IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, May 2026
Impact Factor: 8.2

AMR with ROS Robotics Technology Using Camera and LIDAR

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Abstract: *Autonomous Mobile Robots are really useful in places like offices and schools. They can do things that people normally do such as bringing documents from one place to another. This project is about creating an Autonomous Mobile Robot that can move around by itself using a camera and a special sensor called LiDAR. In schools and offices people usually have to get up and bring documents to someone.*

This can be a lot of work. So, we thought, why not use an Autonomous Mobile Robot to do this job. It can bring documents and other things without anyone having to tell it what to do. the Autonomous Mobile Robot can move around buildings all by itself. It can find things that're in its way and get to where it needs to go without anyone helping.

We used a sensor called LiDAR to help the Autonomous Mobile Robot understand where it is. We also used a camera so we can see what is going on. The Autonomous Mobile Robot uses a computer called an ESP32 to control its movements. It also uses something called ROS2 to communicate and find its way. We tried out the Autonomous Mobile Robot. It worked really well. It can move around safely in places, like hallways and rooms This project is not too hard to do..

Keywords: Autonomous Mobile Robot, ROS Robotics Technology, Camera, 2D LiDAR, Indoor Navigation, SLAM, ESP32

I. INTRODUCTION

In schools and colleges people do a lot of jobs like handing out papers moving small things and files. This takes a lot of time and people that could be used for important things. Autonomous Mobile Robots or AMRs can help with these tasks.

An AMR is a robot that can move around on its own by looking at what's around it and making decisions away. Unlike robots that are controlled from away AMRs do not need people to tell them what to do all the time. They can see things in their way find a path and get where they need to go.

With developments, in robotics software it is now easier to make such systems using platforms that anyone can use.

This project is about building an Autonomous Mobile Robot using ROS robotics technology. The robot has a camera and LiDAR sensors. It can deliver documents and services on its own. The robot is meant to be used inside buildings like college buildings, laboratories and offices. We are using

ROS2 as the software because it helps the different parts of the robot talk to each other reliably. It also supports navigation tools.

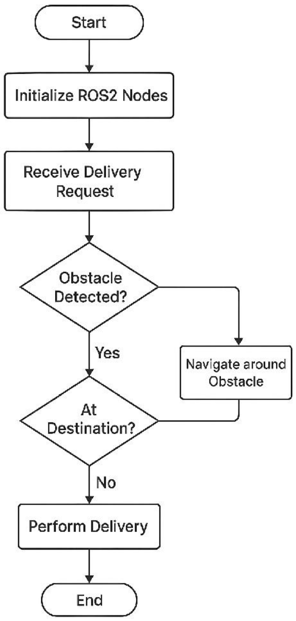

Fig. 1.1 Flowchart of project.

The main goal of this project is to make a robot that's easy to understand and affordable. It should be useful for students to learn about robotics. This project also helps students get hands-on experience with robotics systems.

ROS2 is a platform that people can use to develop robotic applications. It makes it easy for the sensors, motors and control systems in the robot to communicate with each other. ROS2 is better than ROS1 because it is faster, safer and works in time.

In this project we are **using ROS2 with hardware like an ESP32 microcontroller, a 2D LiDAR sensor, wheel encoders and a camera.** These parts help the Autonomous Mobile Robot sense what is, around it plans where it needs to go and move correctly.

For the Autonomous Mobile Robot to move around on its own it needs to be able to do three things. Perceive its surroundings know where it is and control its movements.

Perception means understanding the surroundings using sensors like LiDAR and cameras.

Localization means finding the robot's current position on the map.

Control means giving commands to the motors to reach the target point safely.

I am using ROS2. It is really great. ROS2 helps all these things work together. The ESP32 is in charge of the motors and sensors. At the time a computer that has ROS2 on it does the navigation and mapping and helps with obstacle avoidance. The computer with ROS2 is very important because it does a lot of the thinking. The ESP32 and the computer, with ROS2 work together and that is why it works smoothly with ROS2.

