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MAPPING AND NAVIGATION OF AUTONOMOUS ROBOT WITH LIDAR FOR INDOOR APPLICATIONS†

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Abstract: The work "Mapping and Navigation of Autonomous Robot with LiDAR for Indoor Applications" focuses on the development of an advanced robotic system capable of autonomously navigating and mapping its environment using LiDAR technology. LiDAR (Light Detection and Ranging) has emerged as a powerful sensing technology that enables precise and detailed 2D mapping of the surroundings by emitting laser beams and measuring their reflections. By leveraging LiDAR, this work aims to enhance the capabilities of autonomous robots and unlock their potential in various applications.

The main objectives of this paper encompass several key aspects. Firstly, it involves integrating a LiDAR sensor with the robot's existing hardware and software systems, establishing seamless communication and data exchange. Secondly, the article focuses on developing algorithms and techniques for environment mapping using LiDAR data. This entails utilizing laser-based measurements to construct accurate and detailed 2D maps of the robot's surroundings.

Real-time operation and robustness are vital considerations in this work. The system will be optimized to ensure fast and responsive decision-making based on LiDAR data, allowing the robot to adapt to dynamic environments and changing conditions. It will be designed to handle various scenarios, such as different lighting conditions, diverse terrain, and the presence of moving objects.

Ultimately, the successful completion of this task will lead to the development of an autonomous robot that can independently explore unknown environments, map them in detail, and navigate through them safely and efficiently using LiDAR technology.

Keywords: LiDAR, Autonomous Robot, Navigation, 2-D mapping, Real-Time operation.

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1. Introduction

The "Mapping and Navigation of Autonomous Robot with LiDAR for Indoor Applications" focuses on the development of an advanced robotic system capable of autonomously navigating and mapping its environment using LiDAR technology. LiDAR (Light Detection and Ranging)has emerged as a powerful sensing technology that enables precise and detailed 2D mappingof the surroundings by emitting laser beams and measuring their reflections. By leveraging LiDAR, this work aims to enhance the capabilities of autonomous robots and unlock theirpotential in various applications.

The integration of LiDAR with autonomous robots offers a range of benefits. It enablesrobots to perceive and understand their environment with a high level of accuracy and detail.This, in turn, facilitates safer and more efficient navigation by providing real-time information about obstacles, distances, and geometrical features in the surroundings. environment, which can be used for further analysis, planning, and decision-making.

The main objectives of this work encompass several key aspects. Firstly, it involves integrating a LiDAR sensor with the robot's existing hardware and software systems, establishing seamless communication and data exchange. Secondly, the work focuses on developing algorithms and techniques for environment mapping using LiDAR data. This entails utilizing laser-based measurements to construct accurate and detailed 2D maps of therobot's surroundings.

Real-time operation and robustness are vital considerations in this work. The system will be optimized to ensure fast and responsive decision-making based on LiDAR data, allowing the robot to adapt to dynamic environments and changing conditions. It will be designed to handle various scenarios, such as different lighting conditions, diverse terrain, and the presence of moving objects.

Ultimately, the successful completion of this work will lead to the development of an autonomous robot that can independently explore unknown environments, map them in detail, and navigate through them safely and efficiently using LiDAR technology. The applications of such a system are vast, ranging from autonomous exploration and surveillance to tasks in industries such as agriculture, construction, and search and rescue. By harnessing the power of LiDAR, this work aims to push the boundaries of autonomous robotics and pave the way for innovative solutions in various domains.

The work "Mapping and Navigation of Autonomous Robot with LiDAR for Indoor Applications " addresses several challenges and problems in the field of autonomous robotics. The following problemareas are the focus of this work:

1. Limited perception capabilities: Traditional autonomous robots often rely on limited sensors like cameras or proximity sensors, which have limitations in accurately perceiving the environment. This can lead to incomplete or unreliable information about the surroundings, hindering the robot's ability to navigate and make informed decisions. The work aims to overcome this limitation by integrating LiDAR technology, which provides precise 2D mapping and detailed perception of the environment.

2. Mapping of unknown environments: Navigating and mapping unknown environments pose significant challenges for autonomous robots. Without prior knowledge or pre-existingmaps, robots may struggle to create accurate representations of their surroundings. The work seeks to develop algorithms and techniques that leverage LiDAR data to create detailed and reliable maps in real time, enabling robots to explore and understand unknownenvironments more effectively.

