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# Autonomous Navigation Robot using Slam and Path Planning Based on a Single RP-LIDAR

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**ABSTRACT**

This paper proposes an autonomous robotics system based on a single LIDAR sensor for delivering goods. There are needs to deliver goods such as medical supplies to the hospital and document in office. Although this task is simple, the delivery task is time consuming, tedious, and boring. In this regard, autonomous robotic systems could be a suitable solution. Here-in, we proposed the use of a single RP-LIDAR sensor in a robotic system that is sufficient for delivering goods in indoor environment. The robotic system uses autonomous navigation module which consists of simultaneous localization and mapping (SLAM) of the environment, and path planning for the robot to move safely from its current location to a desired position. In the context of SLAM, Hector SLAM method was opted due to its capability to harness sufficient data from a single LIDAR sensor. When it comes to path planning, the system employs a two-pronged approach. First, a global planner, utilizing the A* algorithm, facilitates long-distance trajectory planning while accounting for static obstacles. Second, a local planner, employing the Trajectory Rollout and Dynamic Window Approach (DWA), ensures real-time obstacle avoidance in the presence of moving obstacles. The approach was evaluated in a laboratory environment (11 meter by 8 meter) and successfully built a path that avoided obstacles in both static and dynamic conditions. This approach for autonomous robotics using a single RP-LIDAR sensor has the potential to revolutionize the delivery industry and other sectors that require autonomous navigation.

## 1. Introduction

This paper presents a novel approach to autonomous robotics using a single RP-LIDAR sensor, focusing on the efficient delivery of goods. The demand for automated delivery systems has been growing across various sectors, such as hospitals, warehouses, offices, and restaurants. Despite the

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seemingly straightforward nature of these tasks, manual deliveries often consume significant time and resources. To address these challenges, autonomous robotic delivery systems are emerging as a promising solution.

In the realm of commercial delivery robots, notable examples such as Swisslog [1], Weasel Auto Guide Vehicle (AGV) [2], Adept robot named Lynx [3] and Kiva system [4] have garnered success in controlled environments like storage warehouses. However, these systems face limitations when it comes to operating in areas with pedestrians, which calls for the development of autonomous delivery robots capable of safely navigating around moving individuals. A standout illustration is the Starship robot [5], which accomplishes pedestrian-friendly autonomous movement but relies on multiple sensors, potentially leading to higher maintenance costs. In other words, a much simpler robotic system that can fulfil full autonomy using a single laser sensor is worthy to be designed and developed.

This research proposes the utilization of a single RP-LIDAR sensor for achieving autonomous navigation in dynamic environments. The core of the robotic system's autonomous navigation module involves two key components: simultaneous localization and mapping (SLAM) for environment understanding and path planning for safe and efficient navigation to designated destinations.

### *1.1 Simultaneous Localization and Mapping (SLAM)*

SLAM represents a cornerstone of autonomous navigation, aimed at concurrently constructing an environmental map and determining the robot's precise position within that map. The early stages of SLAM relied on a fusion of multiple sensors, including odometry sensors for tracking robot movement and observation sensors for acquiring environmental data. Prominent instances of these SLAM methodologies are exemplified by Gmapping and Karto SLAM [6], recognized for their accuracy and reliability in mapping and localization endeavours.

Research by various authors has delved into SLAM techniques, often integrating them with navigation and recognition capabilities. In [7], mobile robot SLAM experiments were conducted within indoor environments using the Robot Operating System (ROS). A compelling exploration into navigation and object recognition is presented in [8], where an assistive device combines these functionalities to aid visually impaired individuals. Moreover, [9] introduced a low-cost mobile platform incorporating sensors such as RPLIDAR and Microsoft Kinect. Path planning algorithms were deployed alongside SLAM in [10], assessing the applicability of SLAM algorithms like GMapping, Hector-SLAM, and Cartographer in indoor rescue contexts. A comparative analysis of ROS-based 2D and 3D SLAM algorithms is detailed in [11], while [12] enhances lidar SLAM using an IMU-based Pedestrian Dead Reckoning (PDR) model. In the proposed fusion, the PDR model is used as a replacement for wheel odometry in vehicular platforms. By comparing and analysing the three SLAM algorithms, the mapping accuracy of the Cartographer algorithm is significantly better than Hector SLAM and Gmapping algorithms [13]. The method of laneway environment modelling and road header positioning based on Self-coupling and Hector SLAM was proposed to solve the problems of difficult extraction of environmental information of coal mine laneway and difficult determination of the position of road header and realization of autonomous mobilization of mine road header [14]. Another work [15] presents a prototype implementation of a mapping mobile robot tailored for indoor environments. In a similar vein, a study [16] endeavours to mitigate issues relating to low mapping accuracy, slow path planning efficiency, and high radar frequency requirements in the domain of mobile robot mapping and navigation within indoor environments. This study proposes a four-wheel drive adaptive robot positioning and navigation system, underpinned by the ROS.

