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Original Research Article

Design and Construction of an Obstacle Avoidance System with Inherent Features

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ABSTRACT

This study focuses on the design of an unmanned autonomous vehicle for environmental monitoring and surveillance. It is made with ultrasonic, atmospheric and Global Positioning System (GPS) sensors to collect real-time data on atmospheric conditions and geographic coordinates. The unmanned autonomous vehicle is powered by 12 V secondary batteries in two parallel sets of three series cells. An M8N GPS module accurately determined the location of the unmanned autonomous vehicle. A high-resolution ESP32-CAM camera handles surveillance which is controlled by an ESP32 microcontroller. A Bluetooth module allows remote control and real-time data transmission. An H-bridge motor driver with pulse width modulation signals ensured precise motor control and various maneuver. Ultrasonic sensors detected obstacles within a defined range but fails with objects below their detection height. The GPS module showed limitations in procuring location data under some specific conditions. However, the system accurately monitored temperature, pressure, and humidity. The live feed although affected by the two-megapixel camera limitations, was successfully streamed to smartphones and laptops through a hotspot connection.

1. INTRODUCTION

In today's technological landscape, the demand for intelligent systems that can move through their surroundings autonomously and interact with the environment has witnessed significant growth (Tang *et a*l., 2023). One area of particular interest is the development of integrated systems capable of obstacle avoidance, surveillance, and atmospheric parameter monitoring (Gageik *et al*., 2015; Villa *et al*., 2016; Pochwala *et al*., 2019). Such systems have great potential in improving the safety, efficiency and environmental monitoring across various applications.

In the past years, obstacle detection depended on methods such as computer vision, Light Detection and Ranging (LIDAR) and Radio Detection and Ranging (RADAR). However, these methods often have limitations in terms of accuracy, cost or environmental conditions (Sivaraman and Trivedi, 2013; Rasshofer and Gresser, 2005). In recent years, ultrasonic sensors, such as the HC-SR04 used in this study, have been a common choice for obstacle detection due to their low cost, ease of integration and reliable performance in indoor environments (Abreu *et al*., 2021; Ma, 2023). In the use of surveillance system technology, standalone closed-circuit television (CCTV) cameras or specialized surveillance systems are usually used for security and monitoring purposes. However, these systems are typically disconnected from the obstacle avoidance aspect and lack real-time data fusion. This disconnect limits their ability to effectively respond to dynamic environments and adapt to changing circumstances (Scanalitix, 2025).

By designing and constructing an unmanned autonomous vehicle that integrates obstacle avoidance, surveillance, and atmospheric parameter monitoring using low-cost components, this study aims to contribute toward addressing these limitations. Solving all these challenges would take more than one study, this work demonstrates a practical, affordable implementation and identifies specific constraints that future research can target.

2. METHODOLOGY

2.1. System Overview

The system is an unmanned autonomous vehicle (UAV) designed for obstacle avoidance, environmental monitoring and surveillance (Villa et al., 2016; Gageik et al., 2015). Figure 1 shows the overall architecture of the autonomous vehicle. The ESP32 microcontroller acts as the brain of the system, coordinating the ESP32-CAM camera, M8N Global Positioning System (GPS) module, HC-SR04 ultrasonic sensor, HC-05 Bluetooth module, atmospheric sensors, and motor driver (Espressif Systems, 2025). A 12 V Direct Current (DC) source, regulated to 5 V, powers the entire system.

