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# NAVIGATION OF ROBOTICS PLATFORM IN UNKNOWN SPACES USING LIDAR, RASPBERRY PI AND HECTOR SLAM

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## ABSTRACT

This research is a base research of an alternative type navigation for our project ARES – Autonomous Research Exploration System. This system is focused on exploration of dangerous indoor spaces like caves, abandoned mines, ruins etc. In manycases, there is poor or no signal from satellite navigation systems and it is necessary to develop accurate navigation for our platform. Our platform is based on several systems like navigation using an inertial navigation unit, visual odometry and 3D space mapping. The result of our system will be a 3D map of space. The developed 3D space mapping needs accurate position for creation of a space map. This paper deals withdevelopment of an alternative position estimation method and implementation of LIDAR sensor and Raspberry PI for 2D space mapping.

**Keywords:** Robot navigation, Exploration system, Space mapping, SLAM

## INTRODUCTION

This paper is base research of an alternative type of navigation and space mappingfor our project ARES. The project ARES is focused on preparing a 3D space map and navigation of a robotics platform in unknown areas. In exterior places, researchers can use a satellite navigation system, which has high precision of position estimation, typically better than 3 meters. In case of an augmentation system like WAAS (Wide Area Augmentation System) in the USA, or like EGNOS (European Geostationary Navigation Overlay Service) in Europe, precision of position estimation is at centimeterlevel (Beran et al, 2014),

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(Jonasand Mandlik, 2013). The precision of these systems highly depends on several conditions like ionosphere or clock error etc. The precision of position estimation using GPS is highly decreased by ionosphere disturbances. The influence of the ionosphere is described in (Rejfek et al, 2014). Unfortunately, in our research we are focused on unknown interior spaces, and in thiscase, satellite navigation is unsuitable due to lots of signal dropouts.

An alternative navigation system is based on RFID tags. This system is based on RFID tags situated in specific positions in buildings, typically on crossroads(Park and Hashimoto, 2009), (Peng and Dong, 2012). This system is suitable for navigation of robotic platforms in known areas because this type of navigation needs preprocessed navigation map,s and this type of navigation is unsuitable for our research.

An alternative system is based on Wi-Fi signal measurement and estimation of position in buildings. This system is described in detail in (Salamah et al, 2016)

The implementation of Hector SLAM for car-like mobile robot navigation is descripted in (Brahimi et al, 2016).An alternative research, based on mapping of space using ROS and SLAM for cooperative robot navigation is descripted in (Reid et al 2013).

At present, our system is divided into two sections. The first section is based on development of accurate navigation for robotic platforms, andthe second section is focused on developing a device which will be able to create an accurate 3D space map.Our 3D space mapping system is based on a self-developed space scanner.The 3D space mapping system is described in detail in (Chmelar et al, 2014). The latest results of development were published in the paper (Chmelar et al, 2017).This system needs accurate position tocreate aprecise 3D space map. The 3D space mapping system needs precision ±30 cm or better. When precision is worse, the mapping system is not able to synchronize a 3D space map. Only in this case, our scanning system can synchronize frames and calculate an accurate 3D space map. Also, if our space mapping system is synchronized, the system can provide relative position estimation with comparison to the previous measurement. This system can be used as alternative position estimation.

The accurate position estimation is provided using sensor fusion like visual odometry and an inertial navigation unit. These data streams are filtered using a Kalman filter. Application of sensor fusion is described in detail in (Beran et al, 2015), (Beran et al, 2016). For better position estimation and 2D space mapping we are developing an alternative position estimation system. Development of this alternative position estimation system based on LIDAR and SLAM is described in this paper.This alternative position estimation and space mapping will be used as fusion of sensors in the final system.

The Hector SLAM is selected for use in our research, because this method provides independent, accurate and reliable type of navigation. Also, Hector SLAM provides big advantage for the navigation of robotics platform, because this type of SLAM needs only one sensor(LIDAR). Other navigation methods, for examplemonocular visual odometry needs camera and gyroscopes for precision navigation.