In a school setting this robot can carry papers from one room to another all by itself. For instance, a teacher can send a document to the exam office using a computer screen. The robot will figure out the way to get there stay away from people and things in the way and get to where it needs to go. **The special sensor called 2D LiDAR** helps the robot see objects while the wheels tell the robot how far it has moved. The camera lets us watch what the robot is doing in time and a memory card keeps track of where the robot has been and what it has delivered.

This robot is really useful. It is also a great way for students to learn. It helps students understand how all the parts of the robot work together like the sensors and the motors and the computer programs. Because it uses parts that're not too expensive and are open for anyone to use schools can afford to buy it. We can also add features to the robot later like

ISSN: 2581-9429

connecting it to the internet or giving it voice commands or even helping it find its way around using special computer programs.

In summary this report is about building a kind of robot called an AMR that uses a camera and a special sensor called LiDAR and a computer program called ROS all, for use in a school. The rest of this report will talk about what other people have done how we built the robot how it moves around what we learned from our experiments and what we think about it all.

II. LITERATURE REVIEW

Many people have tried to make robots that can move around on their inside buildings. At first these robots used things like ultrasonic sensors to detect things in their way. These sensors were not very good because they could only see things that were very close. So, these robots had a lot of trouble in places with a lot of things going on.

Then robots that used **LiDAR** became more popular. LiDAR is good because it can measure how away things are very accurately and make very detailed maps. Some researchers showed that robots that used LiDAR and something called **SLAM** could move around safely inside buildings. A lot of people started using something called ROS because it made it easy to connect sensors and control algorithms together., Now people are looking at something called ROS2 because it makes things communicate faster and makes the whole system more stable. Some projects are also using cameras with LiDAR to help the robot understand what is, around it. The cameras can see what things look like. The LiDAR makes sure the robot knows how far away things are. The LiDAR and cameras work together to help the robot navigate inside buildings.

However, many existing systems are really complicated and costly. This project is about creating an affordable AMR that can still do navigation and delivery tasks well. It's meant to be good for use.

These studies show that using ROS2 with sensors and microcontrollers is a great way to make autonomous robots. ROS2 is good because it makes it easy to add or remove parts handle lots of data and work with devices.

When we combine 2D LiDAR, wheel encoders and ESP32 we get a robot that can navigate and avoid obstacles efficiently. The AMR is suitable, for use because it is simple and low-cost. The integration of **2D LiDAR**, **wheel encoders**, and **ESP32** ensures efficient navigation, obstacle detection, and real-time performance at an affordable cost.

III. PROPOSED SYSTEM

The robot I am working on is a self-driving robot. It is designed to carry documents and do tasks inside buildings. It uses DC motors with gears to move around. These motors are connected to wheel encoders. These encoders help the robot know how far it has traveled and how fast it is going. The brain of the robot is an ESP32 microcontroller. This microcontroller tells the motors what to do. It also talks to the ROS2 system.

The robot has a 2D LiDAR sensor on it. This sensor helps the robot see obstacles in its way. It also helps the robot make a map of where it's The robot also has a webcam. This webcam lets people watch the robot remotely. It can also be used for improvements. All the parts of the robot are connected using ROS2. ROS2 helps all the sensors, control units and navigation software talk to each other.

Here is how the robot works: it gets a destination point. Then it moves to that point by itself. It can even avoid obstacles, on its way.

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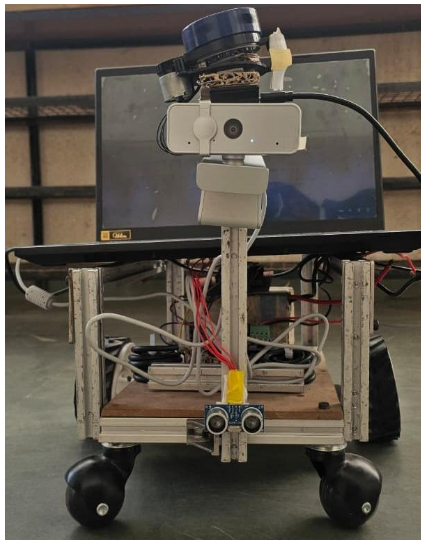

2.1 Prototype design

1. Hardware Design

ESP32 Microcontroller:

The ESP32 is really good for robots because it has two cores and can connect to the internet without any wires. This thing can control the motors read the information from the encoders and talk to the sensors. The ESP32 is like a man between the ROS2 system and the actual hardware so it helps the ROS2 system control the hardware and get information from it at the same time. The ESP32 does not cost a lot of money. It can connect to the internet without wires, which makes the ESP32 a great choice, for robots that people use to learn in school.