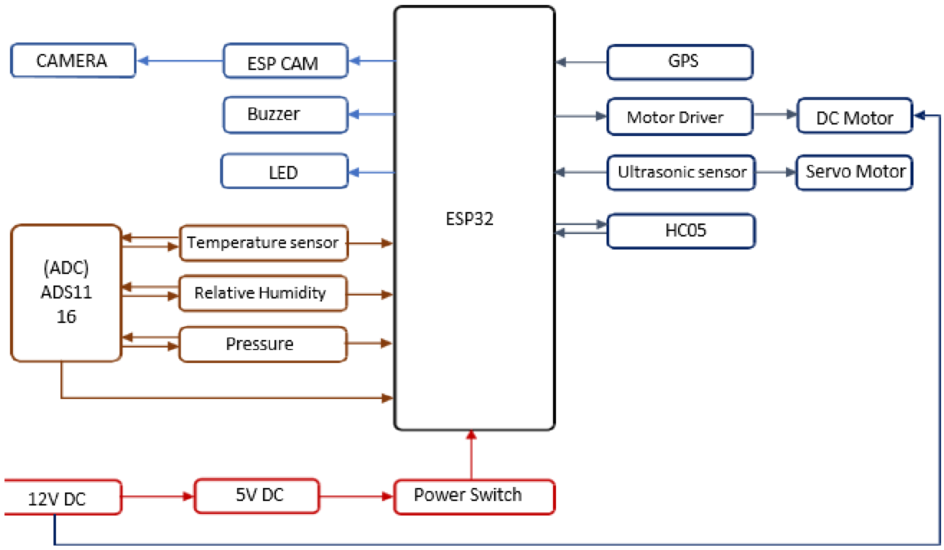

Figure 1: Architecture of the UAV

2.2. Power Supply

This system is powered by a 12 V secondary battery configuration, which consists of two sets of three individual cells connected in series and then these sets are connected in parallel as shown in Figure 2 which are used to provide a DC power supply, so as to operate the various component of the integrated circuit. This results in a 12 V battery pack with increased capacity. Each individual cell has a nominal voltage of 3.7 V, and when three of them are connected in series, the voltage becomes 11.1 V per set. By connecting two sets in parallel, the overall capacity is effectively doubled, providing a 12,000mAh (12Ah) battery pack.

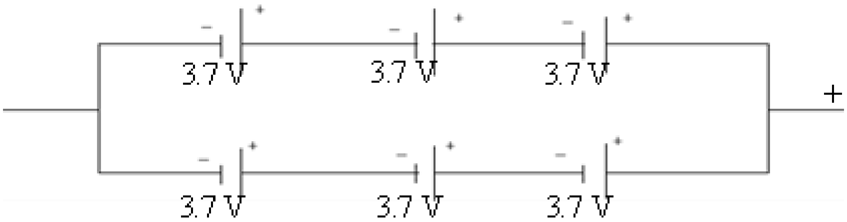

Figure 2: Connection of the battery cells

According to Awalt (2019) for cells connected in series, the total voltage is obtained using Equation (1), while the total charge capacity remains constant as shown in Equation (2).

$$VT = V1 + V2 + V3 ... + Vn \tag{1}$$

$$Total\ charge\ capacity = charge1 = charge2 = charge3 ... = charge\ n \tag{2}$$

According to Awalt (2019), for cells connected in parallel, the total voltage and total charge capacity are obtained using Equation (3) and Equation (4) respectively.

$$VT = V1 = V2 = V3 = Vn \tag{3}$$

$$Total\ charge\ capacity = charge1 + charge2 + charge3 + ... + charge\ n \tag{4}$$

Where VT is total voltage.

The battery life is determined using Equation (5) based on battery capacity and load current (Digikey, 2025).

$$Battery\ life\ (hours) = \frac{Charge\ capacity\ (mAh)}{Current\ (mA)} \tag{5}$$

When fully charged each cell has a voltage of 4.2 V. The battery arrangement used in this study provides a total voltage of 12.6 V and a total charge capacity of 4600 mAh. The estimated battery life is approximately 1.15 hours.

For the second cell, which supplies power for the operation of the microcontroller, a 20000 mAh, 12 V power bank is used for DC power supply.