In recent years, advancements have emerged in the realm of odometry generation, particularly through the utilization of LIDAR-based techniques. A key development in this context has been the realization that a single LIDAR sensor can fulfil both odometry and observation sensor roles, thus enabling the creation of a comprehensive SLAM solution. Among the notable single LIDAR-based SLAM methods, Hector SLAM [17] and Cartographer [18] have garnered attention. These methods leverage the data from a single LIDAR sensor to accomplish robust mapping and localization tasks.

The Hector SLAM algorithm is a popular approach for mapping spaces using LiDAR sensors. The algorithm has been evaluated in various scenarios, including indoor environments and machining workshops. Nagla [19] found that Hector SLAM can create real-time 2D maps of custom-built environments. However, the algorithm suffers from drifting and overlap problems in local maps. To address these issues, Wei [20] proposed an improved Hector SLAM algorithm that uses data fusion of LiDAR and IMU to compensate for invalid laser data. Wei [21] also proposed a trajectory matching algorithm that uses Iterative Closest Point (ICP) and a reference frame to correct the Hector SLAM's error accumulation problem.

In the scope of the present study, the choice of SLAM method is a pivotal decision. Among the available options, Hector SLAM is selected due to its notable advantage in terms of computational efficiency [22]. Sirigool [23] proposes an image processing technique to improve the quality of maps generated by Hector SLAM. Filipenko [24] compares various SLAM systems and finds that Hector SLAM performs well in an indoor environment when compared to other lidar-based SLAM systems. However, the study also finds that monocular ORB SLAM and stereo RTAB Map methods perform better than Hector SLAM in some scenarios. Overall, the papers suggest that Hector SLAM has some advantages, such as being suitable for indoor environments, but also has some limitations that can be addressed with additional algorithms and techniques such as segmentation to detect navigation rules sign [25]. This characteristic is particularly relevant for applications involving delivery robots, as it ensures prolonged operation without excessive power consumption. Once the SLAM process is completed, the resulting map and localization information generated by the SLAM method play a crucial role in the subsequent step of charting a safe path from the robot's current position to its designated target location. This path planning task is executed using specialized algorithms designed for this purpose.

### *1.2 Path-Planning*

Path planning, on the other hand, involves determining the optimal path for the robot to follow to reach its destination while avoiding obstacles. It is a critical component of the autonomous navigation process, enabling the robot to chart a course from its present location to a predetermined goal on a map. The goal of path planning is to ensure the robot's trajectory circumvents all obstacles, minimizing the risk of collisions. This intricate process is typically approached at two distinct levels: global planning for long-distance trajectories and local planning for on-the-fly obstacle avoidance, particularly concerning dynamic obstacles like pedestrians-ans.

At the global planning level, the objective is to devise a path that avoids static obstacles over extended distances. Two prominent algorithms frequently employed for global planning are Dijkstra's algorithm and the A* algorithm [26]. For the present study, the A* algorithm was selected due to its exceptional speed in generating global paths. By leveraging heuristics, A* efficiently determines a path that balances the shortest distance to the goal while considering potential obstacles.

Once the global path has been determined, the local planning phase comes into play. This aspect is pivotal for real-time obstacle avoidance, accounting for dynamic entities such as pedestrians that might unexpectedly cross the robot's path. The DWA (Dynamic Window Approach) planner stands as a widely recognized technique for local planning [27]. This method empowers the robot to adapt its immediate trajectory based on the current environment, evaluating a set of possible velocities and steering angles to select the optimal motion command. It is worth noting that other approaches, such as the teb_local_planner, tend to focus more on Holonomic (car-like) planning strategies [28]. However, in this specific study, the DWA planner was preferred due to the robot's utilization of a non-holonomic drive system.

The selection of the appropriate path planning methods plays a pivotal role in shaping the effectiveness of autonomous navigation systems. By meticulously choosing the A* algorithm for global planning and the DWA planner for local planning, this research ensures a harmonious blend of swift decision-making for extended paths and agile obstacle avoidance in real-time scenarios. This comprehensive strategy not only enhances the efficiency, safety, and adaptability of the autonomous navigation system but also underscores its robustness, particularly in dynamic environments.

