

# IoT-Based Autonomous Delivery Vehicle for Smart School Logistics and STEM EducationS

<sup>1</sup>Nguyen Tai Tuyen, <sup>2</sup>Mai Xuan Dat, <sup>2</sup>Vu Hoang Viet

<sup>1</sup>Faculty of Electronics Engineering , Posts and Telecommunications Institute of Technology

<sup>2</sup>Faculty of Information Technology, Ha Long University

**Abstract - The research describes how to build an autonomous delivery system which operates in educational environments with their structured and predictable environments. The system operates through two navigation systems which allow users to control it manually using Bluetooth and enable the vehicle to follow lines for turning within school environments. The system depends on basic ultrasonic sensors which work with servo-controlled scanning to detect obstacles automatically. The ESP32-CAM module allows video streaming which enables the vehicle mission supervisor to monitor operational time for maintaining continuous safety. The system design follows Internet of Things (IoT) principles through embedded controllers (Arduino UNO and ESP32-CAM) which enable sensor integration and mobile app development using MIT AppInventor. The system consists of easy-to-maintain and affordable hardware and software components which operate as separate modules. The system enables unrestricted movement through standard Vietnamese school buildings. The system operates reliably at Uông Bí secondary school (Quảng Ninh, Vietnam) during testing experiments which demonstrate its ability to detect obstacles and change operation modes on the concourse. The solution demonstrates excellent potential for educational logistics and internal document delivery and STEM and hands-on STEM and IoT education programs.**

**Keywords - IoT; Autonomous Vehicle; ESP32-CAM; Obstacle Avoidance; Line Following; Bluetooth Control; Smart Campus.**

## I. INTRODUCTION

The Internet of Things (IoT) technology has experienced fast development which brought major changes to smart transportation systems and logistics operations and manufacturing facilities and public service delivery. The Vietnamese IoT market has achieved multiple billion-dollar value milestones according to recent market research and experts predict it will continue to expand rapidly through 2025 because of digital transformation initiatives and 5G network development and rising automation needs in industrial and educational environments. The development of these technologies has increased the importance of autonomous mobile robots (AMRs) and automated guided vehicles (AGVs) for optimizing repetitive work and reducing human workforce needs and improving operational performance.

The educational facilities across Vietnam create an ideal setting to implement robotic solutions. School campuses operate as controlled semi-closed areas with stable ground and regular pedestrian movements which distinguish them from public roads. Most Vietnamese educational institutions perform their internal logistics work through manual transportation of documents and examination papers and laboratory tools and administrative materials. The requirement for manual work extends processing time while it generates additional work for staff members who face extended delays when operations reach their peak during examination seasons and administrative deadline periods.

Commercial AGV systems currently available on the market are optimized for industrial warehouses or manufacturing plants. The cost of their solutions exceeds what schools can afford while their implementation needs advanced infrastructure and

complex control systems and expensive LiDAR sensors. The systems fail to meet requirements for budget-limited institutions which include secondary schools and regional colleges because they need affordable solutions with easy operation and minimal upkeep. The design of autonomous vehicles requires small size and affordable construction and simple maintenance for safe operation at educational campuses with restricted funding.

The research develops an affordable autonomous delivery system which targets school environments because of existing delivery system restrictions. The system design includes three operational modes which form its core functionality. The user operates the vehicle through Bluetooth connection by using a smartphone application in manual mode. The vehicle uses dual infrared (IR) sensors to track a pre-defined dark floor line in the line-following (LF) mode which can be set up in school hallways. The obstacle-avoidance (OA) mode uses an ultrasonic sensor attached to a servo motor which scans directions to detect obstacles while searching for new routes.

The system uses an ESP32-CAM module to stream video in real-time which allows users to monitor their delivery operations. The vehicle operates as a functional logistics system and educational IoT/STEM platform because it features modular hardware with structured wiring and simple programming design. Students can observe the sensor-actuator-networking system directly which helps them learn embedded systems and robotics through practical experience.