2.3. Hardware Components

The ESP32 microcontroller serves as the brain of the system which controls and coordinates the operations of other hardware components. The ESP32 microcontroller was chosen for its powerful processing capabilities, built-in Wireless Fidelity (Wi-Fi) and Bluetooth connectivity, compatibility with various sensors and modules and adjustable clock speed between 80 MHz to 240 MHz so it takes less time to execute instructions (Espressif Systems, 2025). The L298 motor driver is connected to the ESP32 microcontroller through digital control pins to receive commands for controlling the motor's speed and direction. Bluetooth Module HC-05 (Bluetooth 2.0 Classic) plays a vital role in the UAV system by providing a wireless communication link between the ESP32 microcontroller and external devices, such as a mobile app or remote-control unit. This enables users to remotely control the UAV and receive telemetry data (Components101, 2023). For the surveillance system, ESP32-CAM module was chosen. This choice can be justified due to its compatibility with ESP32, ability to capture both images and video frames providing flexibility in data collection, and its compact size which makes it suitable for integration into the UAV without adding excessive weight or bulk (Nerd Tutorials, 2024). The SFE_BMP180 sensor monitors temperature, pressure and humidity, while the ADS1116 Analog-to-Digital converter converts this analog signal into digital signal for processing (Texas Instruments, 2024). The M8N GPS module is responsible for providing real-time location data for the UAV (u-blox, 2025). A buzzer produces an audible sound when an obstacle is detected and a light-emitting diode

(LED) which is used to determine when the system is functioning. All hardware components were acquired from a retail store.

2.4. Mechanical Assembly

The mechanical assembly of the system involves constructing the physical structure, integrating the chassis, wheels, and motor mounts, and ensuring the accommodation of the integrated hardware components.

The chassis serves as the framework for the system and provides structural support for other components, considerations are made for stability, durability, and size constraints, the chassis was made with Polyvinyl Chloride (PVC) board. The design makes sure there is adequate space for accommodating the hardware components and allows proper airflow for temperature regulation.

Wheels are fixed to the chassis to help in the movement of the system then considerations are made for wheel size, traction and compatibility with the motor. The design ensures proper alignment and balance for smooth and stable movement.

Motor mounts fix the DC motor in place to ensure its stability and proper alignment with the wheels. The mounts are made to accommodate the specific motor used in the system. Then considerations are made for the mounting mechanism, such as screws, brackets or clamps, to provide secure attachment and easy accessibility for maintenance or replacement.

The mechanical assembly design makes sure there is sufficient space and ensured proper arrangement for the integration of the hardware components. Then considerations were made for the placement and orientation of components such as the microcontroller, motor driver, sensors, camera module and power supply. The design provides appropriate cutouts, slots, or mounting points to securely hold the components in place within the chassis.

Figure 3-7 shows the mechanical assembly process of the UAV. During this process, attention is given to proper alignment, tight fastenings and cable management to avoid interference or damage to the components. Quality assurance measures, such as functional tests, load tests and stability assessments are conducted to ensure the mechanical assembly meets the system's requirements.