## SLAM

The SLAM (simultaneous localization and mapping) is a system based on real-time space mapping. The base of this method was developed in the early nineties by (Leonard and Durrant-Whyte, 1991). Nowadays mapping methods are significantly expanding due to development of powerful and compact devices like the Raspberry PI. Nowadays, using of SLAM is rapidly increasing, for example, in systems of obstacle detection in intelligent car driving. Also SLAM is used for 3D modelling of objects, like historical buildings etc. An example of this 3D modelling is shown inFig.1. In our research we are using Hector SLAM

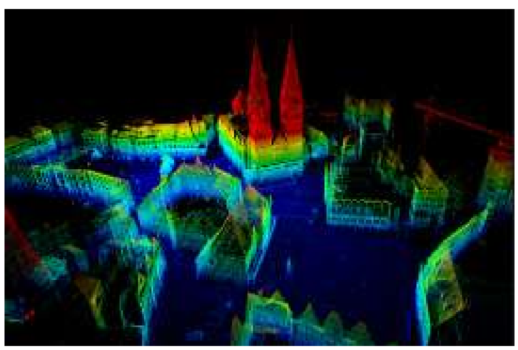


**Fig.1.** Object modeling using Lidar and SLAM(Nuechter, 2016)

## HECTOR SLAM

The Hector SLAM is an open source implementation of the 2D SLAM technique. This method is based on use of a laser scan (in our case from LIDAR) to create a grid map of the surroundings. The benefit of hector SLAM in comparison to other methods of SLAM is: Hector SLAM doesn´t require odometry information. The pose of a robotics platform is estimated only from scanned data. The high update rate and accuracy of LIDAR, provides fast and accurate pose estimation.

The Hector SLAM matching algorithm is based on Gauss-Newton approach method which is described in detail in (Lucas and Kanade, 1983). The matching algorithm tries to find optimal pattern matching of laser scans with a constructed map, by finding the rigid transformation (1). This transformation is minimalized using equation (2).

$$\xi = (px, py, \Psi)^T \qquad (1)$$

$$\xi^* = \min_{\xi} \sum_{i=1}^{n} \left[1 - M\left(S_i(\xi)\right)\right]^2 \qquad (2)$$

Where the function $M\left(S_i(\xi)\right)$ returns map value at $S_i(\xi)$ – endpoint scan world coordinates.

$$\sum_{i=1}^{n} \left[1 - M\left(S_i(\xi + \Delta\xi)\right)\right]^2 \rightarrow 0 \qquad (3)$$

Where ξ is starting estimate, $\Delta\xi$ is the step transformation, which can be estimated by optimizing the error using (3).

Applying the first Taylor expansion and using partial derivate with respect to $\Delta\xi$ to zero yields the Gauss-Newton equation for minimalize process; we get the equation (4).

$$\Delta\xi = H_{inv} \sum_{i=1}^{n} \left[\nabla M\left(S_i(\xi)\right) \frac{\partial S_i(\xi)}{\partial \xi}\right]^T \left[1 - M\left(S_i(\xi)\right)\right] \; (4)$$

Where

$$H_{inv} = \left[\nabla M\left(S_i(\xi)\right) \frac{\partial S_i(\xi)}{\partial \xi}\right]^T \left[\nabla M\left(S_i(\xi)\right) \frac{\partial S_i(\xi)}{\partial \xi}\right]^{-1} (5)$$

**ROBOTICS PLATFORM AND OUR SYSTEM**

Fig.2shows our robotics platform used in our research. The robotics platform contains a laser ranging system (LIDAR) model URG-04LX. The parameters of our scanning device are written in Table 1. The robotics platform is based on a crawler chassis and Raspberry PI 2. The robotics platform is wireless controlled using Wi-Fi. The detailed information about our system is written in Table 2.

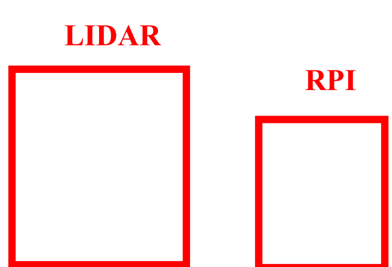


**Fig.2.** Our robotics platform

**Table 1.** Scanning device parameters

| Scanning device - LIDAR | |
|---|---|
| Model | Hokuyo URG-04LX |
| Scan range | 20 - 4000 mm |
| Angle scan range | 240° |
| Angle resolution | 0,36° |
| Samples per one scan | 683 samples |
| One scan time | 100 ms |
| Wavelength of laser | 785nm |

**Table 2.** Our system parameters

| System Parameters | |
|---|---|
| Model | Raspberry PI 2 |
| CPU | 32 Bit ARM Cortex-A7 Broadcom BCM2836 4x900MHz, 1GB SDRAM |
| OS | Ubuntu Mate 16.04 with installed ROS |
| Motor driver | ATMEGA 88, L293B |

**Table 3.** Types of system configurations

| Configuration type | Advantage | Disadvantage |
|---|---|---|
| All on RPI | + Only one device | – Monitor cables<br>– High power consumption<br>– Unsuitable for real system |
| Online data stream | + Best way for real system | – Energy consumption (Wi-Fi) |
| Ros-bags | + Best way for system test<br>+ All data stored | – Is not real-time |