3. Real-time operation and robustness: Autonomous robots operating in real-world scenariosrequire real-time decision-making and robustness. Delays in data processing or inaccuraciesin perception can lead to safety issues or inefficient operations. The work aims to optimizethe system to handle large amounts of LiDAR data in real time, ensuring fast and responsivedecision-making while maintaining robustness in various environmental conditions.

The proposed system consists of a mobile robot powered by an Arduino board and equipped with a LIDAR sensor for room scanning. The LIDAR sensor emits laser beams and measures the time-of-flight of the reflected beams, providing accurate distance measurements. Arduino is responsible for controlling the robot's movements and acquiring data from the LIDAR sensor. Bluetooth connectivity is used to establish a wireless communication link between the robot and a remote server. The robot scans the room by systematically moving and rotating, capturing LIDAR data at different angles. The collected data is processed, and a detailed 2D map of the room is generated. The map data is transmitted to a remote server via Python Flask, enabling real-time visualization andanalysis.

2. Literature Survey

With the new progressions in independent versatility innovation for mobile robots, different service robots have been proposed to aid various businesses, including fabricating, warehousing, medical services, horticulture, and restaurants [1]. Individuals' insight and acknowledgment of artificial intelligence are continually improving with the rise and use of computerized reasoning (artificial intelligence) products, for example, automated robotic entities [2].

Furthermore, staff deficiencies, the continuous interest for item improvement, and the change in the service sectors have pushed the business of restaurants to take on the robotic. To increment work efficiency, administration robots, like the automated guided vehicle (AGV) activity framework, have been executed in Japanese restaurants [3,4]. AGV frameworks have advanced into autonomous mobile robots (AMR) to give more functional adaptability and further developed efficiency because of the improvement of AI innovations, strong onboard processors, ubiquitous sensors, and concurrent area and planning innovation. Customary minimal expense administration robots move by patrolling the line.

Radar-based independent route robots have been generally considered, yet their costs are even basically as high as $17,000 [5]. The utilization of artificial intelligence and robots in restaurants is still in its early stages, supervisors are looking for help with utilizing present day advances to further develop administration [6]. COVID19 has modified the business in light of the fact that the contactless worldview may give clients and staff solace while feasting and working [7].

Many service managers are thinking about deploying service AMRs to provide seamless service and alleviate manpower shortages. Cheong et al. [5] created a Mecanum wheel-based mobile waiter robot prototype for testing at a dining food outlet. Yu et al. [8] created a restaurant service robot capable of ordering, retrieving, and delivering meals. In response to the issues posed by COVID-19, an increasing number of restaurants incorporating robots have appeared in China and the United States [9]. Yang et al. [10] suggested a robotic delivery authentication system that consists of a client, a server, and a robot.

To fulfill the demands of a variety of eateries, many robots for various use cases, such as hotpot, Chinese cuisine, and coffee, have been designed [11]. Despite this, various universities are working to develop a universal, unified, and practical robot system that can be implemented in a range of restaurant application scenarios. One of the most effective implementations of robot handling plates was done for the 2022 Winter Olympics in Beijing. This encouraging example is expected to drive up demand for restaurant robots even further. However, the cost of robots is an important factor for restaurant owners to consider before implementing the technology. Service robots might be constructed on a generic framework instead of the aforementioned development methodologies to minimize development costs. Chitta and co. [12] offered a general and simple control framework for implementing and managing robot controllers in order to increase both real-time performance and controller sharing. [13] Ladosz et al. introduced a robot operating system (ROS) for developing and testing autonomous control functionalities. This ROS can handle a wide variety of robotic systems and is a low-cost, basic, highly versatile, and reconfigurable system. Chivarov et al. [14] explored the interaction and collaboration between robots and Internet of Things (IoT) devices in order to design a cost-oriented autonomous humanoid robot to aid people in everyday life chores. Tkácik et al. [15] showed a prototype for a modular transportable robotic platform that may be used for both research and education. Noh at al [16] presented an open source-based autonomous navigation system for indoor mobile robots, achieving three primary modules: mapping, localization, and planning. It is possible to establish the appropriate adaptation to different service jobs based on the robot design, client traits, and service task characteristics [17].