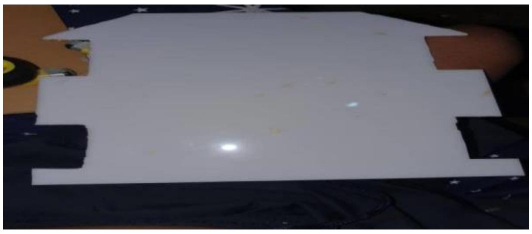

Figure 3: Cut out Stage for chassis implementation

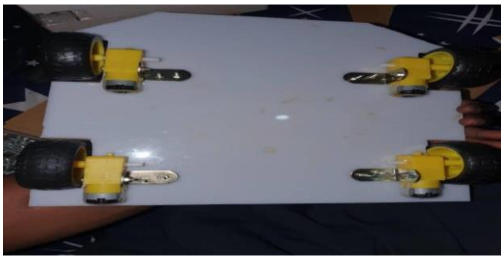

Figure 4: Attachment of DC motor and wheels

Figure 5: Attachment of mechanical support

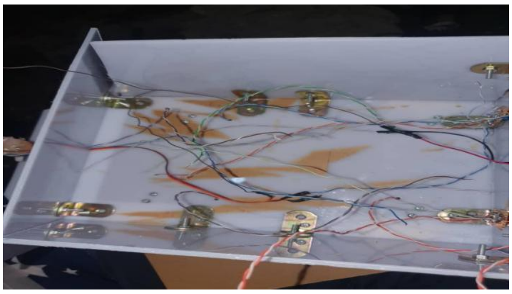

Figure 6: Wiring integration

Figure 7: Interconnection of hardware components

2.5. Circuit Simulation and Software Integration

The schematic diagram was first drawn and simulated using Proteus (version 8.0, Labcenter Electronics) simulation software for intelligent principal layout and accurate analysis (Labcenter Electronics, 2024). The circuit diagram from the simulation is shown in Figure 8. In the UAV system, software integration plays a pivotal role in ensuring that all components work harmoniously together to achieve the system's objectives. The Arduino IDE (version 2.0, Arduino LLC) in C/C++ was used to develop the firmware for the ESP32 (Arduino, 2024).

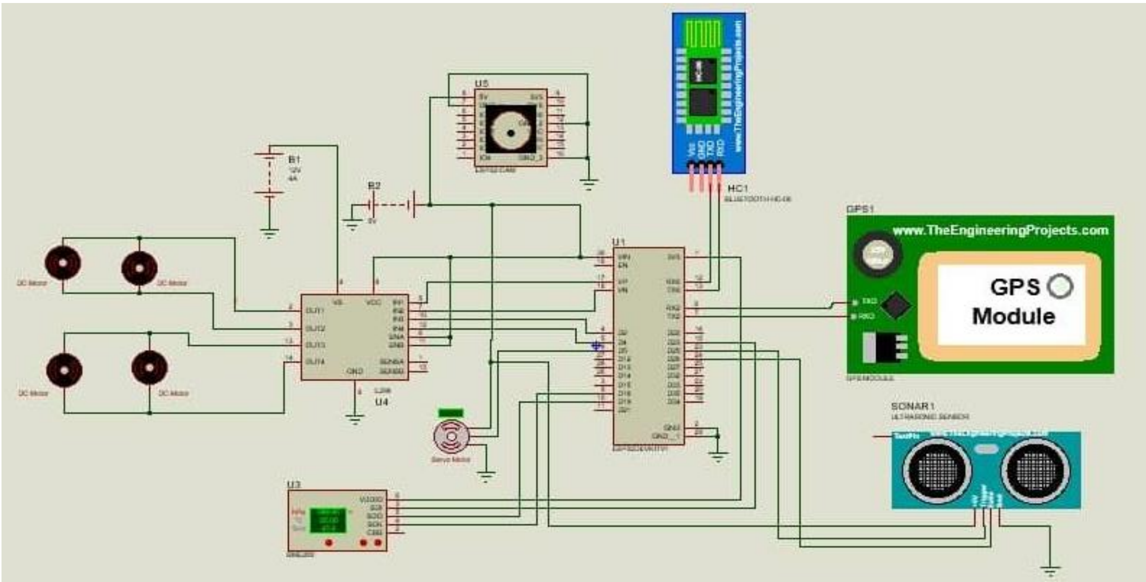

Figure 8: Circuit diagram of the UAV

This firmware controlled the interactions between various hardware components, including sensors, actuators, and communication modules. The Arduino Serial Monitor was used during testing and debugging to view output messages from the ESP32 (Arduino, 2024). For the surveillance component of the system, Open-Source Computer Vision Library (OpenCV) was used in implementing image or video processing algorithms, it provides functions for image capture, analysis, and manipulation (OpenCV, 2024). To test and interact with the Bluetooth communication between the ESP32 microcontroller and mobile devices and laptops, an application called Arduino Blue Control was used, which is a Bluetooth terminal application. Finally, Git was used as a version control system for managing and tracking changes in firmware and software codebase which is essential for collaboration and maintaining code quality (Git SCM, 2024).

2.6. Working Principle

Figure 9 shows the operational flowchart of the UAV, showing the sequential decision-making process from the system initialisation to obstacle detection and response. As shown in Figure 9 the UAV makes use of an ESP32 microcontroller using its processing power, connectivity features (such as Wi-Fi and Bluetooth), and GPIO pins to interface with sensors, actuators, and other components in the vehicle.

