Design and Development of a Smart Measurement Robot for Educational Training

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ABSTRACT

The rapid development of robotics, embedded systems, and intelligent automation technologies has created increasing demand for practical engineering education platforms that combine theoretical knowledge with real-world applications. This research focuses on the design and development of a smart measurement robot intended for educational training purposes. The proposed system aims to provide engineering students with a practical platform for studying robotics, sensor integration, embedded programming, motor control, measurement systems, and basic Internet of Things (IoT) concepts.

The developed robot system integrates several main hardware components, including the ESP32 microcontroller, VL53L0X Time-of-Flight distance sensor, L298N motor driver, DC encoder motors, LCD display module, and a mobile robot chassis. The ESP32 acts as the central processing unit responsible for sensor communication, motor control, data processing, and display management. The VL53L0X sensor is used to perform automatic distance measurement based on Time-of-Flight technology. The robot is capable of moving toward a target object, stopping at a stable position, measuring the distance, processing the collected data, and displaying the measurement result.

The software system was developed using the Arduino IDE platform and C/C++ programming language. Several software modules were implemented, including motor control, sensor reading, data filtering, LCD display, and measurement error calculation. To improve measurement stability, an averaging algorithm was applied to reduce sensor noise and random fluctuations. Experimental tests were conducted under laboratory conditions to evaluate system performance and measurement accuracy. The experimental results demonstrated that the robot achieved stable operation and acceptable measurement accuracy for educational applications.

The research confirms that low-cost hardware components can be successfully integrated into a practical educational robotics platform. The developed robot not only demonstrates the principles of automatic measurement and robotic control but also provides students with hands-on experience in embedded systems and intelligent automation technologies. Furthermore, the modular design of the system allows future expansion toward advanced functions such as IoT monitoring, PID motor control, computer vision integration, and autonomous navigation. Therefore, the proposed measurement robot represents a valuable educational tool for engineering laboratories and robotics training programs.

Keyword: *Smart measurement robot, ESP32 microcontroller, Time-of-Flight sensor, Educational robotics, Embedded systems, Automatic measurement, IoT applications, Motor control*

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1. INTRODUCTION

1.1. Background of the Research

In recent years, the rapid development of science and technology has significantly transformed industrial production, engineering systems, and educational methods. One of the most important technological trends in modern engineering is the development of robotics and automation systems. Robots are now widely used in manufacturing, logistics, healthcare, transportation, inspection, and intelligent production systems.

At the same time, the Fourth Industrial Revolution, commonly known as Industry 4.0, has accelerated the integration of robotics, embedded systems, sensors, Internet of Things (IoT), artificial intelligence (AI), and data communication technologies into modern industrial environments. As a result, engineering students are increasingly required to acquire not only theoretical knowledge but also practical skills related to robotics and intelligent systems. Based on these reasons, the research topic entitled “Design and Development of a Smart Measurement Robot for Educational Training” was selected.

1.2. Research Motivation

The motivation for this research originates from both educational and technological perspectives. From the educational perspective, many engineering students face difficulties when learning embedded systems, robotics, and automatic control because they lack practical opportunities to apply theoretical knowledge. Students often learn concepts such as sensors, PWM control, motor drivers, and communication protocols theoretically but do not have sufficient laboratory systems for experimentation.

A practical robot platform can significantly improve learning effectiveness by allowing students to:

- Assemble real hardware systems.
- Program microcontrollers.
- Test sensor performance.
- Analyze measurement errors.
- Observe robot motion directly.
- Develop engineering problem-solving skills.

From the technological perspective, smart measurement systems are becoming increasingly important in modern industry. Industrial automation systems rely heavily on sensors and robotic platforms for inspection and quality control. Understanding these technologies is essential for future engineers. Therefore, this project aims to bridge the gap between theory and practice by developing a practical educational measurement robot platform.

1.3. Problem Statement

Although robotics and automation technologies are widely studied, many educational institutions still face several challenges in practical robotics training. First, industrial robot systems are expensive. Advanced industrial measurement robots often require specialized equipment and software that exceed the budget limitations of many laboratories. Second, many educational robot kits are designed mainly for programming demonstrations and do not provide realistic measurement or inspection functions. As a result, students may learn basic movement control but have limited exposure to real industrial measurement concepts. Third, students often study sensors and embedded systems separately without understanding how these components are integrated into a complete robotic system. Fourth, there is a need for a training platform that combines:

- Mobile robotics.
- Automatic measurement.
- Embedded programming.
- Sensor integration.
- Data processing.
- Motor control.
- IoT communication.

Therefore, this research focuses on designing and implementing a smart measurement robot system that addresses these educational requirements while maintaining low cost and practical feasibility.

1.4. Research Objectives

1.4.1. General Objective

The general objective of this research is to design, implement, and evaluate a smart measurement robot for educational training purposes using embedded systems and sensor technologies.The proposed robot should be capable of:

- Performing automatic distance measurement.
- Processing measurement data.
- Controlling robot movement.

- Displaying measurement results.
- Supporting future IoT expansion.

The system is intended to serve as a practical educational platform for engineering students.

1.4.2. Specific Objectives

To achieve the general objective, the following specific objectives were established:

a) Study theoretical foundations

The project studies theoretical concepts related to:

- Robotics systems.
- Distance measurement principles.
- Sensor communication.
- IoT fundamentals.

b) Design the robot hardware system

The project designs:

- Robot mechanical structure.
- Electronic circuit system.
- Sensor integration system.
- Power supply system.
- Motor driving system.

c) Develop embedded software

The software system must support:

- Sensor reading.
- Motor control.
- PWM generation.
- Data filtering.
- LCD display.

d) Conduct experiments

The project performs experiments to:

- Test measurement accuracy.
- Evaluate system stability.
- Evaluate educational feasibility.

e) Evaluate educational application potential

The project evaluates how the developed robot can support:

- Laboratory practice.
- Embedded systems education.
- Robotics training.

1.5. Research Scope

1.5.1. Technical Scope

This research focuses mainly on developing a low-cost educational measurement robot. The technical scope includes:

- Mobile robot design.
- Distance measurement using VL53L0X.
- ESP32-based embedded control.
- Basic motor control using L298N.

The project does not focus on:

- Industrial-grade precision measurement.
- Advanced AI algorithms.
- Autonomous navigation systems.
- High-speed industrial robotics.

1.5.2. Experimental Scope

The experiments are conducted under controlled laboratory conditions.

The scope includes:

- Indoor operation.
- Short-range distance measurement.
- Flat target surfaces.
- Basic robot movement.
- Educational performance evaluation.

The project does not include outdoor autonomous operation or industrial deployment.

1.5.3. Educational Scope

The robot is designed primarily for:

- Engineering students.
- Robotics laboratories.
- Embedded systems courses.
- Sensor and instrumentation practice.
- IoT introductory experiments.

The system is intended as a practical educational tool rather than a commercial industrial product.

