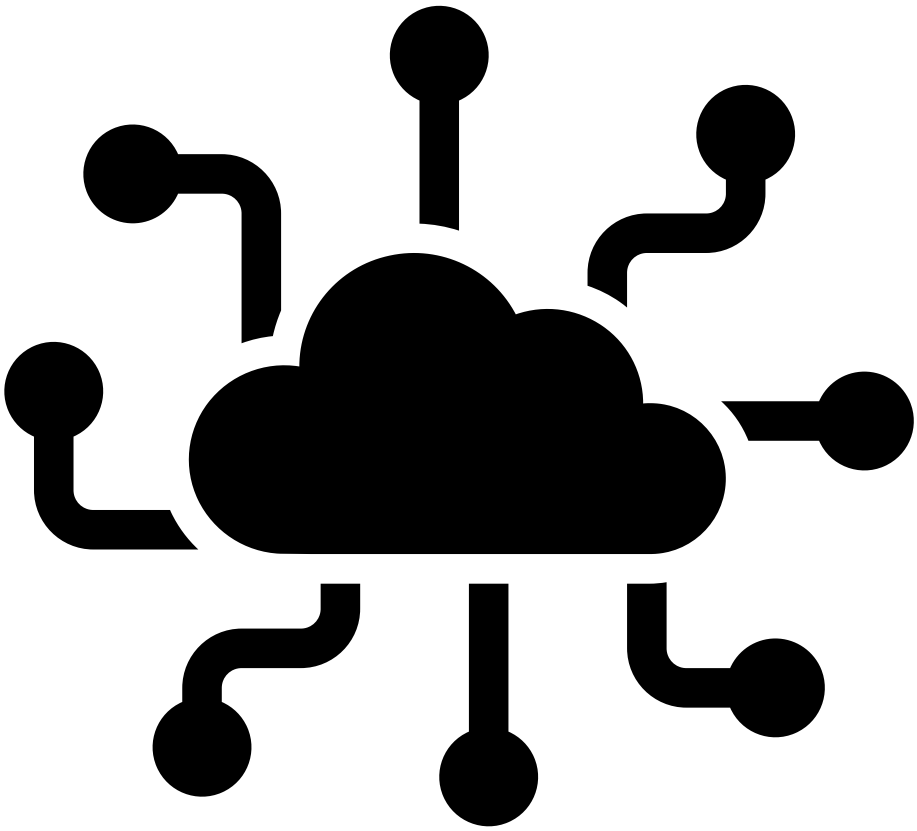
City of Things prototyping kit

HOGESCHOOL ROTTERDAM, PROJECT 7/8
RESEARCH – SLAM



Student
L. de Nijs 1003440 TI2B

Teachers	**Product Owner**	**Chance**
W.M. Tiest	T. Jaskiewicz	First
A.M. de Gier	I. Smit	

Table of Contents

Abstract

Simultaneous Localization and Mapping (SLAM) is an important method for autonomous positioning and navigation of robots. In this research it is first presented what SLAM is. Furthermore, it is presented what the applications are for SLAM and if it is applicable to the Hackerboard.

SLAM is short for Simultaneous Localization and Mapping. SLAM is used for robot navigation in a (un)known environment. SLAM relies on observations made by sensors. These sensors, such as cameras and LiDAR's, are used to provide depth information. The SLAM algorithm uses the depth information to make relations between the observations. With these relations an accurate location can be determined of the robot.

SLAM is used in a lot of robots, with the most popular being a vacuum robot. Without SLAM the vacuum robot will move random, but with SLAM the vacuum robot can move efficiently because it keeps track of its current and past locations. This prevents the vacuum robot to double cross sections of the room.

SLAM will and can be used in the Hackerboard for its clear purpose and its easy integration with ROS, the desired operating system of the Hackerboard.

Introduction

The commissioning parties City of Things Lab010 and Knowledge Centre Creating 010 want to investigate how smart initiative-based connected objects in the smart city (automatic delivery vehicles or safety robots) change daily life and whether they have a positive or negative impact.

For this project, a prototype is to be made in the form of a driving robot that can drive autonomously or remotely (or otherwise). The prototype is intended for designers and non-expert citizens with limited programming knowledge. The prototype must therefore be easy to operate and set up.