## SYSTEM OVERVIEW

Fig.2shows our system configuration. Our system is based on ROS (Robotics Operation System) which is installed on our Raspberry Pi. ROS contains methods and device drivers, which are suitable for robot navigation. The configuration of the system is very important for real-time space mapping. In our system, we tested three system configurations. The first configuration was a system with connected LCD monitor via HDMI. This configuration is unsuitable due to cables, and the highest power consumption. In this case, the microcontroller also drew an online space map using rqt-graph. The second configuration was tested with an online data stream via Wi-Fi and Matlab Software. This configuration is in the middle of power consumption range, from all our experiments. The lowest power consumption is when storing all data streams to ros-bags. In this case, we can only reconstruct the original path as post-processing and this case does not provide online space mapping. The advantage of the last configuration is the possibility of analyzing measured data. The third configuration was selected for the first experiments. After the initial experiments, the second configuration was used for real-time experiments. Also, second configuration is possible to combine with ros-bags, but both methods together have extreme power consumption and for our Raspberry Pi 2,it is unusable for real use. Advantages and disadvantages of analyzed methods are written in Table 3.

The robotics platform is navigated by the user, using Wi-Fi, camera with IR LED and user software. An example of controlling software is shown at Fig.3.

**Fig.3.** Example of controlling software

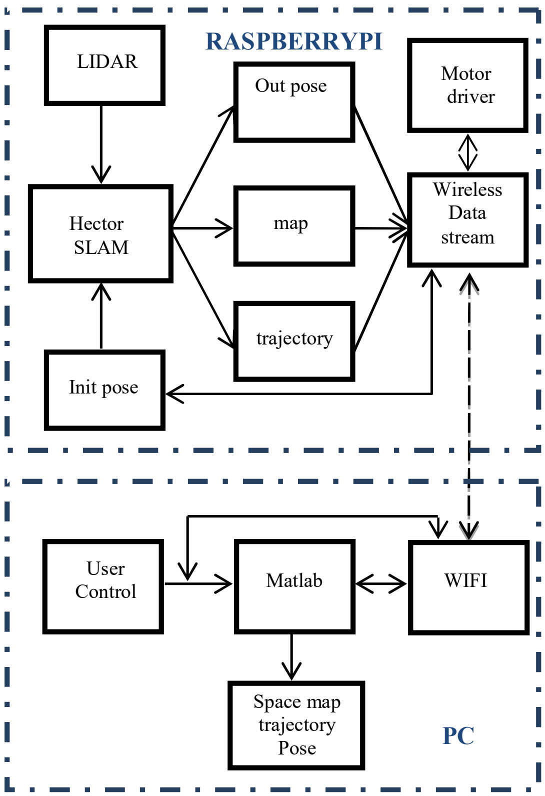
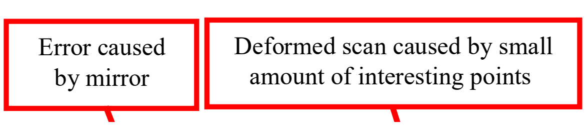



**Fig.4.** System configuration of our platform

## RESULTS

In our research, we measure several measurements in different spaces. The collected measurements and created space map is shown inFig.5 and Fig.6. InFig.5 one floor scan is shown, compared with building plans. InFig.5,two deformations of space mapare shown.



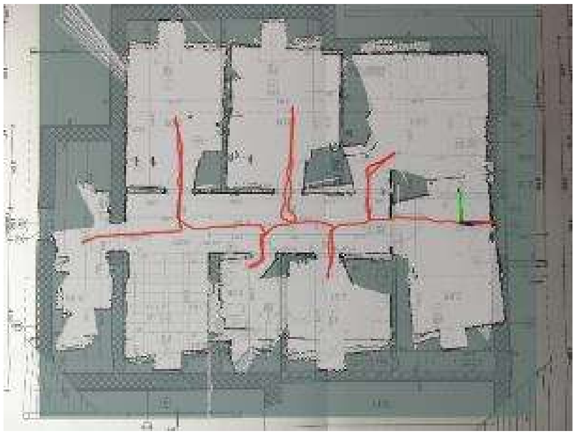
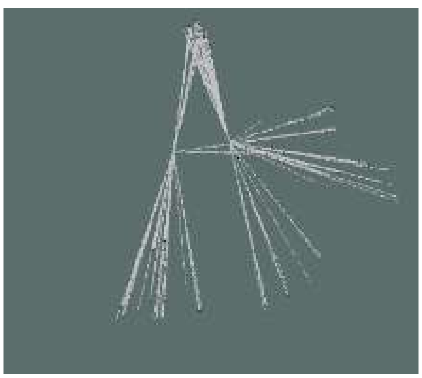


**Fig.5.** One floor scan of building compared with building plans



The first deformation is shown in Fig.5 in the bottom right corner. This deformation is caused by a smooth wall, where an algorithm detects a small number of interesting points and calculates the deformed space map. The second problem is in the top left corner. This error is caused by ray reflection in the mirror on the wall. The red line shows the calculated trace using Hector SLAM. Other examples of space mapping are shown in Fig.6 and Fig.7.