1.6. Research Methodology

To achieve the proposed objectives, several research methods were applied.

1.6.1. Literature Review Method

The first stage involved studying related theories and technologies.

The literature review included:

- Robotics fundamentals.
- Sensor technologies.
- Time-of-Flight measurement.
- IoT communication systems.
- Educational robotics platforms.

Technical datasheets and academic references were also studied to understand hardware specifications and implementation requirements.

1.6.2. System Design Method

After studying the theoretical background, the system architecture was designed.

The design stage included:

- Mechanical structure design.
- Electrical circuit design.
- Power supply planning.
- Algorithm development.

A modular design approach was used to simplify future maintenance and upgrades.

1.6.3. Experimental Method

Experimental methods were used to evaluate system performance.

The experiments included:

- Sensor testing.
- Robot movement testing.
- Measurement accuracy testing.
- Stability testing.

Experimental results were compared with reference measurements to evaluate performance.

1.6.4. Comparative Analysis Method

Measurement results obtained from the robot were compared with standard measurement tools such as rulers or measuring tapes. The analysis included:

- Absolute error calculation.
- Relative error calculation.
- Repeatability evaluation.
- Stability analysis.

This method helped determine whether the robot achieved acceptable educational performance.

1.7. Research Significance

1.7.1. Scientific Significance

From a scientific perspective, the project contributes to educational robotics research by integrating multiple engineering technologies into a single practical platform.

The research demonstrates the feasibility of combining:

- Robotics.
- Embedded systems.
- Motor control.
- IoT concepts.

The project also provides a reference model for future educational robotic systems.

1.7.2. Educational Significance

The educational significance of the project is considerable.

The robot system allows students to:

- Apply theoretical knowledge in practice.
- Practice motor control techniques.
- Analyze measurement systems.
- Develop engineering thinking.

The system also supports project-based learning approaches that improve student engagement and practical skill development.

1.7.3. Practical Significance

Practically, the developed system demonstrates how low-cost hardware can be used to create meaningful engineering training tools.The project may support:

- Robotics laboratory development.
- Embedded systems teaching.
- STEM education activities.
- Research-oriented student projects.

The modular structure also allows future expansion into more advanced robotic applications.

1.8. Proposed System Overview

The proposed system is a mobile measurement robot consisting of several main modules:

- ESP32 microcontroller.
- VL53L0X distance sensor.
- L298N motor driver.
- Power supply system.
- Robot chassis.

The ESP32 acts as the central controller. The VL53L0X sensor measures the distance to the target object using Time-of-Flight technology. The L298N module controls the DC motors, allowing the robot to move and position itself. The robot is designed to operate in laboratory environments and demonstrate the principles of robotic measurement systems.

2. THEORETICAL BACKGROUND

2.1. Overview of Robots and Measurement Robots

2.1.1. Concept of Robots

A robot is a mechatronic system capable of performing specific tasks through actuators, a control system, and pre-programmed instructions. In modern engineering, a robot is not limited to an industrial robotic arm but may also include mobile robots, autonomous robots, service robots, educational robots, or sensor-integrated robotic systems used for measurement and inspection. In this research topic, the robot is not designed as a large-scale industrial robot. Instead, it is developed as a smart measurement robot model for student training. The robot is expected to move, collect measurement data through sensors, process the results, and display information for practical learning purposes.

2.1.2. Role of Robots in Technical Education

In technical education, robots play an important role because they integrate multiple engineering fields. When students study and practice with robots, they do not learn only one subject separately but can combine knowledge from mechanics, electronics, programming, automatic control, sensors, and data processing. The strength of robots in education lies in their visual and practical nature. Instead of only learning theories about sensors or control, students can directly observe how a robot moves, measures distance, processes data, and produces results. This improves knowledge acquisition and develops engineering thinking.

2.2. Measurement Robots

2.2.1. Concept of Measurement Robots

A measurement robot is a robotic system integrated with measuring devices, sensors, and processors to collect data from the environment or from objects under inspection. The measured data may include distance, size, height, position, temperature, humidity, weight, or other physical parameters.A measurement robot can be considered a combination of three technological groups:

- Robotics technology: enabling the system to move or manipulate.
- Measurement technology: enabling the system to collect accurate information.

2.2.2. Practical Significance of Measurement Robots

In industrial production, measurement and quality inspection are important stages. If a product has dimensional errors or technical defects, it may not meet assembly requirements or quality standards. Traditionally, many inspection tasks were performed manually using calipers, micrometers, or conventional measuring tools. However, manual methods have several limitations:

- They depend on the skill of the operator.

- Inspection speed is slow.
- Errors may occur due to manual operation.

Measurement robots help overcome these limitations by automating the measurement process. When properly programmed, robots can perform repeated operations with high stability, reduce dependence on humans, and improve inspection efficiency. In education, a measurement robot model helps students understand the quality inspection process in industry at a simplified model level. Students can practice from design, assembly, programming, and testing to accuracy evaluation.

2.2.3. General Structure of a Measurement Robot

A basic measurement robot usually consists of the following functional blocks:

Functional block	Main function
Mechanical block	Creates the structure, supports components, and ensures stable operation
Drive block	Generates motion for the robot
Central processing block	Processes signals and controls the robot
Display block	Displays measurement results
Power supply block	Provides energy for the whole system

In this research topic, the proposed robot structure includes:

- ESP32 microcontroller as the central processor.
- VL53L0X sensor for distance measurement.
- DC encoder motors for motion.

2.3. Theoretical Basis of Measurement

2.3.1. Concept of Measurement

Measurement is the process of determining the value of a physical quantity by comparing it with a standard unit. In engineering, measurement plays an important role because most control systems require input data from sensors. For a measurement robot, measured data is the basis for decision-making. If the measured data is incorrect, the control system may generate incorrect responses. Therefore, sensor accuracy and stability are important factors.

2.3.2. Errors in Measurement

In practice, no measurement is absolutely accurate. Every measurement contains errors. An error is the difference between the measured value and the true value of the measured quantity.

In this research topic, measurement errors may come from several causes:

- Sensor error.
- Environmental light interference.
- Poor reflective surface of the object.
- Non-optimized data processing algorithm.

Therefore, when designing a measurement robot, multiple measurements should be performed, the average value should be calculated, and the result should be compared with a standard value to evaluate reliability.

2.3.3. Accuracy, Resolution, and Repeatability

In measurement systems, three important concepts should be distinguished: accuracy, resolution, and repeatability. Accuracy indicates how close the measured value is to the true value. A system has high accuracy when the measured result is close to the standard value. Resolution is the smallest change that a sensor can detect. For example, if a sensor can detect a change of 1 mm, its resolution is 1 mm. Repeatability indicates the ability of a system to produce similar results when measuring repeatedly under the same conditions. A good measurement system should have high repeatability. In a measurement robot model for training, the accuracy does not need to reach high-end industrial standards. However, the system must be stable enough for students to observe, analyze, and evaluate results.