2D LiDAR Sensor:

The 2D LiDAR sensor is always looking around. Making a 2D map of the environment. It tells us how away things are which helps the 2D LiDAR sensor find things that are in the way, like obstacles and walls. The ROS2 framework uses the 2D LiDAR sensor data and SLAM algorithms to make the environment map and update it as the 2D LiDAR sensor keeps looking.

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DC Planetary Gear Motors:

These robot motors are used for driving the wheels of the robot. The planetary gear motors are really good because they provide torque and smooth motion. This is very important for the robot to have navigation. It is especially important when the robot is moving on surfaces. The motor driver gets commands from the ESP32. It controls the motor speed and the motor direction of the robot motors.

Wheel Encoders:

Wheel encoders track how much the wheels turn and give information to ROS2 about the robot's movement. This information helps figure out where the robot is and how it is moving. The data from encoders is really important. It helps the robot move in a line and make sharp turns. The feedback, from wheel encoders is key. It helps keep the robot on track.

Motor Driver:

The motor driver helps connect the ESP32 to the DC motors. It changes the small control signals from the ESP32 into signals that can power the motors. This driver also works with PWM.PWM helps control the motor speed The motor driver and ESP32 work together. The ESP32 sends signals. The motor driver makes them strong. The DC motors need signals. The motor driver provides them. It uses PWM for speed. The ESP32 and motor driver make it happen. The motor driver is an interface. It helps the ESP32 and motors talk. The ESP32 gives a signal. The motor driver makes it bigger. The DC motors get the signal. They start moving. The motor driver helps with speed. It uses PWM. The ESP32 is, in charge. It sends the signal. The motor driver does the rest. The DC motors move smoothly.

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Web Camera:

The robot has a web camera on it. This camera lets the person operating the robot see what is happening in time with video streaming and visual feedback. The web camera can also be used for things, like visual SLAM or recognizing objects if we decide to add those features to the robot later on.

128 GB Memory Card:

The memory card is used to store system logs and navigation data and maps and recorded video feeds. This makes it easy to look at the data and make the system better over time. The memory card is really helpful, for storing all this information like system logs and recorded video feeds.

2. Software and Control Architecture

ROS2 Framework:

The ROS2 system is like the brain of the robot' The Navigation2 system in ROS2 figures out how a robot gets to where it needs to go's software. It helps all the parts of the robot talk to each other. These parts include sensors, motors and control programs. They are all connected through units called **nodes**. Each of these nodes has its special job. For example, together. The ROS2 system and the **publisher and subscriber** system are parts of the robots software.one node is in charge of getting data from the **LiDAR sensor.** Another node is, in charge of the motors. Another node figures out the path the robot will take.

The ROS2 system uses a way for the parts of the robot to communicate with each other. This is called the **publisher** and **subscriber** system. One part of the robot the publisher sends out information. Then another part, the subscriber gets this information. Uses it. For example, the ROS2 system uses this **publisher and subscriber** system to help all the parts of the robot work

The **LiDAR node** sends distance data.

The **encoder node** sends movement data.

The **navigation node** uses both to plan a safe path.

The **control node** sends movement commands to the ESP32.

This structure makes the robot reliable and easy to modify or upgrade later.

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Perception Layer:
The perception part is what helps the robot see and understand the things around it. It has a **2D LiDAR sensor** that scans the area to find any obstacles or walls that're close by. This information is used to create a **2D map of the environment.**
The robot also has a webcam that shows a view of where the robot is going. This is really helpful for keeping an eye on the robot. It can also be used later to help the robot recognize things it sees. The robot uses something called **ROS2 that has tools**, like the **SLAM Toolbox.** The SLAM Toolbox is what lets the robot build a map of its surroundings while it is moving around which is called **Simultaneous Localization and Mapping** or the **Perception** Layer uses a method called SLAM for short.