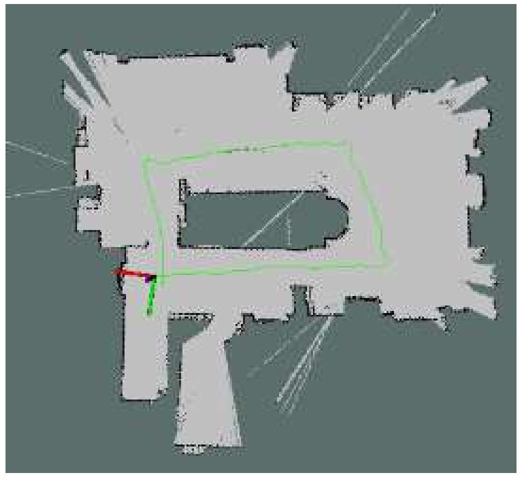


**Fig.6.** Example of closed path mapping (length 10m)

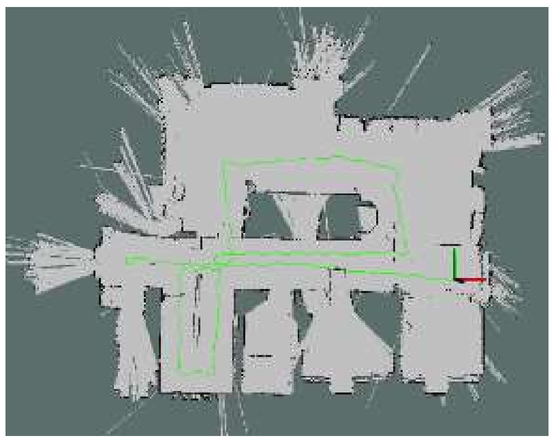


**Fig.7.** Example of closed path mapping two floors in building

In

**Table 3**, only the first five measurements of three path lengths are shown. Every path length measurement has twenty repetitions. These path measurements were tested in a building with many interesting points,which include direct moves and curves. One measurement of a 10m path is shown at Fig.6.

**Table 3.** Table of measurements

| Meas. nr. | Path length 3m | Path length 5m | Path length 10m |
|---|---|---|---|
| 1 | 3,015 | 5,054 | 10,054 |
| 2 | 3,014 | 5,035 | 10,027 |
| 3 | 3,011 | 5,042 | 10,387 |
| 4 | 3,029 | 5,060 | 10,256 |
| 5 | 3,056 | 5,053 | 10,205 |
| Aver [m] | 3,026 | 5,054 | 10,058 |
| Std. Dev. [m] | 0,009 | 0,013 | 0,02 |

InFigure 8,an example of failed space mappingis shown. The algorithm totally failed in the case of open-space without interesting points - in our case when any obstacles are beyond 4m (see Table 1 – Lidar parameters). The way how to improve reliability of this system is to use better LIDAR with higher scan range.

## CONCLUSION AND FUTURE WORK

In this paper a navigation and mapping system based on Raspberry PI, Ubuntu Mate and ROS was described. This method provides an impendent, reliable and accurate data source for our system ARES.

This system is usable only in the case of a powerful microcontroller. In our case, we hada powerful ARM microcontroller (see Table 2), andwhen using an online configuration, thissystem can reliably calculate a path and create a precision space map for only very low speeds (around 5cm per seconds). For faster speeds, our system is not powerful enough, because difficult calculations very quickly exhaust power of the microcontroller. Also, power of the microcontroller is decreasing in time, due to small RAM memory. An alternative way for scanning of space is using a “ros-bags” which stores all data streams to file, and is not so power-consuming like an online data stream through Wi-Fi. For system tests, we tried both methods and the powerful microcontroller method is more suitable for online 2D space scanning and path estimation.

For future, we plan to use a newer Raspberry Pi 3 B, which has more power than the Raspberry Pi 2, which we now use. Also, the Raspberry Pi 3 has a 64bit ARMv8 microcontroller which provides more power for calculations, and when compared to the previous Raspberry Pi 2, provides about 50% higher computing power.

Also, this system will be implemented in our project ARES. This system will be used as an alternative navigation method like visual odometry and mechanical odometry, inertial navigation system and 3D space mapping system. All systems together will create accurate and reliable navigation and a 3D space mapping system for rescue or exploration of unknown areas.

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