2.4. Overview of Sensors in Robots

2.4.1. Concept of Sensors

A sensor is a device capable of detecting changes in a physical or chemical quantity and converting that change into an electrical signal. This signal is then sent to a processor for analysis and use. In robots, sensors act like the "senses" of the system. Humans use eyes to see, ears to hear, and skin to feel; robots use sensors to perceive the environment.

2.4.2. Role of Sensors in Measurement Robots

In a measurement robot, sensors play a central role because the whole task depends on measurement data. Sensors help the robot:

- Determine the distance to an object.
- Detect the measurement position.
- Provide input information for the controller.
- Evaluate environmental conditions.

If the sensor does not operate stably, the measurement result will be inaccurate. Therefore, selecting an appropriate sensor is one of the most important steps in system design.

2.4.3. Classification of Distance Sensors

Several types of distance sensors are commonly used in robotics:

Sensor type	Principle	Advantages	Limitations
Ultrasonic sensor	Measures echo time of sound waves	Low cost, easy to use	Easily affected by noise, medium accuracy
Infrared sensor	Measures reflected IR light	Compact, inexpensive	Affected by color and surface properties
LiDAR	Multi-point laser scanning	Accurate, wide range	High cost

In this research topic, the laser Time-of-Flight sensor is selected because it offers better accuracy than ultrasonic sensors, has a compact size, and can communicate easily with ESP32.

2.5. Distance Measurement Using Time-of-Flight Technology

2.5.1. Principle of Time-of-Flight

Time-of-Flight, abbreviated as ToF, is a distance measurement technology based on the travel and reflection time of a signal. The sensor emits a beam of light or laser toward an object. When the light reaches the object surface, it is reflected back to the sensor. Based on the time between emission and reception, the sensor can calculate the distance.

2.5.2. Advantages of ToF Sensors

ToF sensors have several advantages in measurement robot applications. First, the sensor has a fast response speed. This is suitable for mobile robots because the robot needs to update distance information continuously during operation. Second, the sensor is compact. In an educational robot model, installation space is usually limited, so a compact sensor is easier to mount on the robot frame. Third, laser ToF sensors are less affected by measurement angle than some simple infrared sensors. This helps improve measurement stability under different conditions. Fourth, the sensor can communicate directly with the microcontroller through the I2C protocol, reducing wiring complexity and simplifying the circuit.

2.5.3. Limitations of ToF Sensors

Despite their advantages, ToF sensors also have some limitations:

- Measurement results may be affected by overly shiny or very dark object surfaces.
- Strong ambient light may cause interference in some cases.
- Robot vibration may cause measurement fluctuations.

Therefore, when using a ToF sensor in this research, it is necessary to combine it with data filtering algorithms, such as averaging multiple measurements, removing abnormal values, or measuring only when the robot has stopped and stabilized.

2.6. VL53L0X Sensor

2.6.1. Introduction to the VL53L0X Sensor

The VL53L0X is a distance sensor using Time-of-Flight technology developed by STMicroelectronics. It is a compact laser-ranging module capable of absolute distance. In the measurement robot project, the VL53L0X is suitable because it is compact, easy to program, reasonably priced, and supported by libraries for Arduino and ESP32.

2.6.2. Technical Characteristics of VL53L0X

Some basic characteristics of the VL53L0X are shown below:

Parameter	Reference value
Measurement technology	Time-of-Flight laser ranging
Applications	Distance measurement, robotics, object detection
Advantages	Compact, fast response, absolute distance measurement

The VL53L0X can measure absolute distance and is less dependent on target reflectance than some traditional measurement technologies.

2.6.3. Operating Principle of VL53L0X

The VL53L0X operates according to the following process:

1. The sensor emits an infrared laser pulse.
2. The laser pulse travels to the object in front of the sensor.
3. Part of the light is reflected from the object back to the sensor.
4. The optical receiver inside the sensor receives the reflected signal.

2.6.4. Reasons for Selecting VL53L0X for the Project

In this measurement robot project for student training, the VL53L0X sensor is selected for the following reasons.

First, the sensor is compact and easy to mount on the robot frame. This is suitable for a small mobile robot model used in the laboratory. Second, it uses I2C communication, making connection with ESP32 simple. Only two signal lines, SDA and SCL, are needed for data transmission between the sensor and microcontroller. Third, the sensor is supported by common libraries, so students can easily program it using Arduino IDE or PlatformIO. Fourth, the sensor provides accuracy suitable for educational models. The purpose of the project is not to build an ultra-high-precision industrial measuring machine, but to develop a practical training model that helps students understand measurement principles, control, and data processing.

2.7. ESP32 Microcontroller

2.7.1. Introduction to ESP32

ESP32 is a microcontroller series with integrated WiFi and Bluetooth developed by Espressif Systems. ESP32 is designed for IoT applications, smart control systems, and low-power embedded devices. In this research topic, ESP32 acts as the central processing unit of the robot.

2.7.2. Role of ESP32 in the Measurement Robot System

ESP32 performs the following main tasks:

- Receives data from the VL53L0X sensor.
- Reads encoder pulses from the motors.
- Controls the L298N motor driver.
- Outputs PWM signals to adjust motor speed.
- Displays data on an LCD.

2.7.3. Technical Characteristics of ESP32

Some commonly used characteristics of ESP32 are shown below:

Parameter	Description
Wireless connectivity	2.4 GHz WiFi, Bluetooth
Peripheral interfaces	UART, SPI, I2C, PWM, ADC
Applications	IoT, robotics, sensors, control
Advantages	Low cost, powerful, many supported libraries

2.7.4. Reasons for Selecting ESP32

ESP32 is selected instead of Arduino Uno or other basic microcontrollers because:

- It has higher processing performance.
- It integrates WiFi and Bluetooth.
- It supports many GPIO pins.

2.8. DC Encoder Motor

2.8.1. Concept of DC Motor

In mobile robots, DC motors are usually used to drive wheels. By changing the voltage supplied to the motor or changing the PWM duty cycle, the motor speed can be adjusted.

2.8.2. Encoder in DC Motors

An encoder is a component used to measure the speed or angular position of a motor. It generates electrical pulses when the motor shaft rotates. The microcontroller counts these pulses to determine the number of rotations, speed, or distance traveled by the robot.

2.9. L298N Motor Driver

2.9.1. Introduction to L298N

L298N is a motor driver module based on the L298 integrated circuit. It is a dual H-bridge driver that can control inductive loads such as relays, solenoids, DC motors, and stepper motors. In this project, L298N is used to control the two DC motors of the robot. ESP32 cannot directly provide enough current to drive motors because GPIO output current is very small. Therefore, the L298N driver is needed as an intermediate power stage.

2.9.2. H-Bridge Principle

An H-bridge is an electrical circuit that allows the current direction through a motor to be reversed. When the current direction changes, the rotation direction of the motor also changes.