The system is powered by a 12 V, 4 A DC battery which provides 5 V to different sections of the circuitry via a 5 V voltage regulator for the system to work properly. The ESP32 microcontroller switch is turned ON and allows to establish a connection to a mobile device with the aid of the Bluetooth module. After successful Bluetooth connectivity has been established, the ESP32 microcontroller waits to receive data from the ultra-sonic sensor (HC-SR04), atmospheric parameter monitoring sensors (SFE_BMP180), M8N GPS module and ESP32-CAM connected to it. These sensors and modules get data from the UAVs surrounding.

For surveillance, the camera capture images or video frames. For atmospheric parameter monitoring, the SFE_BMP180 sensor provides real-time environmental data while the M8N reads the exact location of the UAV by triangulation (using signals from multiple GPS satellites to calculate the UAV's position.). The ESP32 reads data from these sensors and modules using its GPIO pins or other interfaces (e.g., 12C, SPI, UART). The ESP32 processes the collected data, image analysis for surveillance and calculations for atmospheric parameters (e.g., calculating air quality index). It also performs data filtering, calibration or fusion to improve accuracy. The processed data is sent to a user interface which can be remotely accessed.

The UAV makes autonomous decisions with the aid of codes which have been programmed into the ESP32 which are sent to the H-bridge motor driver connected to the DC motors which turn the wheels. The H-Bridge is an electronic circuit which allows to control the direction of current flow through the DC motor by using four switching elements (MOSFETs) arranged in “H” shape. The wheels change the direction of motion of the UAV based on logic input. For forward motion, the H-bridge configures the switching elements in such a way that current flows from the positive power supply to the motor in one direction. To move backward, the H-Bridge reverses the direction of current flow through the motor by changing the configuration of the switching elements.

To control the motor’s speed a Pulse Width Modulation (PWM) signal is applied to the PWM input. The duty cycle of this PWM signal determines the average voltage applied to the motor, thus controlling the speed. A higher duty cycle results in faster movement while a lower duty cycle slows it down.

Logic inputs such as IN1, IN2, IN3, IN4, PWM and ENA, play a vital role in controlling the direction and speed of the motors. These inputs allow the precise management of the movement of each wheel of the UAV, enabling the UAV to move in different ways, from simple forward and backward motion to more complex actions like turning, rotating and following specific paths. The combination of these inputs provides the flexibility and control needed to navigate the UAV effectively which are stated as follows.

1. When both IN1 and IN2 are LOW, the H-bridge is in a “brake” or “stop” state, where the motor is effectively short circuited, causing it to stop.
2. When IN1 is HIGH and IN2 is LOW, the motor spins in one direction (clockwise) to achieve forward motion.
3. When IN1 is LOW and IN2 is HIGH, the motor spins in the opposite direction (anticlockwise) to achieve backward motion.
4. To Turn the UAV left, the front left wheel spins clockwise while the back right wheel spins counterclockwise.

5. To turn the UAV right, the front right motor spins clockwise while the left back wheel spins counterclockwise.
6. The ENA input, in combination with the PWM signal allows to enable or disable the PWM based speed control. When ENA is HIGH, the PWM signal’s duty cycle controls the speed and when ENA is LOW, the motor is effectively turned off regardless of the PWM signal.