The research brings new value to the field through its three main contributions. The proposal presents a complete affordable AGV system which meets the needs of Vietnamese educational facilities operating on school grounds. The system demonstrates its environmental adaptability through affordable sensor usage which generates reliable output. The system offers an expandable structure which enables developers to add new capabilities including cloud integration and machine vision and fleet management systems.

The remainder of this paper is organized as follows. The second section reviews current studies about autonomous robots and smart campus logistics systems. Section 3 describes the overall system architecture and methodology. The hardware design appears in Section 4. The software design section of Section 5 describes both control algorithms and mobile application functionality. Section 6 explains the implementation sequence which leads to experimental testing. The results and limitations are presented in Section 7. The paper ends with Section 8 which presents both concluding remarks and details about upcoming research projects.

### **Flowchart TD**

```
A ([Start]) --> B [Initialize the system\n(ESP32-CAM, sensors, motors)]
B --> C{Bluetooth/Wi-Fi connected?}
C -- No --> C
C -- Yes --> D{Select mode}
```

### **Manual**

```
D -- Manual --> M1[Receive commands from the app]
M1 --> M2[Control motors according to commands]
M2 --> D
```

### **Line following**

```
D -- LF --> L1[Read two IR sensors]
L1 --> L2{Line detected?}
L2 -- Yes --> L3[Follow the line]
L2 -- No --> L4[Stop/slow down + search for the line]
L3 --> D
L4 --> D
```

### **Obstacle avoidance**

```
D -- OA --> O1[Measure distance with ultrasonic sensor]
O1 --> O2{Obstacle detected?}
O2 -- No --> O3[Move forward]
O2 -- Yes --> O4[Scan left/right using a servo]
O4 --> O5 [Choose the clearer direction + turn]
O3 --> D
O5 --> D
```

## **II. RELATED WORKS**

Scientists have studied autonomous mobile robots for ten years because these robots operate in warehouse environments and urban delivery systems. Research studies from recent times show that low-cost sensors and microcontrollers work well for creating self-operating navigation systems. The primary warehouse function of AGVs consists of transporting pallets and bins and packages between storage areas and shipping destinations. The systems operate through floor marker and QR code and laser guidance technology which connects to centralized fleet management software.

The research by Dhaliwal and his team showed that warehouse operations became significantly faster after implementing AMRs which used ultrasonic and infrared sensors for navigation in controlled indoor environments.

The researchers demonstrated that safety performance remains unchanged when using affordable sensing solutions instead of expensive LiDAR systems under specific constraint conditions.

The research of Ichikawa et al. appeared in 2023. The research investigated human conduct between pedestrians and cyclists when sidewalk delivery robots operated in a university environment through investigations of compact robots with protected operational systems.

The research findings show that these systems function properly in educational buildings which need to run at safe speeds.

Medical facilities now use autonomous delivery robots to move medical supplies which helps decrease the workload of their staff.

The live stream function becomes accessible through any network-connected device which displays the IP address from the ESP32-CAM serial monitor. The system enables users to monitor the robot through remote access which provides complete visibility and safety features while keeping them away from the moving platform.

The system control sequence follows this sequence. The Arduino system begins its operation by

initializing all its sensors and servo and motor driver peripherals before it starts waiting for smartphone application mode selection.

The system runs continuously by collecting sensor information which gets processed into decisions that drive motor operations. The ESP32-CAM operates independently to capture images while streaming video content through Wi-Fi during this process. The system design becomes more straightforward because of this separation between concerns which also enhances system reliability.