The proposal that was thought up by the project group is to make a kind of waiter robot that can be used as an example of what is possible and what smart objects are possible in everyday life. This robot could be used in a restaurant to autonomously bring food and drinks to a specific table.

For the Hackerboard there needs to be a way to navigate to a certain waypoint. A waypoint, in the case of the Hackerboard, is represented as a table. This table is placed in a room in which the map is known. While travelling to the waypoint the current location of the Hackerboard needs to be known. The location needs to be known for it to react to the environment, for example to avoid a table. To achieve this there needs to be a way to implement this is the Hackerboard. In this research there will be investigated a way called SLAM. SLAM is short for Simultaneous localization and mapping. "SLAM is the computational problem of updating a map of an unknown environment while simultaneously keeping track of an agent's location within it" (Michigan Robotics[1], 2019, September 17).

For this research only common SLAM will be investigated. Common SLAM, also called Visual SLAM or LiDAR SLAM, uses vision sensors. Acoustic and Audio-visual SLAM will be skipped as they have no purpose in the result of the project. To understand SLAM, and to know if it is applicable in the Hackerboard, the following questions needs to be answered.

- The main question is to find out if SLAM is the best navigation algorithm for our use case.
- For implementing SLAM, a deep understanding of the algorithm is needed. So, there will be looked at what SLAM is and how it works.
- Furthermore, there needs to be known what applications SLAM is used for. If there is known what SLAM is used for, there will be seen if there is some common ground in the expected result of our robot. Which is a waiter robot.
- At last, there will be looked at examples of SLAM robots. The similarities in the examples of SLAM robots and the expected result will indicate if SLAM is applicable to the Hackerboard.

[1] https://robotics.umich.edu/research/focus-areas/simultaneous-localization-mapping-slam/

Methodology

This research will use the literature that the internet has to offer us. The literature will consist of news articles, scientific articles, sites of importers and so on. The sources will be checked for authenticity and reliability. Credibility is checked through checking the author, citations, and date.

The algorithm for navigation requirements needs to be set. These requirements are as follows:

- Is suitable for indoor use.
- Does not require expensive (> 1000, -) or complex sensors.
- Easily implemented in ROS.
- Able to navigate by sending waypoints.
- Able to detect obstacles.

If the algorithm uses a map, certain requirements will tie to this. The mapping and localization algorithm also needs to comply with the following: The first requirement is that the generated map is in correspondence to the space it mapped. Furthermore, the algorithm needs to provide an (<10 centimetres) precise location of the robot. At last, the algorithm needs to calculate the fastest route to an endpoint.

What are the alternatives to SLAM?

To know if SLAM is the best navigation method for the Hackerboard the alternatives need to be known. But first there needs to be set certain requirements for these methods to provide a clear benchmark if a method is suited or not.

- Is suitable for indoor use.
- Does not require expensive (> 1000, -) or complex sensors.
- Easily implemented in ROS.
- Able to navigate by sending waypoints.
- Able to detect obstacles.

GPS

One of the ways to get from point a to point b is by using GPS coordinates in combination with distance sensors to provide for the obstacle avoidance part. GPS is short for Global Positioning System." GPS Waypoint Navigation is the ability to provide a robot with a set of GPS waypoints (i.e., a set of latitude / longitude pairs), and have the robot autonomously navigate from its current location to each of the defined waypoints." (Peckover, T. [2](2020, March 05))

GPS modules are easily implemented in embedded systems and does not require expansive hardware. But GPS has one big downside. Most GPS solutions are not suitable for indoor use. This is mostly because of two main reasons. GPS has a low signal strength and low accuracy. "Typically, GPS can reach 5m-10m accuracy in an open outdoor environment which is far from the accuracy of half-meter required by many industrial use cases. The accuracy in indoor space is further degraded." (Tian, L. (2022, April 14)). The accuracy loss in indoor use is degraded because of the low signal strength. In indoor applications a lot of obstacles block the, already weak, signal which degrades the accuracy.

Vector Field Histogram

Vector field histogram is a real time path planning algorithm. The algorithm uses a histogram filled with vectors based on the robot's environment. The robot's environment is known thanks to the data from sensors such as sonar or laser.

A big advantage of using the Vector Field Histogram is it takes the uncertainty and errors of sensor in account. In the histogram certainty numbers are being tracked. The higher the number, the higher the certainty of an obstacle in that place.

