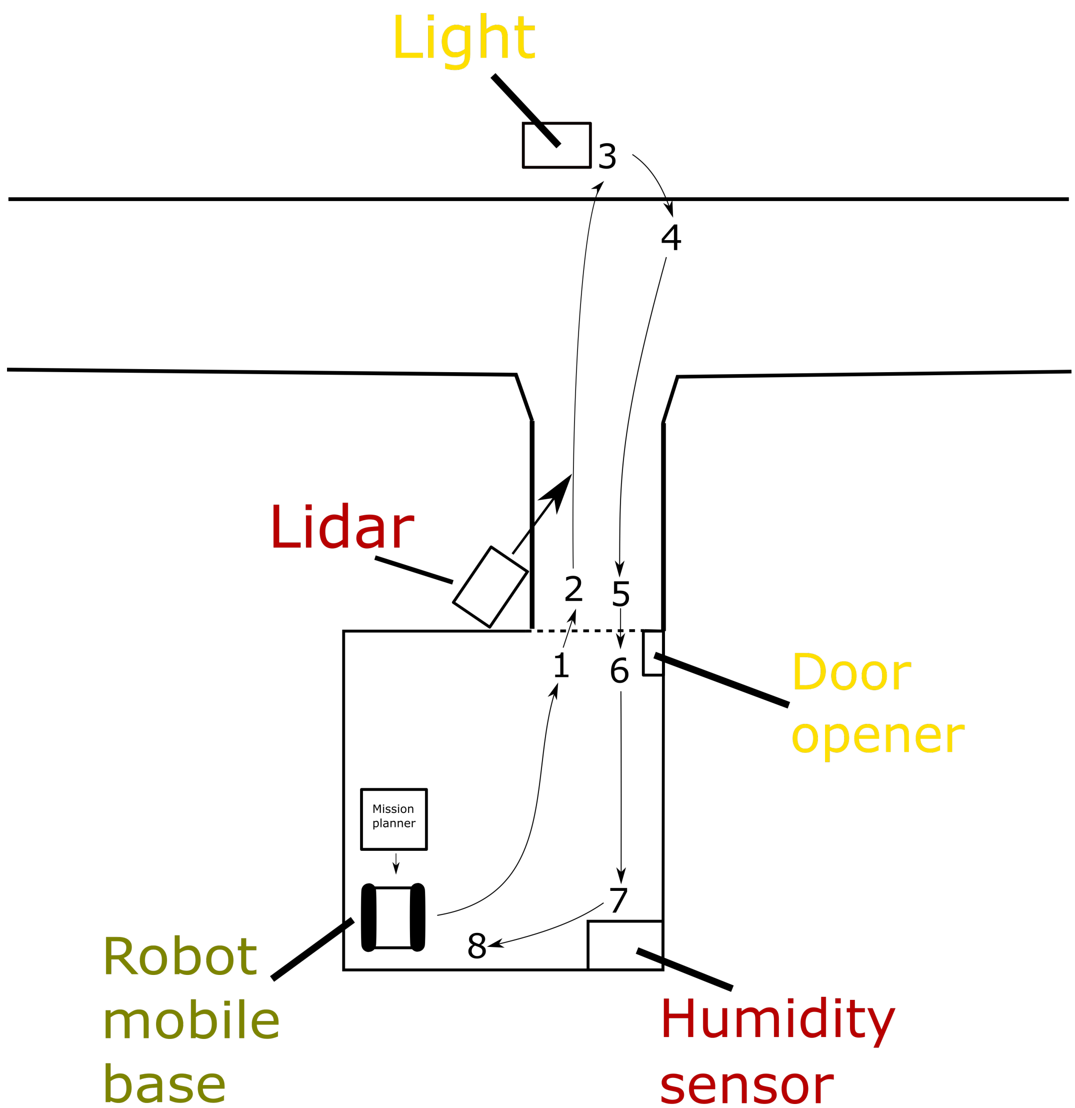

Figure 21: Mission 2

The Mission 2 consists of the following steps:

- go to the warehouse door, stop and open the door (1),

- go outside the warehouse, stop, close the door and check if crossing the road is safe (2),
- then go to the lamp and switch it on (3),
- turn back and drive towards the warehouse, check if the road is empty (4),
- open the door (5),
- pass through the warehouse gate and close the door (6),
- check humidity in the warehouse (7),
- finish the mission near the place from where we started (8).

This mission is focused on the operation of the mission planning system, therefore the mission is more complex. The number of tasks is sufficient to show the advantages of micro-ROS usage.

Mission 2 operations are similar to Mission 1, but the route is more complicated. First we go to the door. Similar to the previous case we have to confirm that we are authorized to open it. Go outside, close the door, check if we can safely cross the road and go to the final effector. Switch it on and go back to the warehouse, open the door and close it again. After return to the warehouse check if the humidity and temperature are still correct, because they could change after opening the door. Finally, stop the robot mobile base and wait for the next tasks.

8 Conclusions

This use-case presents the possibilities of effective use of micro-ROS tools. It shows how simple is possibility to combine basic elements such as sensors and actuators based on microcontrollers to a larger system such as the ROS/ROS2 environment. It will also enable verification of the project assumptions in the field like:

- minimal average power consumption by micro-ROS nodes,
- advanced sleep modes,
- simplicity of implementation in ROS/ROS2 systems,
- ability to run on the restricted resources modules,
- operating in not coherent network environment.

References

[1] 'Simultaneous localization and mapping'. [Online]. Available: https://en.wikipedia.org/wiki/Simultaneous_localization_and_mapping

[2] 'ROS move base'. [Online]. Available: http://wiki.ros.org/move_base