With an H-bridge, the robot can:

- Move forward.
- Move backward.
- Turn left.
- Turn right.
- Stop the motors.

2.9.3. Speed Control Using PWM

PWM is a motor speed control method that changes the pulse width of the voltage signal. Instead of continuously changing the voltage, the microcontroller generates a high-frequency ON/OFF pulse sequence. The ratio of ON time to the total period is called the duty cycle. In the measurement robot, PWM helps adjust the robot speed. When the robot needs to measure, the speed must be reduced or the robot must stop completely to reduce vibration and measurement error.

2.10. I2C Communication

2.10.1. Concept of I2C

The advantage of I2C is that it requires only two signal wires while allowing multiple devices to connect on the same bus. Each device on the I2C bus has its own address.

2.10.2. Application of I2C in the Project

Using I2C makes the circuit more compact, reduces wiring, and is convenient for students during practical assembly. However, when using multiple I2C devices, the address of each device must be checked to avoid address conflicts.

2.11. IoT in the Measurement Robot System

2.11.1. Concept of IoT

IoT, or Internet of Things, is a model in which physical devices are connected to the Internet to collect, transmit, and process data. In a measurement robot system, IoT allows measurement data to be sent from the robot to a computer, smartphone, or online storage platform.

2.11.2. Role of IoT in the Project

Integrating IoT increases the practical value of the project. In an educational environment, students can learn more about wireless data transmission, network protocols, and monitoring systems. In a production environment, the IoT function can be used to store product quality inspection data. This data can be stored in a file, database, or displayed on a dashboard.

2.12. Robot Control Algorithms

2.12.1. Basic Motion Control

A two-wheel differential-drive mobile robot is usually controlled by changing the speed and rotation direction of the two wheels. If both wheels rotate in the same direction and at the same speed, the robot moves straight. If one wheel rotates faster than the other, the robot turns. If the two wheels rotate in opposite directions, the robot can rotate in place. In this project, the robot does not need complex movement. Its main task is to move to the measuring position, stop, perform measurement, and display the result.

2.12.2. Basic Measurement Algorithm

The measurement process can be designed as follows:

1. Start the system.
2. Check the sensor.
3. Move the robot to the measurement position.
4. Stop the robot.
5. Wait briefly for the system to stabilize.
6. Perform multiple sensor measurements.
7. Remove abnormal values.
8. Calculate the average value.
9. Display the result.
10. Store or transmit data if necessary.

Multiple measurements help reduce the effect of noise. For example, instead of taking only one value, the system can take 10 measurements and calculate the average.

2.12.3. Measurement Data Noise Processing

Sensor data may be noisy due to vibration, light, object surface, or electrical interference. Therefore, data processing methods are necessary. Some common methods include:

Arithmetic averaging: Taking multiple measurements and calculating the average value. This method is simple, easy to program, and suitable for an educational model.

Median filtering: Sorting measured values and selecting the middle value. This method helps remove abnormal values.

Threshold limiting: If the measured value exceeds the allowed range, the system ignores that value.

2.13. PID Control

2.13.1. Concept of PID

PID is a controller consisting of three components:

- P: Proportional.
- I: Integral.
- D: Derivative.

PID is commonly used to control speed, position, temperature, or other quantities that need stabiliation.

2.13.2. Application of PID in the Measurement Robot

In this project, PID can be used to control motor speed. When the robot moves, if the two motors do not rotate evenly, the robot may deviate from its path. The encoder measures the speed of each wheel, and the PID controller adjusts the PWM signal so that both wheels rotate more steadily. The controller increases PWM for the left wheel and decreases PWM for the right wheel so that the robot moves straighter. Within the scope of this project.

2.14. Data Display System

2.14.1. Role of Data Display

Data display allows users to observe measurement results and robot operating status. For an educational model, data display helps students easily check the program and evaluate experimental results.

2.14.2. Display Options

Several display methods can be used:

Display method	Advantages	Limitations
I2C LCD	Low cost, easy to use, compact	Displays limited information
Serial Monitor	Easy for programming tests	Requires computer connection
Mobile application	Convenient	More complex

In the initial stage, the project can use an I2C LCD for direct display. It can later be expanded to a web interface to improve modernity and practicality.

2.15. Relationship Between Theory and System Design

The theoretical contents in this chapter provide the direct foundation for system design in the next chapter. Therefore, Chapter 2 is not only a theoretical presentation but also the foundation for Chapter 3: design and construction of the measurement robot model.

2.16. Chapter Summary

Chapter 2 has presented the theoretical background related to the research topic of a smart measurement robot for student training. The main contents include an overview of robots, measurement robots, measurement systems, distance sensors, Time-of-Flight technology, the VL53L0X sensor, the ESP32 microcontroller, DC encoder motors, the L298N driver, I2C communication, IoT, control algorithms, and measurement data processing.

3. SYSTEM DESIGN AND DEVELOPMENT

3.1. Chapter Introduction

Based on the theoretical background presented in Chapter 2, this chapter focuses on the design and development of the proposed smart measurement robot model. The system is designed as an educational and experimental platform that allows students to practice robotics, embedded programming, sensor integration, motor control, data acquisition, and measurement error analysis. The main purpose of this chapter is to describe how the measurement robot is designed from the system level to the component level. The chapter presents the technical requirements, system architecture, hardware design, software design, measurement algorithm, control method, communication structure, and implementation plan.

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3.2. System Design Objectives

3.2.1. General Design Objective

The general objective of the system design is to develop a mobile robot capable of performing basic automatic distance measurement tasks using a Time-of-Flight sensor, processing the measured data through an ESP32 microcontroller, and displaying or transmitting the results for educational purposes.

The robot must be able to:

- Move to a measurement position.
- Stop at a stable position.
- Measure the distance to an object.
- Process the measurement data.
- Display the measured value.

3.2.2. Specific Design Objectives

The specific design objectives are as follows:First, the system must have a simple and stable mechanical structure. Since the robot is designed for student practice, the mechanical frame should be easy to assemble, modify, and maintain.Second, the robot must use low-cost but practical electronic components. Components such as ESP32, VL53L0X, L298N, DC encoder motors, and I2C LCD are suitable because they are widely available, affordable, and supported by many open-source libraries. Third, the robot must be able to perform real measurement tasks. The measured value should come from an actual sensor, not from simulation. This allows students to understand measurement noise, sensor limitations, calibration, and error analysis. Fourth, the system must be modular. Each block such as sensor, motor, power supply, display, and communication should be designed as an independent module. This makes troubleshooting easier and allows future upgrades.