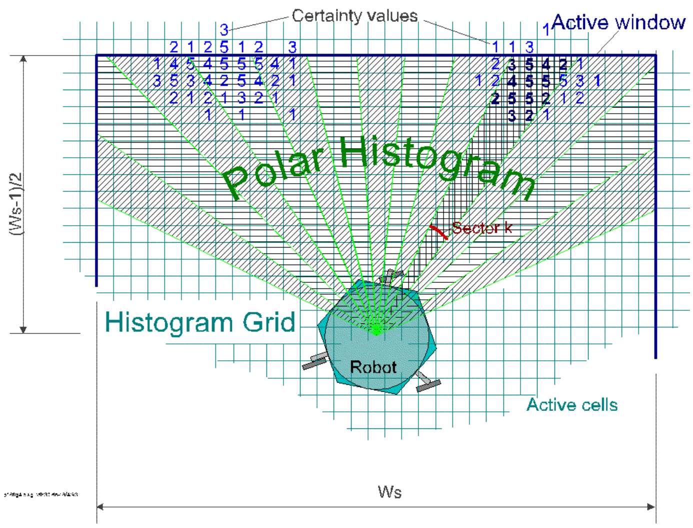


Figure 1 - A vector field histogram (Johann, B. (n.d.))

[2] https://www.wevolver.com/article/a.better.solution.for.gps.waypoint.navigation

Vector Field Histogram complies with the specified requirements. Except the implementation with ROS. This also means that sending waypoint will be significantly harder.

AMCL

AMCL is short for Adaptive Monte-Carlo Localizer. A Monte Carlo Localization algorithm is an algorithm used in robots to localize using a particle filter. ACML is remarkably similar to slam. Same as SLAM, AMCL uses a map to locate itself within the map using laser sensors. The key difference between AMCL and SLAM is that SLAM will localize the robot while it creates a map. This provides the opportunity to change the initial map. Also, the origin of the map will change each time SLAM is started. AMCL requires a previously laser-generated map. This means that no changes will be done in the original map. So, in a dynamic location (like changing the location of tables) ACML will not be usable. (Stein, P. (2016, November 14))

Conclusion

The three alternatives may provide ‘a’ solution to our problem. But they all have their downsides. GPS is not suitable for indoor use. Vector Field Histogram is significantly harder to implement and AMCL is not usable in a dynamic location. SLAM meets the set requirements, as explained further in this research.

What is SLAM?

What is SLAM? SLAM is short for Simultaneous Localization and Mapping, which is a method in which a robot or an autonomous vehicle will map his surroundings and simultaneously tries to locate itself in the map. (Riisgaard, S. (n.d.)) At first glance it seems like a chicken-and-egg problem, the robot needs the map to locate itself, but it also needs the location to create the map. But, generally speaking, this problem is 'solved'. SLAM provides the solution to the problem of indoor robotics and moving object, because SLAM uses sensors and maps instead of GPS location. In SLAM both the trajectory of the robot and the location of all obstacles are known, even without prior knowledge of the environment. To understand SLAM, one must realize that all data are estimates. When more observations are made the correlations between these observations increases the estimated location of these observations. But all these observations have some margin of error, as shown in figure 1. While the relations between observations are certain the position of the robot remains uncertain (Durrant-Whyte, H. & IEEE. n.d.).

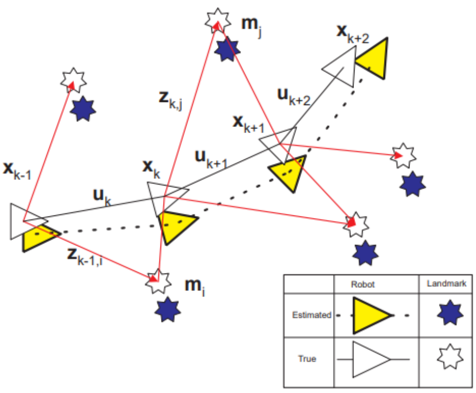


Figure 2, SLAM problem - stars are obstacles, triangle is robot. This shows the true and the estimated location. (Durrant-Whyte, H. & IEEE. n.d.).