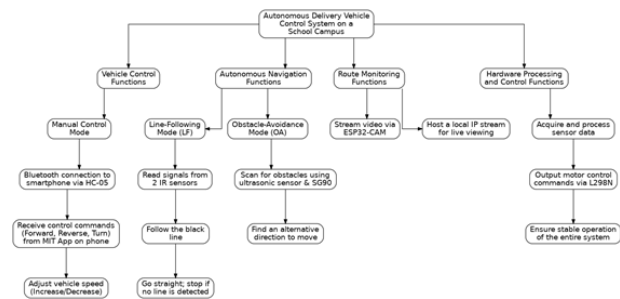


Figure 1 The proposed system hardware and communication layers are shown in this block diagram

### III. SYSTEM ARCHITECTURE AND DESIGN

#### System Architecture Overview

The system architecture unites sensing and control and communication and actuation elements into a small IoT-based autonomous vehicle which operates best in school-campus environments. The system operates through two controllers which use the Arduino UNO for navigation and sensing and motor control and the ESP32-CAM for independent image capture and video streaming operations.

The sensing subsystem depends on an SRF05 ultrasonic sensor which operates with a SG90 servo for directional scanning and two TCRT5000 infrared sensors for line detection. The system detects obstacles and tracks lines through its ability to detect distances between objects and analyze surface reflections. The L298N H-bridge driver enables motor control through PWM and direction signals

from the Arduino which control speed and movement.

The HC-05 Bluetooth module allows system control through its ability to send manual commands and operating mode selections to the smartphone application. The system uses a lightweight acrylic/PVC chassis which contains two DC motors and a caster wheel to maintain stability through its design that places the center of gravity low. The ESP32-CAM camera rests on a small support to achieve unblocked forward visibility.

The system design creates an affordable educational platform which enables smart-campus logistics operations and STEM education programs.

### Hardware Subsystem

The hardware subsystem uses affordable components which achieve performance and cost efficiency and operational reliability. The Arduino UNO functions as the main controller which serves as the system's central processing unit. The system operates through the Arduino UNO which reads data from IR and ultrasonic sensors and executes Bluetooth commands and controls motor speed through PWM signals. The Arduino UNO received selection for this project because it offers simple operation and strong durability and extensive community backing which benefits educational environments.

The ESP32-CAM module functions as an independent controller which streams video content. The system includes an OV2640 camera and Wi-Fi functionality which provides real-time visual feedback. The Arduino system controls motion and navigation but the ESP32-CAM module performs image capture and HTTP streaming functions. The system maintains responsive motion control during video streaming operations because it distributes tasks.

The system uses an ultrasonic distance sensor and two IR line sensors as its sensor suite. The SRF05 ultrasonic sensor operates on a SG90 servo motor which enables it to perform environmental scanning in front of the vehicle. The system uses distance measurements to detect obstacles and select safe

directions for operation during OA mode. The IR line sensors (TCRT5000 modules) are mounted under the front chassis to detect floor surface reflectivity which produces digital signals for line detection.

The L298N dual H-bridge driver enables independent control of two DC motors for motor actuation. The Arduino UNO sends PWM signals and direction commands to the L298N dual H-bridge driver. The system controls motor speed through PWM signal duty cycle adjustments which it sends to ENA and ENB pins. The system determines motor direction by using IN1–IN4 pins which enable motor movement in both forward and backward directions.

The HC-05 Bluetooth module enables wireless communication between the robot and user smartphones. The module enables standard UART communication while displaying status through its integrated LED indicator. The Bluetooth module allows smartphone users to transmit control commands to the Arduino UNO board which enables both manual operation and mode selection.

The mechanical framework uses an acrylic or PVC chassis to support two DC motor-driven wheels and a passive caster wheel which provides stability. The system contains all electronic boards and battery packs within the chassis to achieve a compact design that maintains a low center of gravity. The ESP32-CAM camera module rests on a short mast which points slightly downward to show the area in front of the robot.