Localization and Mapping:
Localization is when the robot figures out where it is on the map. The robot looks at information from a thing like the **LiDAR** and the **wheel encoders** and sometimes the **IMU** to work out its position on the map. The robot uses something called the **AMCL (Adaptive monte Carlo localization)** method in ROS2 to find its location. This is helpful because even if the robot slips a little or moves unevenly it can still know where it is. When the robot starts up it loads a map that it saved earlier from a **memory card.** Then it finds its location on this map. Once the robot knows where it is, on the map it can start moving towards the goal. The robot uses Localization to do all this.

Path Planning and Navigation:
The **Navigation2** system in ROS2 figures out how a robot gets to where it needs to go. It works in two steps:
Global Planner: Plans the best route from the starting point to the goal.
Local Planner: Detects new obstacles and avoids them in real time.
If a person walks in front of the robot the LiDAR sensor detects it. The Navigation2 system then immediately changes the path so the robot does not hit the person. Once the person moves out of the way the robot keeps going toward its goal. The Navigation2 system and the LiDAR sensor work together. The robot uses the Navigation2 system to navigate. The Navigation2 system uses the LiDAR sensor to detect obstacles.
Motion Control:
The robot moves because of the motion control system. ROS2 tells the ESP32 how fast and in which direction to go.The ESP32 then uses the motor driver to control the DC planetary gear motors.The wheel encoders track how much each wheel turns. Sends this info back, to ROS2.
This helps ROS2 make sure the robot goes straight and turns the way.The motion control system makes all this workThe ESP32 and ROS2 work together to make the robot move correctly.The robot uses the motion control system to move.

IV. PROBLEM FORMULATION

PID Control:
The motors are controlled using a **PID controller.** This PID controller checks if the motor speed is what it is supposed to be. If the motor speed is not matching the target speed the PID controller makes some changes. It. Increases the power or decreases the power to the motors. This helps to fix the difference, between the motor speed and the target speed.
The movement of the motors becomes smooth when the PID controller does its job. The PID controller also helps to prevent the motors from moving in a jerky motion. This is because the PID controller is always checking the motor speed and making changes to keep it smooth. The motor speed and the target speed of the motors are always being checked by the PID controller.

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The formula used is

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt}$$

Where:
$e(t)$= error between desired and actual speed
K_p, K_i, K_d are constants used for tuning the controller.

Data Logging and Monitoring:

All the data from the sensors camera and navigation system is stored on a 128 GB memory card. I can keep an eye on the robot's position and movement using **RViz**. It is a visualization software that comes with ROS2.This software really helps me when I am testing or troubleshooting or trying to make the robot work better. The robots performance can be improved with the help of RViz software and the data, from the sensors camera.

Wireless Communication:

The robot connects to a computer or mobile interface through **Wi-Fi.**

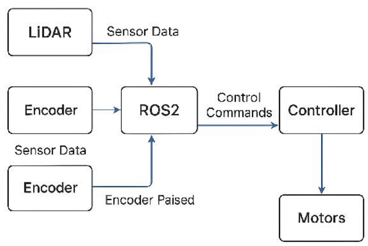

*Fig. 3.1 Working Methodo*logy

V. RESULT AND DISCUSSION

The developed AMR with ROS2 technology using camera and lidar was successfully tested in an indoor academic environment like classrooms, corridors and offices. The main goal was to see how accurately the robot could map the surroundings navigate between points avoid obstacles and complete delivery tasks efficiently.

The robot used a 2D LiDAR sensor to scan the area and create a map with the SLAM Toolbox in ROS2.This process produced an accurate 2D layout of the test area. The AMCL localization system helped the robot identify its position on the map with precision. The map could be reused for operations without remapping, saving time and making navigation faster.