3. Implementation Process

The aim of the work "Mapping and Navigation of Autonomous Robot with LiDAR" is to develop a robotic system that can autonomously navigate and map its environment usingLiDAR technology. LiDAR (Light Detection and Ranging) is a remote sensing method thatuses laser beams to measure distances and create detailed 3D representations of the surroundings. The specific objectives of this work include Sensor integration, Environment mapping, and Autonomous navigation of the robot. By achieving these objectives, the work aims to create an autonomous robot capable of exploring and navigating unknown environments using LiDAR technology, enabling applications such as autonomous exploration, surveillance, mapping, and potentially even tasks in fields like agriculture, construction, or search and rescue. Figure 1 shows the block diagram of the design to be implemented. It consists of the following main blocks:

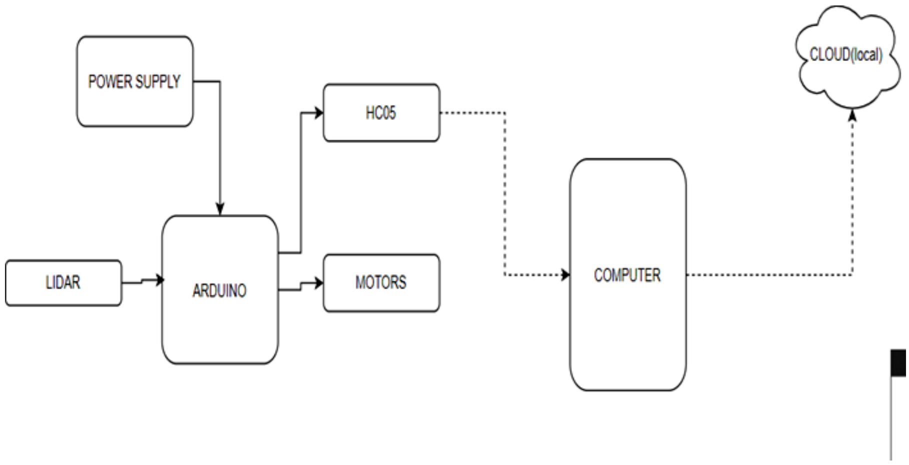


Figure 1. Block Diagram.

Lidar Scanner Sensor: The Lidar scanner sensor is mounted on the robot and continuously emits laser beams in various directions. These laser beams reflect off objects in the robot's surroundings and return to the sensor. The sensor measures thetime the laser beams return, allowing it to calculate the distance to the objects.

Power Supply: The power supply provides the necessary electrical power to all the components of the robot, including the Lidar scanner sensor, Arduino Nano, motors, and Bluetooth module.

Arduino Nano: The Arduino Nano acts as the brain of the robot. It receives the distance data from the Lidar sensor and processes it to determine the robot's environment. The Arduino Nano then sends the processed data to the motors for navigation control and to the HC05 Bluetooth module for transmission to a PC.

HC05 Bluetooth Module: The HC05 Bluetooth module enables wireless communication between the robot and a PC. It receives the processed data from the Arduino Nano and transmits it to the PC for further analysis and visualization.**Motors:** The motors are responsible for the movement of the robot. Based on the processed data received from the Arduino Nano, the motors are controlled to navigatethe robot in its environment, avoiding obstacles detected by the Lidar scanner sensor

Flask Server and Website: The Flask server is a web framework that runs on a PC. It receives the Lidar data transmitted by the robot through the HC05 Bluetooth module. The server processes the data and hosts a website that allows users to visualize the Lidar data in the form of a graph.