3.3. System Requirements

3.3.1. Functional Requirements

The proposed measurement robot must satisfy the following functional requirements:

No.	Functional requirement	Description
1	Robot movement	The robot can move forward, backward, turn left, turn right, and stop
2	Distance measurement	The robot can measure distance using a VL53L0X ToF sensor
3	Data processing	The measured data can be filtered and averaged
4	Result display	The system can display measured distance on an LCD or serial monitor
5	Motor control	The robot can control motor speed using PWM

3.3.2. Non-Functional Requirements

In addition to functional requirements, the system must meet several non-functional requirements.The system should be low-cost so that it can be replicated in laboratories or studentprojects. The design should use popular components that are easy to buy and replace.the system should be safe for students to operate. The voltage level should be low, and the wiring should be arranged clearly to avoid short circuitsThe system should be easy to maintain. Each module should be accessible for testing and replacement.The system should be reliable enough for repeated experiments.

3.4. Overall System Architecture

3.4.1. General Architecture

The proposed system is divided into several main blocks:

- Power supply block.
- Central processing block.
- Sensor block.
- Motor driver block.
- Actuator block.

The ESP32 microcontroller acts as the central control unit. It receives measurement data from the VL53L0X sensor through I2C communication, controls the motor driver through digital and PWM signals, reads encoder signals if required, and sends processed results to the display or monitoring interface.

3.4.2. Description of System Blocks

a) Power Supply Block

The power supply block provides electrical energy to all components. The robot uses a battery source, typically a lithium battery pack. Since different components require different voltage levels, a voltage regulator module is used to provide stable voltage. A stable power supply is important because voltage fluctuation can affect both motor performance and sensor accuracy.

b) Central Processing Block

The ESP32 is selected as the central processing unit. It performs several important tasks:

- Initializes system components.
- Reads sensor data.
- Controls motors.
- Processes measured values.
- Displays results.
- Handles communication.
- Executes the measurement algorithm.

ESP32 is suitable for this project because it has sufficient processing capability, supports I2C, PWM, GPIO, and wireless communication.

c) Sensor Block

The sensor block uses the VL53L0X Time-of-Flight distance sensor. This sensor measures the distance from the robot to the target object. The measured data is transmitted to ESP32 through the I2C bus. To improve measurement accuracy, the sensor should be mounted firmly and aligned with the target surface.

d) Motor Driver Block

The motor driver block uses the L298N module. The ESP32 cannot directly drive DC motors because the current required by the motors is much higher than what ESP32 GPIO pins can provide. Therefore, the L298N module acts as an intermediate power driver. The L298N receives control signals from ESP32 and supplies power to the motors. It allows the robot to move forward, backward, turn, and stop.

3.5. Hardware Design

3.5.1. Mechanical Design

The mechanical structure of the robot is designed as a two-wheel differential-drive platform. This structure is simple, low-cost, and widely used in educational mobile robots.

The robot includes:

- Two driving wheels.
- One caster wheel for balance.
- A chassis frame.

The mechanical design must ensure that the robot remains stable during movement and measurement. If the frame vibrates excessively, the distance sensor may produce unstable results. Therefore, the sensor should be fixed firmly to the front of the robot.

3.5.2. Chassis Design

The chassis is the main body of the robot. It supports all other components, including motors, battery, ESP32, driver module, sensor, and display. For this project, acrylic or 3D-printed plastic is suitable because the model is intended for laboratory training, not heavy industrial operation. The chassis should provide enough space for wiring and component replacement. It should also maintain a low center of gravity to reduce the risk of tipping over.

3.5.3. Sensor Mounting Design

The VL53L0X sensor is mounted at the front of the robot. The mounting position directly affects measurement performance. If the sensor is tilted, the measured distance may be different from the actual perpendicular distance. Therefore, proper alignment is required before experimentation.

3.5.4. Motor and Wheel Arrangement

The robot uses two DC motors placed on the left and right sides of the chassis. Each motor drives one wheel. A caster wheel is placed at the front or rear to maintain balance. This arrangement is called differential-drive configuration. It allows the robot to move and turn by controlling the relative speeds of the two wheels. This configuration is suitable for educational purposes because it is simple and easy to understand.

3.6. Electrical Design

3.6.1. Electrical System Overview

The electrical system connects all hardware components and ensures stable operation of the robot. It includes:

- ESP32 controller.
- VL53L0X sensor.
- L298N motor driver.
- DC encoder motors.
- LCD display.

The electrical design must consider voltage compatibility, current requirements, noise reduction, and grounding.

3.6.2. Power Supply Design

The robot requires different voltage levels for different components. A typical power supply design may include:

Component	Required voltage	Notes
DC motors	6–12 V	Depending on selected motor
L298N driver	6–12 V motor supply	Provides motor driving power
ESP32 board	5 V input or 3.3 V regulated	Depends on board type
VL53L0X module	3.3 V or 5 V	Depends on breakout module
LCD I2C	5 V or 3.3 V	Depends on module

The motor power supply and logic power supply should be carefully arranged. Motors may generate electrical noise and voltage drops when starting. If the ESP32 shares the same unstable supply without proper regulation, the microcontroller may reset or read incorrect sensor data.

3.6.3. ESP32 Pin Assignment

The pin assignment must be planned carefully to avoid conflicts between I2C, PWM, encoder, and motor control signals. A possible pin assignment is shown below:

Function	ESP32 pin	Description
I2C SDA	GPIO 21	Data line for VL53L0X and LCD
I2C SCL	GPIO 22	Clock line for VL53L0X and LCD
Motor A IN1	GPIO 26	Direction control

Motor A IN2 GPIO 27Direction control

Motor B IN3 GPIO 14Direction control

This table can be adjusted depending on the actual ESP32 board and hardware layout.

3.6.4. Sensor Circuit Connection

The VL53L0X sensor is connected to ESP32 through I2C.

Basic connection:

VL53L0X pin	ESP32 pin
VCC	3.3 V or 5 V
GND	GND
SDA	GPIO 21
SCL	GPIO 22

Before operation, the sensor must be initialized in software. If the LCD also uses I2C, both devices can share SDA and SCL lines as long as their I2C addresses are different.

3.6.5. Motor Driver Connection

The L298N module receives control signals from ESP32 and supplies power to the motors. Basic connection:

L298N pin	Connected to
IN1	ESP32 direction pin
IN2	ESP32 direction pin
IN3	ESP32 direction pin
IN4	ESP32 direction pin
ENA	ESP32 PWM pin

It is important that the GND of the ESP32 and L298N are connected together. Without common ground, the control signals may not be recognized correctly.

3.7. Software Design

3.7.1. Software Architecture

The software is designed in a modular structure. Each module performs a specific task, making the program easier to understand and maintain.

The main software modules include:

- System initialization module.
- Sensor reading module.
- Motor control module.
- Measurement processing module.

The modular approach is suitable for student training because students can modify one part of the program without affecting the entire system.

3.7.2. System Initialization

When the robot is powered on, the software first initializes all required components.

The initialization process includes:

1. Start serial communication.

2. Initialize I2C bus.
3. Check VL53L0X sensor.
4. Initialize LCD display.
5. Configure motor control pins.

If any component fails during initialization, the system should display an error message. For example, if the sensor is not detected, the LCD can show "Sensor Error".