Visual SLAM uses images from visual sensors such as cameras. Visual sensors provide a lot of information usable in SLAM operations. They can detect obstacles and can provide the information of the locations between these obstacles. In visual SLAM one or more visual sensors can be used. Because normal cameras provide 2D footage in a 3D environment. This results in the problem to define depth. The problem that arises can be fixed by putting a checkboard pattern in de frame of the camera. The checkerboard pattern is used to calibrate the camera because it provides a sense of depth. Another solution is to provide AR-markers in de room at different distances. AR is an abbreviation of Augmented Reality. These markers look like QR-codes and are distinct pattern you can hang in a room. The camera can detect these markers and can be calibrated at these distances (MATLAB & Simulink, n.d.). A simpler solution to this manner is to use a second camera. With this setup, using two cameras, there is a possibility to calculate the difference of the two different footages the cameras provide. This is called stereoscopy. The two different footages of the camera's simulate the human eyes, which allows for depth data (Yousif, K., 2015, November 13).

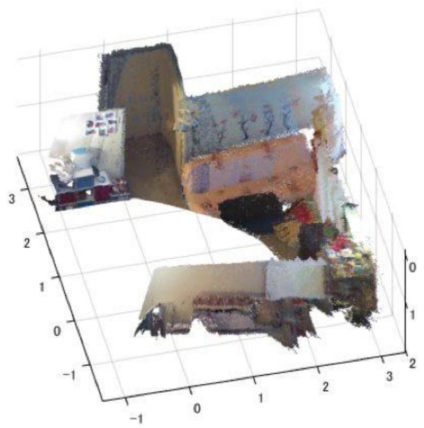


Figure 3 - Map of a room used in visual SLAM. Footage is provided by a RGB-D camera. (MATLAB & Simulink, n.d.).

LiDAR SLAM uses a LiDAR sensor to provide the needed information for SLAM purposes. A LiDAR (Light Detection and Ranging) sensor uses a laser to calculate the distance to an object. Laser pulses are sent

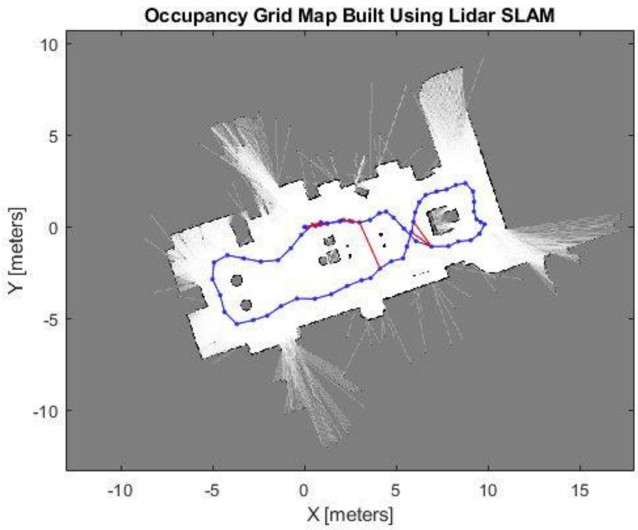


Figure 4 - Map provided by a 2D LiDAR. (MATLAB & Simulink, n.d.)

out and reflect to an object. A LiDAR measures the time it took for the laser to reflect and calculates the distance. LiDAR's are more precise than camera's and offer great speed. (Song, K. T., 2018, 1 October). More common and cheaper LiDAR's are 2D, but the more expensive LiDAR sensors provides 3D data. Constructing a map with a LiDAR uses the 2D or 3D data from the LiDAR. The localization part of SLAM uses the travelled distance. But there is a downside using LiDAR with SLAM applications. In an environment with too few obstacles, the data from the LiDAR provides insufficient unique features. In addition, matching the data of the LiDAR requires great processing power. To counter these problems LiDAR SLAM may require additional data provided by wheel odometry or GPS. (MATLAB & Simulink (n.d.))

Applications of SLAM

One of the most common and well-known usage of SLAM is a vacuum robot. Without SLAM it will just move randomly without knowing its location. Because the robot would not keep its location it may skip parts of the floor. This is not desirable. In addition, because the past track of the vacuum is not known, the robot will go over parts multiple times. This will result in more battery drainage because it moves longer than the vacuum needs to. (MATLAB & Simulink (n.d.)) What is learned from this is that SLAM is perfectly applicable in indoor activities, as it does not require a signal to be sent out.