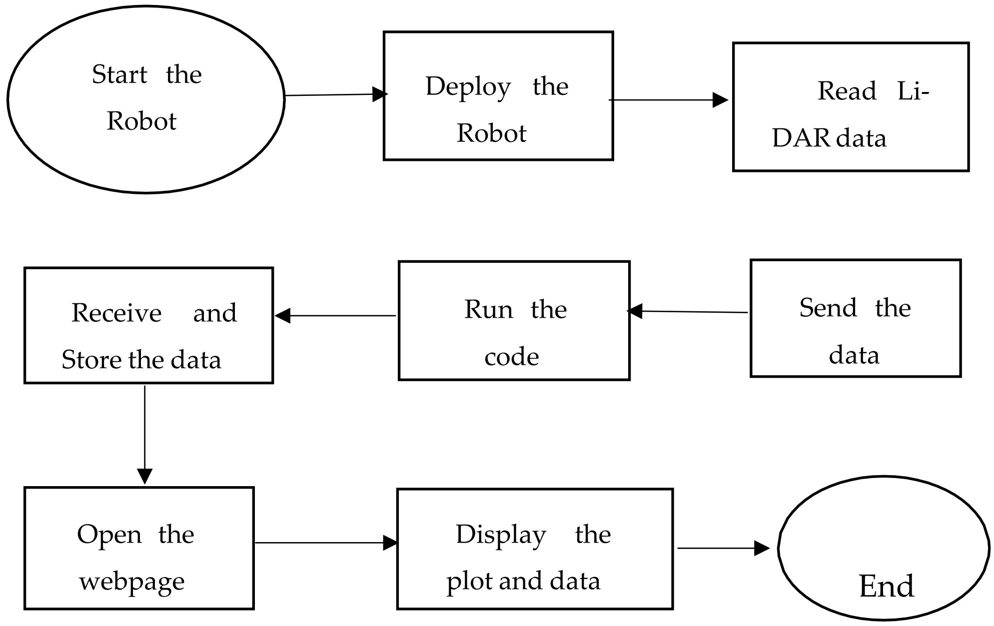


Figure 2. Flow Chart.

The flow of the work process is shown in figure 2.

Step-1: Start the Robot and LiDAR sensor.

Step-2: Deploy the robot into an unknown environment.

Step-3: The LiDAR sensor will start reading the data and according to the data read by thesensor, the robot will start to move by avoiding the obstacles present in front of it.

Step-4: The robot will send the LiDAR data to the computer to which it is connected withthe help of Bluetooth connectivity.

Step-5: Now, we have to run the code on the computer, to which the robot is connected, in anew terminal in the Visual Studio Code.

Step-6: As we execute the code, a server is initialized, and it receives and processes the dataand stores it in a CSV file, and later uses the data for plotting.

Step-7: Now, as we execute the code, we get a link in the terminal opened by us for executingthe code, we have to double-click on it to open a webpage called "HOME".

Step-8: The webpage "HOME" displays the plot of the data points sent by the LiDAR sensorand if we click on the "VIEW" button of the webpage, the received data is displayed in the form of a table.

Step-9: After the analysis is done on the received data, we can close the webpage and switchoff the robot to end the process.

4. Results and discussions

The system built as a part of the work, Mapping and Navigation of Autonomous Robot with LiDAR, consists of a mobile robot powered by an Arduino board and equipped with aLIDAR sensor for room scanning. The LIDAR sensor emits laser beams and measures the time-of-flight of the reflected beams, providing accurate distance measurements. Arduino isresponsible for controlling the robot's movements and acquiring data from the LIDAR sensor. Bluetooth connectivity is used to establish a wireless communication link between the robot and a remote server. The robot scans the room by systematically moving and rotating, capturing LIDAR data at different angles. The collected data is processed, and a detailed 2D map of the room is generated. The map data is transmitted to a remote server viaPython Flask, enabling real-time visualization and analysis. The figure 3 of the robot built as a part of this work is displayed below:

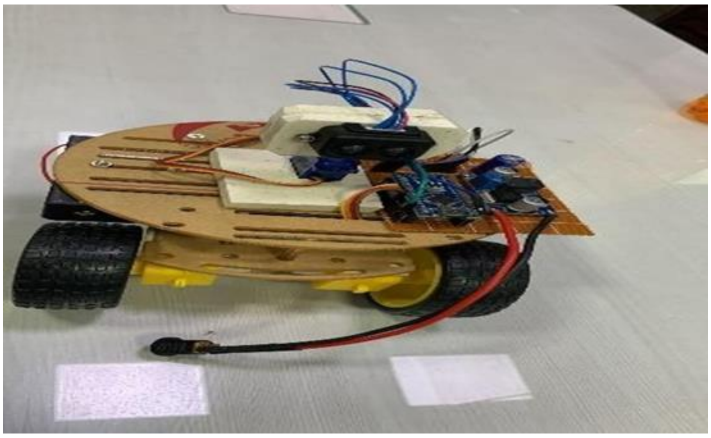
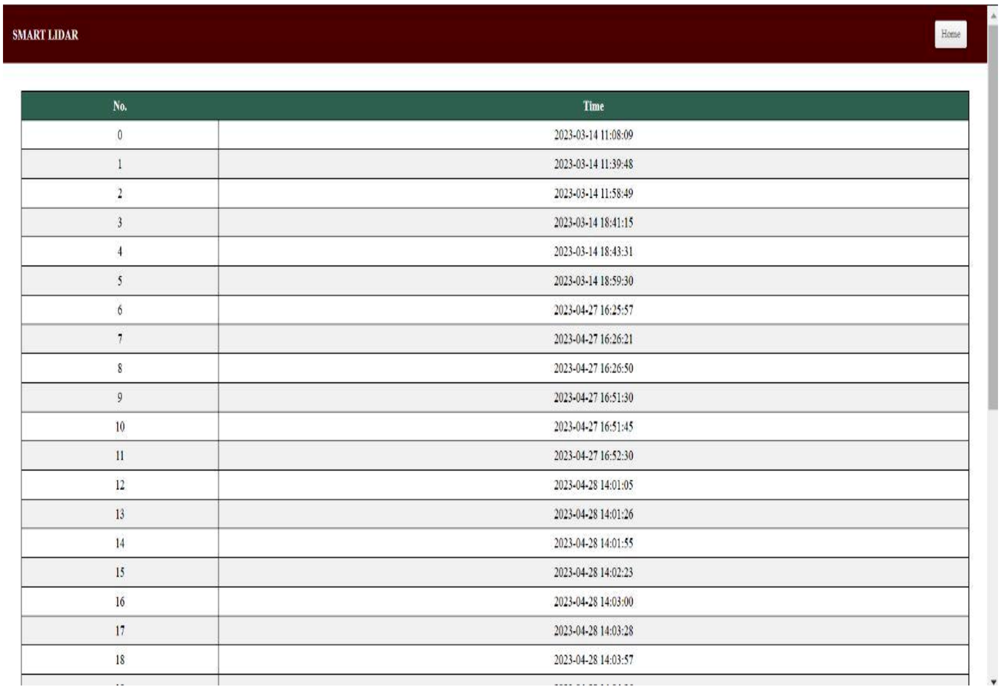