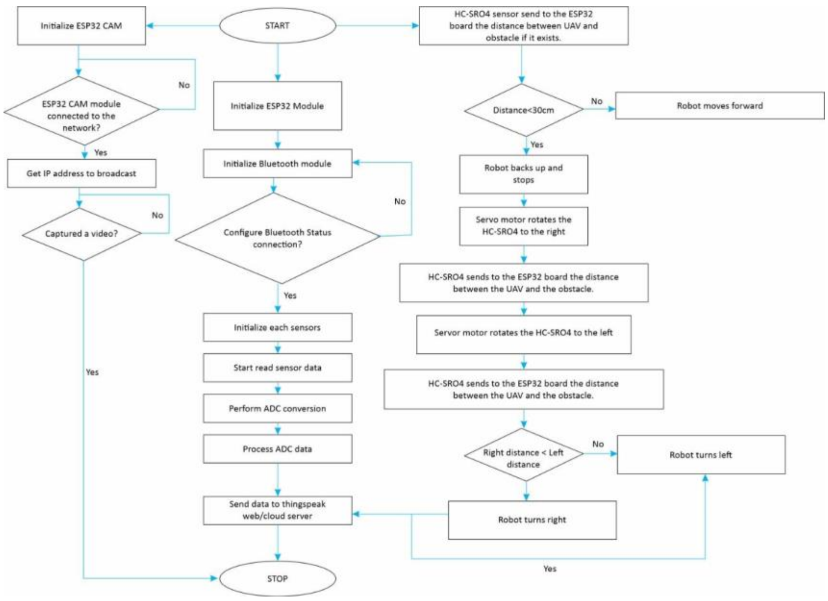

Figure 9: System flowchart

3. RESULTS AND DISCUSSION

3.1. Live Feed Functionality

A setup that allowed real-time video streaming to a remote device was established to evaluate the live feed functionality. Users could access the live feed by connecting to the hotspot SSID generated by the system and using an IP address. The live feed was viewable on both smartphones and laptops (monitoring screen). The live feed functionality demonstrated reasonable performance in terms of accessibility and real-time viewing. However, it's important to note that the video quality was less than optimal due to the use of a 2-megapixel camera in the ESP32-CAM. As a result, the images displayed were appeared pixelated and lacked fine detail as shown in Figure 10. However, the live feed system was still functional enough to support real-time monitoring of the UAV’s surrounding.

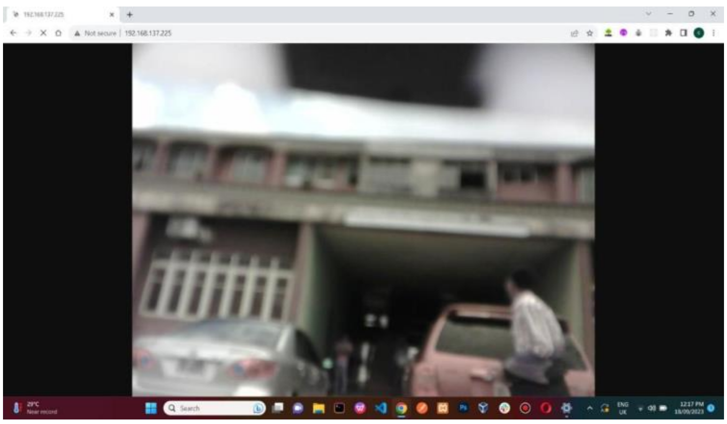

Figure 10: Screenshot of live feed from camera

3.2. Obstacle Detection and Avoidance

This system used an obstacle detection algorithm primarily relying on the ultrasonic sensor (HC-SR04). During testing, the system could detect many types of obstacles including various objects in its path. However, there were limitations in identifying certain obstacles, especially when it came to calibration issues. This created a challenge in accurately distinguishing objects and estimating the size and proximity of this object. The obstacle avoidance mechanism was designed to ensure the safety of the UAV. In cases where obstacles were successfully detected, the system demonstrated reliable performance in steering the UAV away from them.

3.3. GPS Location

The system made use of an M8N GPS module to determine the UAV's location accurately. This module was essential for navigation and surveillance purposes. However, during testing, difficulties were encountered in obtaining precise GPS location data. The system consistently struggled to provide accurate coordinates leading to uncertainties in the UAV's position. Factors such as signal interference and environmental conditions may have contributed to these inaccuracies. Achieving reliable GPS location data was identified as essential for autonomous navigation and tracking.

3.4. Atmospheric Parameter Monitoring

The system successfully made use of environmental sensors for monitoring temperature, pressure and humidity. The ADS1116 Analog-to-Digital Converter (ADC) supported data collection, contributing to environmental analysis. The system successfully collected consistent data for temperature, pressure and humidity during operation as shown in Figure 11. While the data collected showed valuable insights into environmental conditions, further analysis will be necessary to fully use this information for applications like weather forecasting and climate research.