In response to the burgeoning demand for automated delivery systems across various industries [29], there's an urgent need for streamlined autonomous robotics solutions. Manual delivery processes often incur substantial time and resource expenditures, prompting the advent of autonomous robotic delivery systems. However, existing commercial robots encounter challenges when navigating dynamic environments with pedestrians. To bridge this gap, this research endeavours to develop a simplified autonomous navigation system utilizing a single RP-LIDAR sensor. By harnessing advanced SLAM techniques and path planning algorithms, the research seeks to revolutionize goods delivery efficiency while ensuring secure traversal through diverse environments. This concerted effort not only addresses existing limitations but also paves the way for a future where autonomous delivery systems seamlessly integrate into everyday operations, reshaping the landscape of logistics and service industries.

## 2. Methodology

### *2.1 Outline*

This section outlines the comprehensive methodology employed for the development of an autonomous navigation robot system founded on a single RP-LIDAR sensor. The structure of this endeavour encompasses Section 2.2, detailing the software design and development for autonomous navigation, and Section 2.3, elaborating on the hardware design and development of the autonomous robot.

### *2.2 Software Design*

The overview of the autonomous navigation software is shown in Figure 1. The following discussion defines the procedural framework employed within this software. The process starts at the robot's frame, where the RP-LIDAR sensor, capable of emitting 400 laser beams at a frequency of 10 Hz, acquires laser data. This laser data serves as the fundamental input to the Hector SLAM system. Hector SLAM then undertakes the processing of the laser scan data to generate a 2D map of the environment while simultaneously establishing the precise location of the robot. Leveraging the output from Hector SLAM and in conjunction with a designated goal location, the path planning module constructs a global path. This global path subsequently informs the operations of the local planner, which orchestrates the robot's trajectory to circumvent dynamic obstacles. The resultant robot trajectory is then relayed to a low-level controller responsible for the manipulation of the robot's wheels. In this specific endeavour, an Arduino microcontroller serves as the chosen low-level controller, facilitating the translation of trajectory commands from the local planner into motor control signals, ultimately governing the robot's movement dynamics.

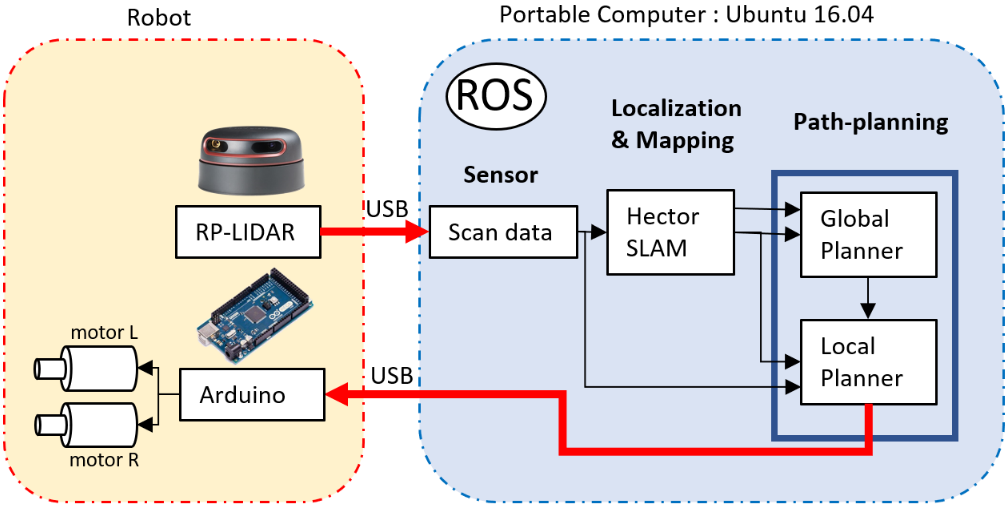

**Fig. 1.** Overview of software design

### *2.3 Hardware Design*

The hardware design of the autonomous robot is visually portrayed in Figure 2 and Figure 3. This section offers a detailed exposition of the hardware configuration. The robot is propelled by two motors strategically positioned on the left and right sides, as depicted in Figure 2. The modulation of velocity differences between these motors orchestrates the direction of the robot's movement. The pivotal RP-LIDAR sensor is situated atop the robot, an arrangement that maximizes its field of view for effective environmental sensing, as visualized in Figure 2. On the robot's right side, the integration of the Arduino microcontroller and motor drive components is evident, showcased in Figure 3.