Figure 3. Robot integrated with LiDAR scanner.

The webpage created as a part of this work is called "HOME" and it displays the plot of the data points received from the robot with the help of Bluetooth connectivity and the figure of the plot(figure 4) obtained is shown below:

Figure 4. Plotting of data points.

As shown in the above figure 4, if we click on the "VIEW" button, we can see the data received in the form of a table 1.


SMART LIDAR Home

No.	Time
0	2023-03-14 11:08:09
1	2023-03-14 11:39:48
2	2023-03-14 11:58:49
3	2023-03-14 18:41:15
4	2023-03-14 18:43:31
5	2023-03-14 18:59:30
6	2023-04-27 16:25:57
7	2023-04-27 16:26:21
8	2023-04-27 16:26:50
9	2023-04-27 16:51:30
10	2023-04-27 16:51:45
11	2023-04-27 16:52:30
12	2023-04-28 14:01:05
13	2023-04-28 14:01:26
14	2023-04-28 14:01:55
15	2023-04-28 14:02:23
16	2023-04-28 14:03:00
17	2023-04-28 14:03:28
18	2023-04-28 14:03:57

Table 1: Data in the form of a table

We can click on any row of the table to get the plot of the data points at a particular date and time and it is shown in figure 5.

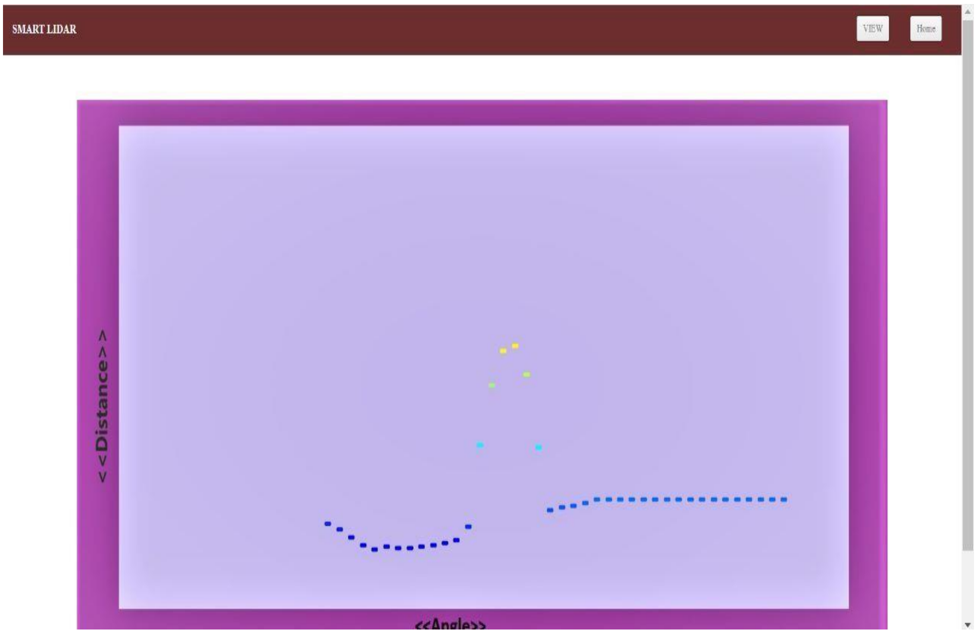


Figure 5. Plot of data points at a particular time.