3.7.3. Motor Control Program

The motor control program is responsible for controlling direction and speed. Basic motor functions include:

- moveForward()
- moveBackward()
- turnLeft()
- turnRight()
- stopRobot()
- setMotorSpeed()

The motor speed is controlled using PWM. For measurement tasks, the robot should move at a moderate speed to avoid overshooting the target position. Before taking a measurement, the robot should stop completely.

3.7.4. Sensor Reading Program

The sensor reading module reads distance data from the VL53L0X sensor. The basic process is:

1. Request measurement from sensor.
2. Read distance value.
3. Check whether the value is valid.
4. Store the value in memory.
5. Send the value to the processing module.

The program should check for invalid values. For example, if the measured distance is outside the sensor range, the system should ignore it or ask for another measurement.

3.8. Measurement Algorithm

3.8.1. Measurement Procedure

The measurement process is designed to ensure stability and reliability.

The procedure is as follows:

1. Robot starts.
2. System initializes all components.
3. Robot moves toward the target object.
4. Robot stops at the measurement position.

This procedure helps reduce error caused by movement vibration and unstable sensor readings.

3.9. Control Algorithm

3.9.1. Basic Movement Control

The robot uses basic motion control for initial implementation. The two DC motors are controlled by setting direction pins and PWM signals.

Basic logic:

Robot action	Left motor	Right motor
Move forward	Forward	Forward
Move backward	Reverse	Reverse

This control method is simple and suitable for the first prototype.

3.9.2. Closed-Loop Speed Control

For improved performance, encoder feedback can be used to implement closed-loop speed control. The encoder provides real-time speed information, and the controller adjusts PWM to maintain the desired speed.

The control process is:

1. Set target speed.
2. Read encoder pulses.
3. Calculate actual speed.
4. Compare actual speed with target speed.

This approach helps the robot move more stably and improves measurement positioning.

3.10. Data Display and Monitoring Design

3.10.1. LCD Display Design

The LCD display is used to show basic information such as:

- System status.
- Measured distance.
- Measurement number.
- Error value.
- Sensor status.

3.10.2. Serial Monitor Display

During programming and testing, Serial Monitor is useful for debugging. It can display:

- Raw sensor values.
- Filtered values.
- Motor PWM values.
- Encoder pulses.
- Error messages.

Serial Monitor helps students understand how data changes during robot operation.

3.10.3. IoT Monitoring Extension

Since ESP32 supports WiFi, the system can be expanded to send data to a web dashboard. The web dashboard may display:

- Real-time distance.
- Measurement history.
- Error graph.
- Robot status.
- Battery level.

This extension improves the educational value of the project because students can practice IoT data transmission and visualization.

3.11. Component Selection

3.11.1. Main Components

The main components selected for the system are shown below:

No.	Component	Function
1	ESP32	Central controller
2	VL53L0X	Distance measurement
3	L298N	Motor driver
4	DC encoder motors	Robot movement
5	I2C LCD	Data display

3.11.2. Reasons for Component Selection

The selected components are appropriate for this project because they are:

- Low-cost.
- Easy to purchase.
- Easy to program.
- Suitable for student practice.
- Supported by many libraries.

3.12. Expected System Operation

The expected operation of the robot is described as follows. When the robot is powered on, the ESP32 initializes all modules. The LCD displays the system status. The robot then moves toward the target area. When it reaches the measurement position, the motors stop. The system waits briefly to reduce vibration. After that, the VL53L0X sensor performs several distance measurements.

3.13. Safety and Reliability Considerations

3.13.1. Electrical Safety

Because the system is used in an educational environment, electrical safety is important. The robot should use low-voltage power sources, and all wires should be properly insulated. Safety measures include:

- Using a power switch.
- Avoiding exposed wires.
- Checking polarity before powering on.
- Using voltage regulators.

3.13.2. Mechanical Safety

The robot should move at a moderate speed to avoid collisions. Sharp edges on the chassis should be avoided. The battery and electronic modules should be fixed firmly. Mechanical safety measures include:

- Securing the battery.
- Fixing the sensor bracket.
- Avoiding loose wheels.
- Using a stable chassis.

3.13.3. Measurement Reliability

To improve measurement reliability, the following solutions should be applied:

- Stop the robot before measuring.
- Take multiple measurements.
- Remove abnormal values.
- Use stable power supply.
- Keep the sensor clean.

3.14. Educational Application Design

3.14.1. Student Practice Activities

The system is designed not only as a robot prototype but also as a training platform. Students can perform several practice activities such as:

- Assembling the robot frame.
- Connecting ESP32 with sensors.
- Programming distance measurement.
- Controlling motors with PWM.
- Reading encoder pulses.

3.15. Chapter Summary

This chapter has presented the design and development of the proposed smart measurement robot system. The system is designed as a practical educational platform that combines mechanical design, electrical circuits, embedded programming, sensor measurement, motor control, and data processing. The chapter described the system objectives, functional requirements, overall architecture, hardware design, electrical design, software structure, measurement algorithm, control method, display system, component selection, safety considerations, and educational applications.

4. IMPLEMENTATION, EXPERIMENTATION, AND SYSTEM EVALUATION

4.1. Chapter Introduction

After completing the theoretical study and system design presented in the previous chapters, this chapter focuses on the implementation, experimentation, and evaluation of the proposed smart measurement robot system. The main purpose of this chapter is to verify whether the designed system can operate according to the proposed objectives and satisfy the educational requirements of the project.

4.2. Hardware Implementation

4.2.1. Mechanical Assembly

The robot chassis was assembled using a lightweight mobile robot platform. The platform includes two DC encoder motors mounted on both sides of the chassis and one caster wheel used for balancing. During assembly, careful attention was paid to the sensor position because the alignment of the sensor directly affects measurement accuracy. The sensor was mounted at the front side of the robot and positioned parallel to the ground surface to ensure stable measurement conditions.

4.2.2. Electronic Circuit Assembly

The electronic system was assembled according to the circuit design presented in Chapter 3. The ESP32 acts as the main controller and communicates with all peripherals. All grounds were connected together to ensure proper signal reference between the modules. To reduce electrical noise generated by the motors, the following solutions were applied:

- Shortening high-current motor wires.
- Separating signal wires from motor power wires.
- Using decoupling capacitors near the controller and motor driver.
- Using stable voltage regulators for the ESP32.

The completed electronic system was tested step-by-step before full operation.

4.2.3. Sensor Installation

The VL53L0X sensor was mounted on a dedicated bracket at the front of the robot. The bracket was designed to keep the sensor stable during robot movement.

The following factors were considered during installation:

- Sensor height from the ground.
- Sensor angle alignment.
- Distance from the robot frame.
- Mechanical vibration isolation.

4.3. Software Implementation

4.3.1. Development Environment

The software for the robot was developed using the Arduino IDE platform. The ESP32 board package and required sensor libraries were installed before programming.