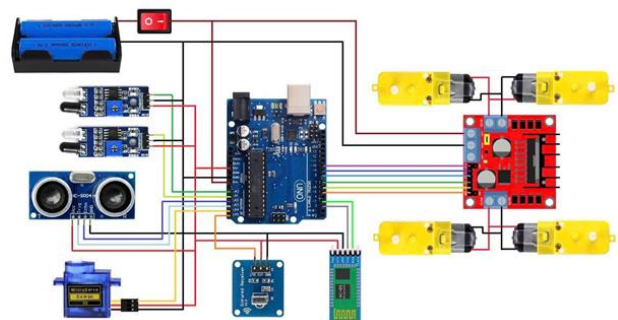


Figure 2. The hardware wiring schematic shows the physical arrangement of components on the chassis.

### Software subsystem

The system consists of two main software components which include the Arduino firmware for sensing and decision-making and actuation and the ESP32-CAM firmware for video streaming. The system uses a custom Android application developed with MIT App Inventor to offer users a control interface for manual operation and mode selection.

The Arduino sketch contains distinct functions which organize the code structure for better maintenance and understanding. The firmware initializes all I/O pins for IR sensor connections and ultrasonic trigger/echo and motor driver inputs and servo control and Bluetooth serial communication. The Arduino UNO received selection for this project because it provides simple operation and strong durability and extensive community backing which benefits educational environments.

The ESP32-CAM module operates as a secondary controller which specializes in video streaming operations. The system includes an OV2640 camera and Wi-Fi capabilities which enable real-time video transmission. The Arduino system operates as the motion controller and navigator but the ESP32-CAM module executes image capture and HTTP streaming operations. The system maintains responsive motion control during video streaming operations because it distributes tasks.

The system uses an ultrasonic distance sensor and two IR line sensors as its sensor suite. The SRF05 ultrasonic sensor operates on a SG90 servo motor which enables it to perform environmental scanning in front of the vehicle. The system uses distance measurements to detect obstacles and select safe directions for operation during OA mode. The IR line sensors (TCRT5000 modules) are mounted under the front chassis to detect floor surface reflectivity which produces digital signals for line detection.

Motor actuation is achieved through an L298N dual H-bridge driver which controls two DC motors independently. The driver system accepts PWM signals together with direction commands which the Arduino UNO sends to it. The system controls motor speed through PWM signal duty cycle adjustments

which are sent to the ENA and ENB pins. The system determines motor direction by using IN1–IN4 pins which enable motor forward and backward operation.

The HC-05 Bluetooth module allows the robot system to establish wireless communication with user smartphones. The module enables standard UART communication and features a status LED which shows the current pairing status. The Bluetooth module allows users to transmit control commands from their smartphones to the Arduino UNO board for operating the system manually and selecting operating modes.

The mechanical structure contains a lightweight acrylic or PVC chassis which supports two DC motor-driven wheels and a passive caster wheel for stability. The system contains all electronic boards and battery packs within the chassis to achieve a compact design which maintains a low center of gravity. The ESP32-CAM camera module rests on a short mast which points slightly downward to show the area in front of the robot.

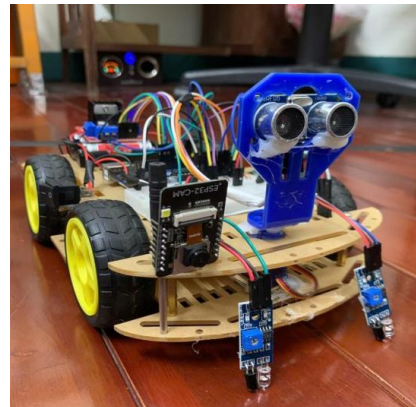


Figure 3. The hardware wiring schematic shows the physical arrangement of components on the chassis

#### IV. SYSTEM IMPLEMENTATION AND EXPERIMENTAL SETUP

##### Hardware Assembly Process

The hardware assembly followed the system architecture and wiring diagrams which Section 2.3.2 provided. The system assembly process required mechanical frame mounting and sensor module

installation and motor driver integration and Arduino UNO and ESP32-CAM controller connection to all system components.