During experiments the robot's navigation performance was tested between destinations. The ROS2 Navigation2 stack helped the robot plan paths from its starting point to target locations within the mapped area. The global planner chose the route while the local planner adjusted the robot's movement to avoid obstacles. The robot moved smoothly. Maintained a stable speed while turning or crossing narrow areas. When an unexpected object was placed in its path the LiDAR sensor detected it immediately. The robot recalculated a route within seconds ensuring safe movement without collisions. The robots motion control was handled by a PID control algorithm on the ESP32 microcontroller. This system helped maintain movement and corrected small speed errors. The DC planetary gear motors provided torque and stability.

The navigation performance of the robot was also tested between multiple destinations. Using the ROS2 Navigation2 stack, the robot planned paths from its starting point to various target locations within the mapped area. The global planner selected the shortest route, while the local planner continuously adjusted the robot's movement to avoid obstacles.

The robot moved smoothly and maintained a stable speed while turning or crossing narrow areas. When an unexpected object was placed in its path, the LiDAR sensor detected it immediately, and the robot recalculated a new route within a few seconds, ensuring safe movement without collisions. The robot could carry loads like documents or envelopes without losing balance. On slightly uneven surfaces the robot maintained steady motion with minimal vibration.

Wireless communication and monitoring were achieved through Wi-Fi connectivity. The user could observe the robot's movement and live camera feed in RViz through the ROS2 interface. This real-time monitoring helped test and verify the robot's path and performance.

All operational data were saved automatically on the 128 GB memory card.

Overall, the robot performed well. Achieved a high success rate in completing document deliveries. It navigated efficiently through the mapped environment. Avoided obstacles effectively. The system proved reliable for use offering a smart and automated way to deliver documents.

The results show that ROS2, ESP32 and 2D LiDAR create a cost- flexible platform for developing autonomous robots. The modular design of ROS2 makes it easier to expand the system in the future. Although the current version depends on lighting and Wi-Fi conditions further improvement can be made by adding more advanced sensors. The robot shows potential for use in colleges and universities not only for service purposes but also as a learning platform, for students.

VI. CONCLUSION

This project shows that an **Autonomous Mobile Robot can work well using ROS robotics technology with a camera and LiDAR for delivering documents and services on its own.** The Autonomous Mobile Robot can move around by itself avoid things that're in its way and get to where it is supposed to go.

The use of ROS2 and hardware that is not too expensive makes the system very good for schools. In the future the Autonomous Mobile Robot can be made to do more things like listen to voice commands recognize objects and charge itself automatically. Overall, this project is a way to learn about autonomous robotics in a simple and easy to understand way.

The results of the experiment show that the Autonomous Mobile Robot can make a map of a room plan a path and avoid things that are in its way all by itself. The ROS2 framework was very important in helping all the different parts of the system work together and talk to each other which made it easier to design and fix problems. The use of parts that're not too expensive but still work well made the project something that schools can afford and use to teach students, which shows that advanced robotics can be used in schools. In a school the Autonomous Mobile Robot can help staff by automating the process of moving documents between offices and departments. It is also a tool for students to learn about robotics, control systems and programming with ROS2. The fact that the system is source makes it easy for students and teachers to customize it and do more research.

In the future the system can be made better by adding things like voice control, face recognition and scheduling through a website. Using LiDAR or depth cameras can make the Autonomous Mobile Robot even better at knowing where it is and avoiding things. Also, the system can be made to work for a time without stopping by adding a way for it to charge itself automatically. The same idea can also be used in hospitals or offices where the Autonomous Mobile Robot can save time and make things more efficient.

Overall, the Autonomous Mobile Robot using ROS robotics technology with a camera and LiDAR is a step, towards making smart and automated systems that can deliver services in schools. It shows that modern robotics technology can be used for tasks and gives students a chance to learn and try new things in the field of autonomous robotics.

VII. ACKNOWLEDGMENT

The authors sincerely express their gratitude to Dr. R. A. Kapgate for his valuable guidance, continuous support, and encouragement throughout this project. We also thank the *Department of Mechatronics Engineering, Sanjivani College of Engineering, Kopargaon*, for providing necessary resources and facilities to complete this research successfully.

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