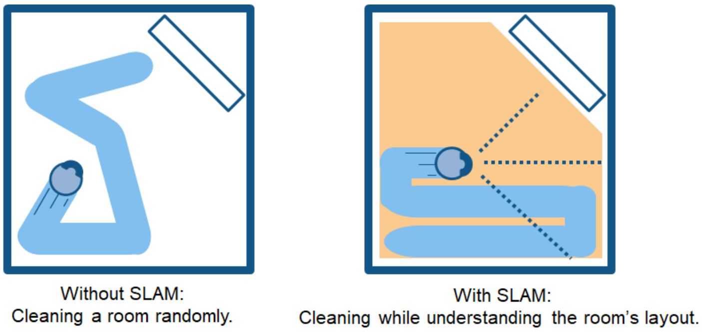


Figure 5 - A vacuum robot without and with SLAM. (MATLAB & Simulink (n.d.))

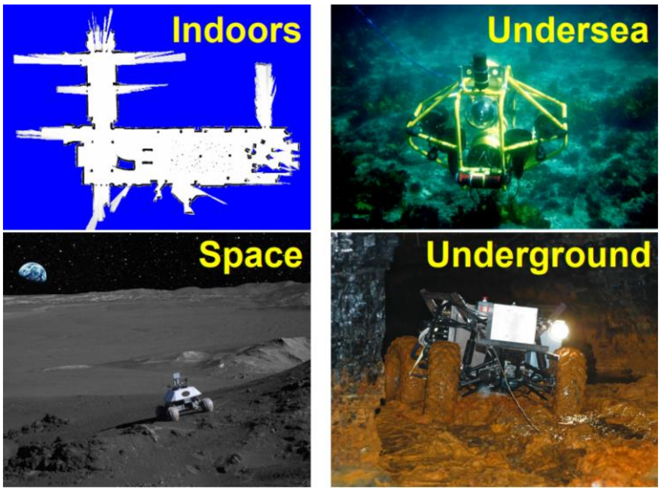


Figure 6 - SLAM applications. (Burgard, W. (n.d.))

Another application is when keeping track of more than one robot is desirable. For instance, in a warehouse application. In a warehouse that uses multiple robots each robot needs to know the location of the other robots. SLAM makes this possible because it keeps track of each of the robots' locations. These locations can be communicated to each other, and the robots will react as needed.

SLAM does not only find its applications on land. SLAM is also used in the air, in space and even underwater (Burgard, W. (n.d.)). SLAM in the air is used for unmanned surveillance aircrafts. These aircraft are deployed to satellite denied areas. In space SLAM is used for mapping the terrain of certain planets (Andert, F. Krause, S. (2017, 1 June)). One of the SLAM space projects is NASA's own robot called smart-SPHERES. Smart-SPHERES is a bowling-ball sized satellite. These spheres are able to move autonomously, using SLAM, and feature different sensors. The spheres propel themselves using cold gas. Smart-SPHERES feature a custom-3D sensor to keep track of the position and orientation whilst constructing a 3D map of its environment (Blau, P. (2018, 4 April)). Underwater SLAM is for reef monitoring and marine purposes. For the data to be useful accurate positioning and navigation are required. But because GPS is quickly not useable underwater. SLAM was

Figure 7 - NASA's smart-SPHERES (Blau, P. (2018, 4 April))

the solution for this problem because a robot is able to navigate to the unknown environment the sea has to offer (Zhoa, W. L. (2019, September)).

Is SLAM applicable in the Hackerboard?

The purpose of the Hackerboard is to travel in a restaurant. In this restaurant it needs to be able to navigate and calculate its path. To calculate the shortest path the Hackerboard requires a map of the environment. Furthermore, for the shortest path the location of the Hackerboard and the endpoint are necessitated. Moreover, the Hackerboard will feature obstacle avoidance. These obstacles can be stationary objects, like tables, or moving objects, like people. (Cheng, J. Liu, Z. He, J. Deng, Y. Zhang, H. (2021, July))

SLAM can be a solution for implementing these features. SLAM has been one of the most popular strategies for implementing autonomous navigation. Because the SLAM method constructs a map while it operates, it makes it applicable to operate in different environments. This way the Hackerboard is able to be used in alternate rooms, which is desirable for testing purposes or in an environment where tables orientations may change.