The DC motors received their permanent installation on a 3D-printed chassis which used the L298N motor driver to connect them to power modules for maintaining vehicle stability during movement. The vehicle received its ultrasonic sensor installation on a SG90 servo motor for directional scanning while two infrared sensors were placed at the front to detect specific line patterns.

The Arduino UNO board received its sensor and module connections through the functional diagram which included the HC-05 Bluetooth module and the ESP32-CAM module with its programming board and the L298N motor driver. The team conducted a thorough examination of all connections to verify that signals followed their designated routes and power systems ran independently. The original document includes images which demonstrate the assembly process and sensor placement and device front view.

The device operated as a small modular system which enabled users to select between multiple operational modes for conducting dependable tests in educational settings.

### **Firmware Deployment**

The Arduino IDE operated as the primary platform which enabled users to upload control logic to both Arduino UNO and ESP32-CAM modules during their firmware development and deployment process.

### **Arduino UNO Programming**

The UNO firmware system executes all real-time operations required for vehicle control through its programming.

The system operates through sensor data collection from ultrasonic and infrared sensors and L298N driver control of DC motors and servo motor angles for obstacle detection and Bluetooth commands from the HC-05 module. The system operates in three modes which include Manual and Line-Following (LF) and Obstacle-Avoidance (OA). The system uses non-blocking routines to achieve real-

time decision making and motor control and mode transition functions.

### **ESP32-CAM Programming**

The ESP32-CAM module operates as a built-in video-streaming server which generates a local Wi-Fi network to transmit frames through HTTP/MJPEG. Users can access vehicle monitoring through their web browser after receiving their IP address from the source document.

### **Mobile Application Integration**

The development team built a custom control application through MIT App Inventor. The application interface enables users to manage connections and navigate through the interface using directional buttons and mode selection buttons and speed control through a slider. The application sends command strings through Bluetooth which the Arduino processor executes in real time.

The system design allows researchers to test various operational conditions through continuous system component connectivity.

### **Experimental Scenarios**

The system required multiple delivery runs of identical operations to match the delivery procedures which occur in school campuses. The testing process needed full verification of sensors and modules before beginning each test run.

### **Manual Control Scenario**

**The mobile application allowed users to control the vehicle remotely for testing its:**

The system tested its ability to move in all directions and its speed control function and its Bluetooth connection stability and response time delay. The test proved that the system functioned in real-time while all system components maintained continuous communication with each other.

### **Line-Following Scenario (LF Mode)**

The vehicle operated on a black-line track which was established in a controlled testing area. The test evaluated two aspects of infrared sensor performance and vehicle stability during curved movements and its ability to correct path deviations.

The test environment duplicated school campus internal routes to establish specific delivery routes.

### **Obstacle-Avoidance Scenario (OA Mode)**

The ultrasonic sensor triggered the servo motor to scan 180° fully whenever it detected any obstacles. The testing environment included stationary obstacles which researchers placed at different distances and positions to assess system performance.

The system proved its ability to detect distances by stopping correctly while using servo-scanning data to pick new routes before resuming its journey. The system proved its ability to detect obstacles and find alternative routes.

The system operated independently as a vehicle system which navigated through difficult environments without needing any boundary markers for direction.

### **Live Video Monitoring Scenario**

The ESP32-CAM video stream underwent testing to determine its stability and latency and reliability when operating under indoor lighting conditions. The test results showed that supervisors gained instant route tracking capabilities which improved their ability to monitor operations while maintaining safety standards.

### **Software Subsystem**

The system development took place at Ông Bí Secondary School located in Quảng Ninh Vietnam. The system evaluation process needed actual school testing to prove its operational capabilities and verify its logistics functionality in real-world environments.