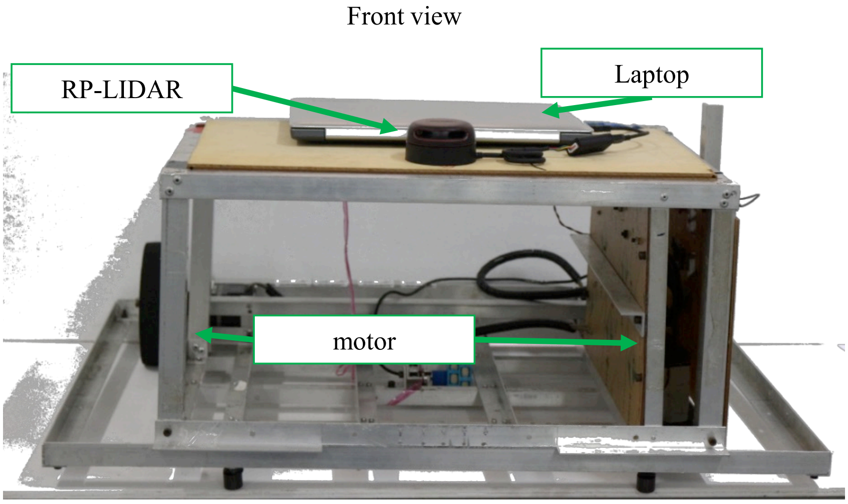

**Fig. 2.** Front view of hardware design

By combining a detailed software framework for autonomous navigation with a well-considered hardware layout, this methodology presents a comprehensive blueprint for the creation of an effective autonomous navigation system utilizing a single RP-LIDAR sensor. The ensuing sections delve deeper into the specifics of each facet, collectively contributing to the establishment of a robust and versatile robotic system.

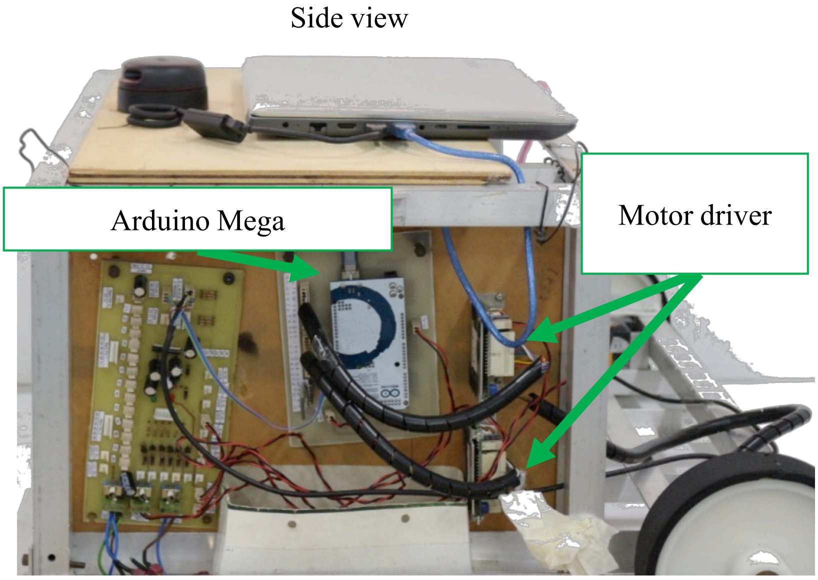

**Fig. 3.** Side view of hardware design

## 3. Results

The efficacy of the developed autonomous navigation robot system, rooted in a single RP-LIDAR sensor, was subjected to comprehensive evaluation within a controlled laboratory setting. This section presents an in-depth analysis of the experimental results, encompassing two distinct scenarios: a laboratory environment devoid of obstacles and a laboratory environment featuring a newly introduced obstacle meant to simulate pedestrian movement.

The laboratory chosen for the evaluation had dimensions of approximately 11 meters by 8 meters, as illustrated in Figure 4. This area served as the testing ground for assessing the robot's navigation ability under two conditions; laboratory without obstacle and with new obstacle (which represents pedestrian).