In addition, SLAM is also straightforward to implement in ROS. ROS is the desired platform on which the Hackerboard will run. There are various packages in ROS that implements SLAM, like gmapping, HectorSLAM or RTABMAP (Ibragimov, I. Z. (2017, October 1)).

Figure 8 - The PuduBot - https://www.pudurobotics.com/product/detail/pudubot

Finally, there are numerous examples of restaurant robots implementing the SLAM method. Like the PuduBot. The PuduBot features Visual SLAM and LiDAR SLAM, which makes it perceiving virtually everything. The PuduBot is one of the market leaders in the restaurant robot market.

Conclusion

SLAM seems at first sight like a chicken and an egg problem. To conclude, for localization is a map needed and for mapping the location is needed. But SLAM is the solution to problems where navigation and obstacle avoidance is needed. SLAM is used in applications where there is common ground with the Hackerboard. Whilst SLAM can appear in different shapes, the main principle remains clear. SLAM is a popular, yet useful technique.

- Is suitable for indoor use.
- Does not require expensive (> 1000, -) or complex sensors.
- Easily implemented in ROS.
- Able to navigate by sending waypoints.
- Able to detect obstacles.

If we look at the set requirements, SLAM meets them all. SLAM is suitable for indoor use because it does not require a signal to be sent out. It does not require expensive sensors, is easily implemented in ROS and is able to receive waypoints in the generated map.

Recommendations

Our recommendation is that the Hackerboard will be SLAM based. Depending on our research of sensors, the Hackerboard will be based on Visual SLAM or Laser Slam. SLAM provides the solution to the problem of navigation, mapping and obstacle avoidance and is easily implemented with ROS.

References

Michigan Robotics. (2019, September 17). Simultaneous Localization & Mapping (SLAM). Retrieved 4 June 2022, from https://robotics.umich.edu/research/focus-areas/simultaneous-localization-mapping-slam/

Riisgaard, S. (n.d.). SLAM for Dummies. https://dspace.mit.edu/. Consulted on 19 march 2022, off https://dspace.mit.edu/bitstream/handle/1721.1/36832/16-412JSpring2004/NR/rdonlyres/Aeronautics-and-Astronautics/16-412JSpring2004/A3C5517F-C092-4554-AA43-232DC74609B3/0/1Aslam_blas_report.pdf

Durrant-Whyte, H. & IEEE. (n.d.). SLAM tutorial paper. Durrant-Whyte_Bailey_SLAM-tutorial-I. Consulted on 20 march 2022, off https://people.eecs.berkeley.edu/~pabbeel/cs287-fa09/readings/Durrant-Whyte_Bailey_SLAM-tutorial-I.pdf

Yousif, K. (2015, November 13). An Overview to Visual Odometry and Visual SLAM: Applications to Mobile Robotics. SpringerLink. Consulted 20 March 2022, from https://link.springer.com/article/10.1007/s40903-015-0032-7?fbclid=IwAR2j_ERnMT8ywstuWp6HXdF8qBaqF1Qt4E_0XJWI_8_ZPGQxMDRcoBt7jbw&error=cookies_not_supported&code=b36eea48-0b18-423b-896f-e39e7ea10486

MATLAB & Simulink (n.d.). What Is SLAM (Simultaneous Localization and Mapping) – Consulted on 25 March 2022, off https://www.mathworks.com/discovery/slam.html

Song, K. T. (2018, 1 October). Navigation Control Design of a Mobile Robot by Integrating Obstacle Avoidance and LiDAR SLAM. IEEE Conference Publication | IEEE Xplore. Consulted on 25 march 2022, off https://ieeexplore.ieee.org/abstract/document/8616313?casa_token=1NLmAb0lawIAAAAA:XM0ocuSBLfFrAeYQ_W-ZjSOEpwiq2XBBLh9PLWAOBgFRiJz1g6HlJepcccvgJsYmJOnVkJpUEDwTnw

Burgard, W & Stachniss C & Arras, K & Bennewitz, M. (n.d.). From University of Freiburg. slam pptx. ais.informatik.uni-freiburg.de. Consulted on 26 March 2022, off http://ais.informatik.uni-freiburg.de/teaching/ss12/robotics/slides/12-slam.pdf

Andert, F. Krause, S. (2017, 1 June). Optical aircraft navigation with multi-sensor SLAM and infinite depth features. Published in 2017 International Conference on Unmanned Aircraft Systems (ICUAS) | IEEE Xplore. Consulted on 26 March 2022, off https://ieeexplore.ieee.org/document/7991319

Blau, P. (2018, 4 April). Smart SPHERES – Spaceflight101 – International Space Station. Spaceflight101 - smartSPHERES. Consulted on 26 march 2022, off https://spaceflight101.com/iss/smart-spheres/#:%7E:text=Smart%2DSPHERES%20is%20a%20free,%2C%20docking%20and%20tele%2Doperations.