The first step of hardware assembly involved placing the DC motors and caster wheel and battery pack onto the chassis frame. The system installation process involved connecting the Arduino UNO to the L298N motor driver and HC-05 Bluetooth module and IR sensors according to the hardware schematic. The system includes an ultrasonic sensor and SG90 servo which operate from a front-mounted bracket to perform environmental scanning. The ESP32-CAM

module receives its power supply from a 5V connection which requires stable current flow to prevent system failures.

The system underwent basic functionality tests after Arduino firmware upload through USB connection to verify motor control and sensor data and Bluetooth communication. The ESP32-CAM required an external USB-to-serial adapter for programming to check its Wi-Fi connection and video streaming capabilities.

The experimental tests included three main scenarios which involved following lines on a custom track and navigating through a corridor with fixed objects and using Bluetooth and video streaming for manual control. The line-following track consists of black electrical tape applied to a light-colored floor which includes straight sections and 45-degree bends and 90-degree turns. The system performed obstacle avoidance tests by placing objects at different distances to verify its ability to detect and navigate around them.

### **Results and Discussion**

The experimental results demonstrate that the vehicle design meets all its essential design specifications. The robot achieved a 91% success rate while following the 12-meter track which included multiple turns during line-following tests. The system failed to operate correctly because of short light variations and periodic line section interruptions caused by objects in the way.

The robot system successfully detected objects between 25 and 60 cm during obstacle-avoidance tests. The system performs obstacle detection through ultrasonic sensor measurements before it stops the vehicle and then scans for available space through the servo-mounted sensor to select a new path. The system successfully avoided obstacles 88% of the time but made errors because of surface reflections and floor irregularities that disrupted distance measurement accuracy.

The Bluetooth application for manual control offered users an easy-to-use interface that responded quickly to their commands. The system enables users

to operate the robot from a range of up to 9 meters inside buildings while maintaining minimal delay. The system enables students to observe robot behavior through direct teleoperation and for educational purposes to review robot operations.

The ESP32-CAM camera module streams video at 18–22 frames per second when it gets enough light. The video stream operates continuously for more than 15 minutes. The system performance deteriorates when lighting conditions become poor because it produces lower frame rates and shows increased image noise.

The system offers various advantages which make it suitable for smart campus logistics operations and STEM education programs. The system operates with budget-friendly components which enable its use in secondary schools and local universities because of its affordable price. The system design includes separate modules which enable easy maintenance and repair operations and system updates. The system offers three operational modes which include manual control and line following and obstacle avoidance for flexible use in different scenarios and educational activities.

Multiple system restrictions were discovered during the testing process. The ultrasonic sensor produces incorrect measurements when it detects curved or soft or highly absorbent surfaces which leads to incorrect obstacle detection. The IR line sensors need special calibration because their performance depends on both environmental lighting and floor surface properties. The ESP32-CAM module requires a stable 5V power supply to function properly because insufficient power supply can cause system failures.

The system can achieve better distance measurement accuracy through the replacement of ultrasonic sensors with time-of-flight (ToF) sensors like the VL53L0X. The system can estimate its position through encoder-based odometry which will enhance its path tracking capabilities. The system will achieve full autonomous navigation beyond line following through the use of affordable LiDAR sensors and SLAM algorithms during its future

development stages. The system enables remote monitoring and analytics and multi-robot coordination through its cloud connectivity features and data logging capabilities.

## V. CONCLUSION

The research developed an affordable autonomous delivery system which operates specifically for school campus environments. The system provides effective support for school logistics operations through its integration of IoT technology and multi-sensor navigation and Bluetooth control and real-time video streaming. The system's modular design structure enables different educational institutions across Vietnam to implement and expand their systems.

The system operated steadily and produced precise results throughout all tests which took place at Uông Bí Secondary School. The system shows potential for improvement through hardware and control algorithm enhancements which will address the current system limitations. The system functions as an excellent educational resource because it enables students to work directly with embedded systems and robotics and IoT systems.

The research project will create environmental resistance improvements and sophisticated control systems which will enhance navigation capabilities and cloud-based monitoring for distant system tracking and data assessment.

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