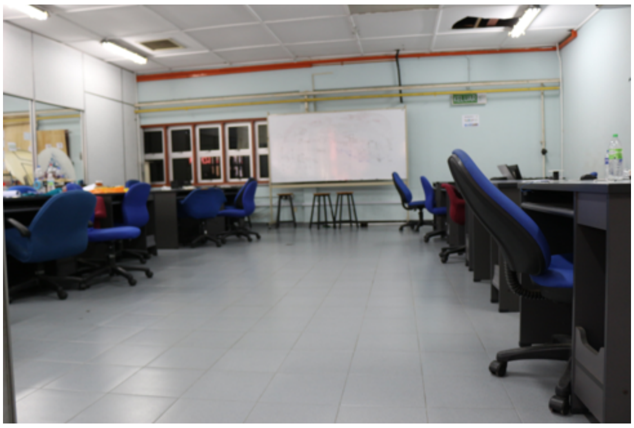

**Fig. 4.** Laboratory size 11m x 8m

The first experimental condition involved evaluating the autonomous robot's ability to create a Simultaneous Localization and Mapping (SLAM) map and subsequently devise a path within an obstacle-free laboratory environment, as demonstrated in Figure 5. Notably, the autonomous robot demonstrated its proficiency in successfully constructing a SLAM map of the surroundings. Additionally, the robot's path planning capabilities were showcased, as it adeptly planned and traversed a path to a predefined goal position (indicated by the 4.05m green line). These results underscore the robot's capacity for autonomous navigation within a controlled, obstacle-free setting

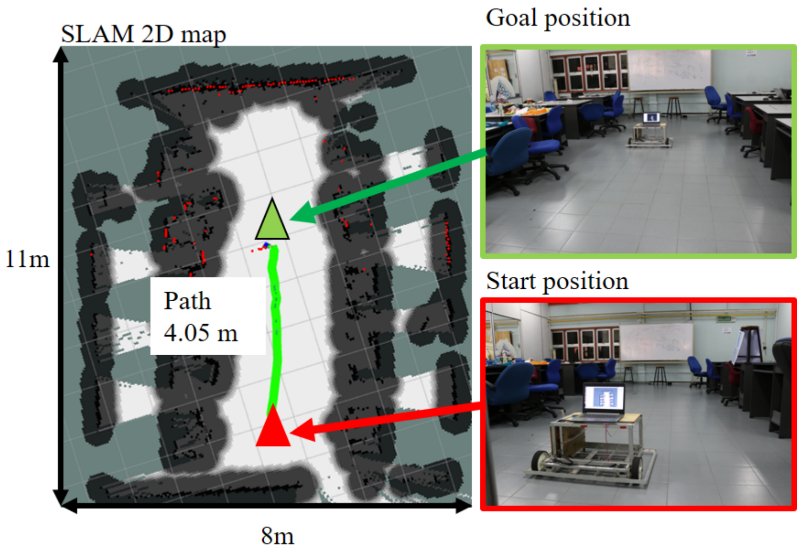

**Fig. 5.** Experiment without obstacle

In summary, the comprehensive evaluation of the autonomous navigation robot system under both obstacle-free and obstacle-introducing conditions underscores its ability to successfully create SLAM maps, plan effective paths, and adapt to dynamic obstacles. These results contribute to the validation of the proposed approach's effectiveness in facilitating safe and efficient autonomous navigation within real-world environments.

## 4. Conclusions

In conclusion, this study has introduced and demonstrated the effectiveness of an autonomous navigation robot system that hinges on the utilization of a single LIDAR sensor, particularly in environments where pedestrian presence is a consideration. The proposed approach integrates several key components to facilitate smooth and safe navigation.

The cornerstone of this approach lies in the deployment of Hector SLAM, which empowers the robot to dynamically construct an environment map while simultaneously pinpointing its own location. Subsequently, the employment of the A* algorithm for path planning ensures that the robot moves through the environment with caution, avoiding potential collisions with obstacles. Moreover, the incorporation of the Dynamic Window Approach (DWA) further enhances the robot's responsiveness by enabling real-time obstacle avoidance, especially in scenarios involving dynamic elements like pedestrians.

The experimental validation conducted in a controlled laboratory setting measuring 11 meters by 8 meters under two distinct conditions - one absence of obstacles and the other featuring the introduction of an obstacle to simulate pedestrian movement - validates the robustness of this approach. In both scenarios, the autonomous navigation robot effectively executed its designated tasks by adeptly generating obstacle-free paths. This success underscores the adaptability and reliability of the proposed system in varying real-world contexts, reaffirming its potential for use in environments where pedestrian interaction is a crucial factor.

In summary, this study presents a promising step toward the development of autonomous navigation robots that can confidently navigate within environments inhabited by pedestrians. By harnessing the capabilities of a single RP-LIDAR sensor and a combination of path planning algorithms, we have demonstrated the feasibility of building paths that circumvent obstacles, leading to safer and more efficient autonomous navigation systems. As we move forward, this work could serve as a foundation for further advancements in the realm of robotics, contributing to the creation of more sophisticated and adaptable autonomous systems.

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