- It is beginner-friendly.
- It supports ESP32 development.
- It has many open-source libraries.
- It is suitable for educational purposes.

4.3.2. Main Program Structure

The software was divided into several modules to improve readability and maintainability.

Main program modules included:

- System initialization module.
- Motor control module.
- Sensor measurement module.

4.3.3. Motor Control Programming

Motor control was implemented using PWM signals generated by the ESP32. Higher duty cycles generate higher average voltage and therefore higher motor speed. The robot speed was intentionally kept moderate during experiments to reduce vibration and improve measurement stability.

4.3.4. Sensor Data Acquisition

The VL53L0X sensor communicates with ESP32 through I2C communication. The sensor library was used to simplify initialization and data reading. To reduce measurement noise, multiple measurements were performed before calculating the final value.

4.3.5. Data Filtering Algorithm

Raw sensor data may fluctuate due to environmental noise or vibration. Therefore, a filtering algorithm was implemented.

4.4. Experimental Setup

4.4.1. Experimental Environment

Experiments were conducted in a laboratory environment under controlled conditions. The experiments were conducted indoors to minimize environmental disturbances such as strong sunlight, dust, or wind.

4.4.2. Measurement Equipment

The following equipment was used during experiments:

Equipment	Purpose
Ruler or measuring tape	Reference distance measurement
Robot prototype	Measurement system
Laptop computer	Programming and monitoring
USB cable	ESP32 programming
Power supply / battery	System operation

The ruler was used as the reference measurement tool for error comparison.

4.5. Experimental Results

4.5.1. Raw Measurement Data

The robot was tested at several reference distances. The following table presents sample measurement results:

Test No.	Reference Distance (mm)	Measured Distance (mm)	Absolute Error (mm)
1	100	102	2
2	150	148	2
3	200	203	3

The results show that the measurement error remained relatively small within the tested range.

4.6. System Performance Evaluation

4.6.1. Measurement Accuracy

The robot achieved acceptable measurement accuracy within the designed operating range. The error was influenced by:

- Sensor resolution.
- Robot vibration.
- Surface reflectivity.
- Environmental lighting.
- Alignment accuracy.

For educational applications, the obtained accuracy is sufficient to demonstrate practical measurement principles.

4.6.2. Robot Motion Performance

The robot successfully performed basic movements:

- Forward motion.
- Backward motion.
- Turning.
- Stopping.

The differential-drive structure was simple and stable for laboratory operation. These issues can be improved in future work using PID speed control.

4.6.3. Sensor Performance

The VL53L0X sensor demonstrated several advantages:

- Fast response time.
- Compact size.
- Stable short-range measurement.
- Simple integration with ESP32.

The sensor performed best when measuring flat surfaces with moderate reflectivity.

4.6.4. Software Performance

The software operated reliably during experiments. The modular programming structure simplified debugging and testing. The averaging filter effectively reduced noise and improved measurement stability.

4.7. Advantages and Limitations

4.7.1. Advantages

The developed robot system has several advantages:

- Low implementation cost.
- Simple structure.
- Easy programming.
- Real measurement capability.
- Educational suitability.
- Expandable design.
- Stable operation under laboratory conditions.

The system is suitable for student training in:

- Robotics.
- Embedded systems.
- Sensors.
- Automatic control.
- IoT fundamentals.

4.7.2. Limitations

Despite its advantages, the system still has several limitations. First, the measurement range is limited by the VL53L0X sensor capability. Second, the robot movement accuracy is still relatively basic because no advanced navigation or closed-loop trajectory control was implemented. Third, the system may experience measurement fluctuation under strong environmental light. Finally, the robot is designed mainly for educational purposes rather than industrial deployment.

4.8. Future Improvement Directions

Several future improvements can be proposed:

- Implement PID motor speed control.
- Add obstacle avoidance algorithms.
- Integrate wireless monitoring dashboard.

These improvements would increase both educational value and practical application potential.

4.9. Educational Evaluation

4.9.1. Educational Benefits

The robot provides students with practical experience in:

- Mechanical assembly.
- Electronic circuit wiring.
- Embedded programming.
- Sensor integration.
- Measurement systems.

Students can directly observe the relationship between theory and practical implementation.

4.9.2. Suggested Laboratory Activities

Possible laboratory exercises include:

Activity	Learning Outcome
Sensor calibration	Understand measurement error
PWM motor control	Learn speed control principles
Encoder measurement	Learn feedback systems
Data filtering	Understand signal processing

These activities help students develop practical engineering skills.

4.10. Chapter Summary

This chapter presented the implementation, experimentation, and evaluation of the proposed smart measurement robot system.The hardware and software systems were successfully developed and tested. Experimental results demonstrated that the robot could perform automatic distance measurement with acceptable accuracy and stability for educational purposes. Although the system still has some limitations, it demonstrates the feasibility of developing a low-cost educational measurement robot and provides a foundation for future research and system expansion.

5. CONCLUSION AND FUTURE DEVELOPMENT

5.1. Chapter Introduction

This chapter presents the final conclusions of the research project entitled “Design and Development of a Smart Measurement Robot for Educational Training”. The chapter summarizes the main achievements of the study, evaluates the overall performance of the developed system, discusses the scientific and educational contributions of the project, and proposes possible future development directions. The main objective of the project was to design and implement a low-cost, educationally oriented smart measurement robot capable of performing automatic distance measurement using embedded systems and sensor technology.

5.2. Summary of Research Objectives

At the beginning of this research project, several objectives were proposed regarding the development of a practical educational robot system. These objectives included:

- Studying the theoretical foundations of robotics, measurement systems, sensors, embedded systems, and automatic control.
- Designing a mobile robot platform capable of performing automatic distance measurement.
- Implementing the robot using affordable and accessible hardware components.

Through the implementation process, all main objectives were successfully achieved.

5.3. Research Achievements

5.3.1. Theoretical Contributions

One important achievement of this project is the integration of multiple engineering disciplines into a single educational system. The project combined knowledge from:

- Robotics.
- Embedded systems.
- Sensors and measurement systems.
- Motor control.

These theoretical discussions provide useful educational material for future students and researchers.

5.3.2. Hardware Development Achievements

The project successfully developed a complete robot prototype consisting of:

- ESP32 microcontroller.
- VL53L0X distance sensor.
- L298N motor driver.
- DC encoder motors.

The mechanical structure was compact, lightweight, and suitable for laboratory use. The electronic system was assembled successfully and demonstrated stable operation during testing.

5.3.3. Software Development Achievements

The embedded software system was successfully implemented using the Arduino IDE platform and C/C++ programming language. The modular programming structure improved code readability and simplified debugging and maintenance. The software successfully performed:

- Real-time sensor measurement.
- PWM motor speed control.
- LCD data display.
- Measurement averaging and filtering.
- Basic robot movement functions.

The ESP32 microcontroller demonstrated sufficient processing capability for all implemented tasks.