Zhoa, W. L. (2019, September). Review of SLAM Techniques for Autonomous Underwater Vehicles. LAM Techniques for Autonomous Underwater Vehicles. Consulted on 26 March 2022, off https://dl.acm.org/doi/pdf/10.1145/3366194.3366262

Cheng, J & Liu, Z & He, J & Deng, Y & Zhang, H. (2021, July) Application of Simultaneous Location and Map Construction Algorithms Based on Lidar in the Intelligent Robot Food Runner – Published in: Journal of Physics: Conference Series. Application of SLAM. Consulted on 27 March 2022, off https://www.proquest.com/openview/c3f78f0a360efc7fedb4cb2671ce883c/1?pq-origsite=gscholar&cbl=4998668

Ibragimov, I. Z. (2017, October 1). Comparison of ROS-based visual SLAM methods in homogeneous indoor environment. IEEE Conference Publication | IEEE Xplore. Retrieved 27 March 2022, from https://ieeexplore.ieee.org/abstract/document/8250081

Peckover, T. (2020, March 05). A Better Solution for GPS Waypoint Navigation. Wevolver. Retrieved 4 June 2022, from https://www.wevolver.com/article/a.better.solution.for.gps.waypoint.navigation

Tian, L. (2022, April 14). GPS Indoor Positioning & Location Tracking. Redpoint Positioning. Retrieved 4 June 2022, from https://www.redpointpositioning.com/blog-gps/

Johann, B. (n.d.) VFF and VFH -- Fast Obstacle Avoidance for Mobile Robots. VFF and VFH. Retrieved 4 June 2022, from http://www-personal.umich.edu/%7Ejohannb/vff&vfh.htm

Stein, P. (2016, November 14). Difference between localisation with AMCL and SLAM - ROS Answers: Open-Source Q&A Forum. ROS Answers. Retrieved 4 June 2022, from https://answers.ros.org/question/246747/difference-between-localisation-with-amcl-and-slam/

Glossary

Word	Meaning
Hackerboard	The hacked hoverboard on which our project is based on.
SLAM	SLAM is the computational problem of updating a map of an unknown environment while simultaneously keeping track of an agent's location within it.
LiDAR	Light detection and ranging. LiDAR is a method for calculating distances using a laser sensor. (See Research Sensors)
Algorithm	In mathematics and computer science, an algorithm is a finite sequence of well-defined instructions, typically used to solve a class of specific problems or to perform a computation.
ROS	The Robot Operating System (ROS) is a set of software libraries and tools that helps build robot applications.
Augmented Reality	Augmented reality (AR) is an interactive experience of a real-world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information.
ACML	Adaptive Monte Carlo Localization, navigational algorithm.
GPS	Global Positioning System
Vector Field Histogram	Vector field histogram is a real time path planning algorithm

Changelog

Version	Date	Adjustment	Author
1.0	18/03/2022	First version	Leandro de Nijs
1.1	19/03/2022	Filled in Frame (intro, methodology etc)	Leandro de Nijs
1.2	20/03/2022	Filled in Frame (Theoretical Framework)	Leandro de Nijs
1.3	25/03/2022	Addition research, answer sub question	Leandro de Nijs
1.4	26/03/2022	Addition research, answer sub question	Leandro de Nijs
1.5	27/03/2022	Addition research, answer sub question	Leandro de Nijs
1.6	31/03/2022	Addition research, answer sub question	Leandro de Nijs

1.7	05/04/2022	Applied feedback from ‘Experimenten dak’	Leandro de Nijs
1.8	15/05/2022	Fixed references after workshop	Leandro de Nijs
1.9	04/06/2022	Applied feedback from teacher	Leandro de Nijs