Figure 11: Result of atmospheric measurement

3.5. Bill of Engineering Measurement and Evaluation (BEME)

The materials that were used in the design of the UAV as well as their cost are shown in Table 1.

4. CONCLUSION

This study has successfully designed and constructed an UAV which was used in integrating obstacle avoidance, real-time surveillance and environmental monitoring. This study has contributed greatly to the field of integrated autonomous systems. The major contributions include the implementation of a functional live feed system for real-time surveillance and the integration of environmental sensors for atmospheric parameter monitoring. The system showed reliable obstacle detection and avoidance performance within the operational range of the HC-SR04 ultrasonic sensor and successfully transmitted environmental data including temperature, pressure and humidity to a remote user interface. Despite this study archiving several milestones, it also have limitations that should be acknowledged.

1. Video quality was compromised due to the 2-megapixel camera.
2. Challenges persisted in accurately identifying certain obstacles.
3. GPS accuracy issues affected precise navigation.

Further analysis was identified as necessary to unlock the full potential of atmospheric parameter data.

Table 1: Bill of engineering measurement and evaluation

S/N	Materials	Unit	Cost (Naira)
1	Microcontroller	1	36,000
2	Obstacle detection sensor	1	15,500
3	Power supply unit	1	30,000
4	DC-DC converter	2	15,000
5	Motor driver	2	30,000
6	DC Wheels	4	12,000
7	Gearbox	4	5,000
8	Cat 6 connectors	Bulk	15,000
9	Angle brackets	Bulk	10,000
10	ESP32 Cam	1	35,500
11	Bluetooth	1	9,000
12	WiFi hub + Multiplexer	1	11,000
13	Screws + Nuts	Bulk	8,000
14	LiPo Battery + BMS		32,000
15	Perf board	2	2,400
16	Glue	2	5,000
17	Power switch	4	4,000
18	Resistors (1 KΩ, 4.7 KΩ,, 10 KΩ, 100 KΩ), Capacitors (10 nF, 100 uF, 220 pF, 100pF)	Bulk	3,000
19	Male and Female headers	Bulk	10,000
20	Chassis	2	30,000
21	Hot glue	10	4,000
22	Soldering kit	1	46,000
23	Masking tape	5	1,500
24	Spacer	Bulk	3,000
25	GPS	1	40,000
26	Breadboard	1	5,000
27	12-bit Analog to Digital Converter (ADC)	1	9,000
28	Temperature, Pressure and Relative Humidity sensor	1	10,000
29	Anti-Theft/Tampering		30,000
30	Buzzer	1	1000
31	High Torque Stepper Motor	1	20,000
32	Driver shield + PWM	1	5,000
33	LED	1 Pack	20,000
34	Lithium Ion Battery	1 count (Pack of 8)	30,000
35	Servo Motor	1	20,000
36	Screwdriver	1 set	12,000
37	Multimeter	1	40,000
38	Ac Adapter	1	15,000
39	Logistics		25,000
		Total	600,000

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Abreu, D., Toledo, J., Codina, B. and Suárez, A. (2021). Low-cost ultrasonic range improvements for an assistive device. Sensors, 21(12), p. 4250. Available at: https://doi.org/10.3390/s21124250

Arduino (2024). Arduino IDE Documentation. Available at: https://docs.arduino.cc/software/ide-v2 (Accessed: 17 October 2025).

Awalt, A. (2019). Series and parallel battery circuits. DigiKey. Available at: https://www.digikey.com/en/blog/series-and-parallel-battery-circuits (Accessed: 15 December 2025).

Components101 (2023). HC-05 Bluetooth Module. Available at: https://components101.com/wireless/hc-05-bluetooth-module (Accessed: 17 October 2025).

DigiKey (2025). Battery life calculator. Available at: https://www.digikey.com/en/resources/conversion-calculators/conversion-calculator-battery-life (Accessed: 15 December 2025).