5. Discussions

Mapping and navigation are crucial components of an autonomous robot's functionality.LiDAR (Light Detection and Ranging) is a commonly used sensor technology for mappingand navigation tasks. LiDAR provides the robot with accurate 3D spatial information, enabling it to perceive its surroundings and make informed decisions about movement and path planning. Here are some key discussions to consider for the work on mapping and navigation of an autonomous robot with LiDAR:

i. LiDAR Technology: Begin by discussing the fundamentals of LiDAR technology, including how it works, the types of LiDAR sensors available (e.g., rotating, solid-state), and their respective pros and cons. Explain the principles of laser scanning, time-of-flight measurement, and the generation of point clouds.

ii. Sensor Integration: Discuss how LiDAR can be integrated into an autonomous robot's sensor suite. Explore the potential combination of LiDAR with other sensors like cameras, ultrasonic sensors, or inertial measurement units (IMUs) for a comprehensive perception system. Address the challenges and benefits of sensor fusion for accurate mapping and navigation.

iii. Path Planning and Navigation: Address the role of LiDAR in path planning and navigation. Discuss how LiDAR data can be used to generate occupancy grids, create cost maps, or detect obstacles in real-time.

iv. Obstacle Avoidance: Focus on the utilization of LiDAR data for obstacle detection and avoidance. Discuss techniques like point cloud processing, clustering, or segmentation to identify and classify obstacles in the environment. Address challenges such as dynamic obstacles, sensor occlusions, or sensor noise and discuss strategies to overcome them.

v. Real-time Processing and Optimization: Discuss techniques for real-time processing and optimization of LiDAR data to ensure efficient mapping and navigation. Explore approacheslike downsampling, voxelization, or octree-based representations to handle large point clouddatasets effectively.

vi. Environmental Considerations: Address the impact of different environmental factors on LiDAR performance, such as lighting conditions, weather conditions (e.g., rain, fog), or reflective surfaces. Discuss techniques or sensor configurations that can mitigate these challenges and ensure reliable mapping and navigation.

vii. Future Trends and Challenges: Discuss current research trends and emerging technologies in LiDAR-based mapping and navigation. Address challenges such as robustness in complexenvironments, faster and more accurate mapping algorithms, and the integration of AI and machine learning techniques for improved perception.

6. Conclusion and Future work

In summary, The system built as a part of the implementation work, Mapping and Navigation of Autonomous Robotwith LiDAR for indoor applications, consists of a mobile robot powered by an Arduino board and equipped with aLIDAR sensor for room scanning. The LIDAR sensor emits laser beams and measures the time-of-flight of the reflected beams, providing accurate distance measurements. Arduino isresponsible for controlling the robot's movements and acquiring data from the LIDAR sensor. Bluetooth connectivity is used to establish a wireless communication link between the robot and a remote server. The robot scans the room by systematically moving and rotating, capturing LIDAR data at different angles. The collected data is processed, and a detailed 2D map of the room is generated. The map data is transmitted to a remote server viaPython Flask, enabling real-time visualization and analysis.

This work presents a novel and efficient approach for room scanning and mapping. By utilizing LIDAR technology, Arduino control, Bluetooth connectivity, and Python Flask integration, the work enables real-time generation, visualization, and analysis of room maps. The system offers the potential for a wide range of applications, including robotics, smart home automation, and indoor navigation. The work's implementation demonstratesthe feasibility and effectiveness of using LIDAR for accurate room scanning and lays the foundation for further research and development in this field.

FUTURE SCOPE:

The work offers several possibilities for future expansion and improvement. Some potential areas for future development include implementing SLAM (Simultaneous Localization and Mapping) algorithms for simultaneous mapping and localization, integrating additional sensors for environmental data collection (e.g., temperature, humidity), incorporating machine learning techniques for advanced map analysis and objectrecognition, and enhancing the robot's autonomy by incorporating path planning algorithms.

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Conflicts of Interest: The authors declare no conflicts of interest.

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