5.3.4. Experimental Achievements

Experimental testing confirmed that the robot system could perform automatic distance measurement with acceptable accuracy for educational applications. The experiments demonstrated that:

- The robot could move stably on flat surfaces.
- The sensor could provide real-time distance measurements.
- The averaging algorithm improved measurement stability.

The relative measurement error remained within an acceptable range for a low-cost educational robot system.

5.4. System Evaluation

5.4.1. Measurement Performance Evaluation

The developed robot achieved relatively stable measurement performance under laboratory conditions.
The VL53L0X sensor provided:

- Fast response time.
- Stable short-range measurements.
- Compact integration capability.
- Low power consumption.

The averaging algorithm reduced measurement fluctuation and improved repeatability. The measurement error was influenced by several factors:

- Sensor resolution limitations.
- Surface reflectivity of target objects.
- Mechanical vibration during operation.

Although the system was not designed as a high-precision industrial measuring device, it successfully demonstrated the principles of automatic robotic measurement.

5.4.2. Motion Control Evaluation

The differential-drive robot platform successfully performed basic movements such as:

- Forward motion.
- Backward motion.
- Left turning.

The robot demonstrated stable movement on flat surfaces. However, some movement deviation was observed due to unequal motor speed and mechanical differences between the motors.

5.4.3. Educational Evaluation

From an educational perspective, the developed robot system provides significant learning value. Students can use the system to practice:

- Robot assembly.
- Electronic circuit integration.
- Sensor calibration.
- Embedded programming.

The system provides direct interaction between theoretical concepts and practical implementation, which is highly beneficial for engineering education.

5.5. Advantages of the Proposed System

The developed robot system offers several advantages.

5.5.1. Low-Cost Design

One of the major advantages of the system is its affordability. The selected hardware components are widely available and relatively inexpensive, making the robot suitable for educational institutions with limited budgets. Low-cost implementation also allows multiple robots to be developed for classroom activities and laboratory experiments.

5.5.2. Modular Structure

The robot was designed using a modular approach. Each subsystem, including sensing, control, motor driving, display, and communication, can operate independently. This modular structure offers several benefits:

- Easier troubleshooting.
- Simpler maintenance.
- Better educational understanding.
- Easier future upgrades.

5.5.3. Expandability

The use of ESP32 provides strong expandability for future development.

Possible future expansions include:

- Wireless monitoring systems.
- Web dashboards.
- Autonomous navigation.

The system therefore provides a strong foundation for future robotics and IoT research projects.

5.5.4. Educational Suitability

The developed robot is highly suitable for educational applications because:

- The system architecture is easy to understand.
- The hardware is accessible for students.
- The robot demonstrates real engineering concepts.
- Students can perform practical experiments.

This makes the project highly valuable for robotics and embedded systems laboratories.

5.6. Limitations of the Current System

Despite the successful implementation, the system still has several limitations.

5.6.1. Limited Measurement Range

The VL53L0X sensor has a relatively short measurement range compared with industrial sensors. The robot is therefore suitable mainly for short-distance measurement experiments. Long-range measurement applications would require more advanced sensors such as LiDAR systems.

5.6.2. Basic Navigation Capability

The current robot only performs basic movement operations and does not include advanced navigation functions such as:

- Path planning.
- Simultaneous localization and mapping (SLAM).
- Obstacle avoidance algorithms.
- Autonomous route optimization.

The robot must therefore operate in controlled laboratory conditions.

5.6.3. Limited Measurement Functions

The current version measures only distance. It does not yet support:

- Shape recognition.
- Surface inspection.
- Object classification.
- Multi-point scanning.
- 3D reconstruction.

5.6.4. Environmental Sensitivity

The measurement accuracy may be affected by:

- Strong ambient light.
- Highly reflective surfaces.
- Uneven ground surfaces.

Improved filtering algorithms and mechanical stabilization would help reduce these effects.

5.7. Future Development Directions

The proposed robot system can be expanded significantly in future research.

5.7.1. PID Speed Control

Future versions of the robot should implement PID-based motor control to improve movement accuracy and stability.

PID control would allow:

- More accurate speed regulation.
- Straighter movement trajectories.
- Better positioning accuracy.
- Improved measurement repeatability.

This control strategy would significantly improve robot motion quality.

5.7.2. IoT and Cloud Integration

Future systems may integrate cloud communication and wireless monitoring.
Possible IoT features include:

- Real-time dashboard visualization.
- Cloud data storage.
- Remote monitoring.
- Smartphone applications.
- Online measurement reports.

This would make the robot more suitable for Industry 4.0 educational environments.

5.7.3. Computer Vision Integration

Another important development direction is the integration of computer vision systems.
Possible vision-based functions include:

- Object recognition.
- Dimension estimation.
- Surface defect inspection.
- QR code detection.
- Object tracking.

Computer vision would significantly increase the intelligence level of the robot.

5.7.4. Autonomous Navigation

The robot may be upgraded into an autonomous mobile robot capable of:

- Environment mapping.
- Path planning.
- Obstacle avoidance.
- Autonomous target positioning.

Additional sensors such as IMU modules, ultrasonic sensors, LiDAR, or cameras would be required for these functions.

5.7.5. Educational Expansion

The robot can also be expanded into a complete educational platform supporting multiple laboratory subjects such as:

- Embedded systems.
- Robotics.
- Automatic control.
- Sensors and instrumentation.

This would increase the long-term educational value of the project.

5.8. Scientific and Educational Contributions

5.8.1. Scientific Contributions

This research contributes to the study of low-cost educational robotics systems by integrating:

- Distance measurement technology.
- Embedded control systems.
- Mobile robot motion.
- Data processing algorithms.
- IoT-oriented communication.

The project demonstrates how a practical measurement robot can be implemented using accessible hardware and software technologies.

5.8.2. Educational Contributions

From an educational perspective, the project provides:

- A practical laboratory model.
- A multidisciplinary learning platform.
- Hands-on engineering experience.
- Real measurement experiments.
- Programming practice opportunities.

Students can better understand how theoretical engineering concepts are applied in real systems.

5.9. Final Conclusion

This research successfully designed, implemented, and evaluated a smart measurement robot intended for educational training and practical laboratory applications. The developed system integrated:

- ESP32 microcontroller.
- VL53L0X Time-of-Flight sensor.
- L298N motor driver.

- DC encoder motors.
- LCD display interface.
- Embedded software modules.

The robot successfully performed automatic distance measurement with acceptable accuracy and stable operation under laboratory conditions. The experimental results confirmed that the proposed system is technically feasible, educationally valuable, and suitable as a low-cost robotics training platform. Although the current system still has limitations regarding navigation intelligence, advanced sensing, and industrial-level precision, it provides a strong foundation for future development in robotics, IoT, embedded systems, and intelligent measurement technologies. The project demonstrates that a low-cost smart robot can effectively support engineering education by combining theoretical knowledge with practical experimentation and system implementation.

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