Dong, S., Gao, X., Mostafavi, A., and Gao, J. (2022). Modest flooding can trigger catastrophic road network collapse due to compound failure. *Communications Earth & Environment*, 3, p. 38. Available at: https://doi.org/10.1038/s43247-022-00366-0

Espressif Systems (2025). ESP32 Programming Guide. Available at: https://docs.espressif.com/projects/esp-idf/en/latest/esp32/ (Accessed: 17 October 2025).

Gageik, N., Benz, P., and Montenegro, S. (2015). Obstacle detection and collision avoidance for a UAV with complementary low-cost sensors. *IEEE Access*, 3, pp. 599–609. Available at: https://doi.org/10.1109/ACCESS.2015.2432455

Git SCM (2024). Git Version Control System. Available at: https://git-scm.com (Accessed: 17 October 2025).

Labcenter Electronics (2024). Proteus Design Suite. Available at: https://www.labcenter.com (Accessed: 17 October 2025).

Ma, J. (2023). Obstacle detection and avoidance using ultrasonic sensors in autonomous robots. *Highlights in Science, Engineering and Technology*, 71, pp. 68–78. Available at: https://doi.org/10.54097/hset.v71i.12378

OpenCV (2024). Open Source Computer Vision Library. Available at: https://opencv.org (Accessed: 17 October 2025).

Pochwała, S., Gardecki, A., Lewandowski, P., Somogyi, V. and Anweiler, S. (2020). Developing of low-cost air pollution sensor — measurements with unmanned aerial vehicles in Poland. Sensors, 20(12), p. 3582. Available at: https://doi.org/10.3390/s20123582

Random Nerd Tutorials (2024). ESP32-CAM AI-Thinker Guide. Available at: https://randomnerdtutorials.com/esp32-cam-ai-thinker-pinout/ (Accessed: 17 October 2025).

Rasshofer, R.H. and Gresser, K. (2005). Automotive radar and lidar systems for next-generation driver assistance functions. *Advances in Radio Science*, 3, pp. 205–209. Available at: https://doi.org/10.5194/ars-3-205-2005

Scanalitix (2025). From passive to purposeful: The evolution of video surveillance. Scanalitix. Available at: https://scanalitix.com/from-passive-to-purposeful-the-evolution-of-video-surveillance/ (Accessed: 8 May 2025).

Sivaraman, S. and Trivedi, M.M. (2013). Looking at vehicles on the road: A survey of vision-based vehicle detection, tracking, and behavior analysis. *IEEE Transactions on Intelligent Transportation Systems*, 14(4), pp. 1773–1795. Available at: https://doi.org/10.1109/TITS.2013.2266661

Tang, Y., Zhao, C., Wang, J., Zhang, C., Sun, Q., Zheng, W.X., Du, W., Qian, F., and Kurths, J. (2023). Perception and navigation in autonomous systems in the era of learning: A survey. *IEEE Transactions on Neural Networks and Learning Systems*, 34(12), pp. 9604–9624. Available at: https://doi.org/10.1109/TNNLS.2022.3167688

Texas Instruments (2024). ADS1115 Analog-to-Digital Converter. Available at: https://www.ti.com/product/ADS1115 (Accessed: 17 October 2025).

u-blox (2025). NEO-M8 Series GNSS Modules. Available at: https://www.u-blox.com/en/product/neo-m8-series (Accessed: 17 October 2025).

UNDP (2023). Nigeria Flood Impact, Recovery and Mitigation Assessment Report 2022–2023. Available at: https://www.undp.org/nigeria/publications/nigeria-flood-impact-recovery-and-mitigation-assessment-report-2022-2023 (Accessed: 26 May 2024).

Villa, T.F., Gonzalez, F., Miljievic, B., Ristovski, Z.D., and Morawska, L. (2016). An overview of small unmanned aerial vehicles for air quality measurements. *Sensors*, 16(7), p. 1072. Available at: https://doi.org/10.3390/s16071072

Zhou, X., Wang, Z., Wang, H., Xu, C., and Gao, F. (2020). EGO-Swarm: A fully autonomous and decentralized quadrotor swarm system in cluttered environments. *arXiv [Preprint]*. Available at: https://arxiv.org/abs/2011.04183 (Accessed: 17 October 2025)..