Remote-Controlled and Autonomous Electric Vehicle (EV)

Oluwafemi Emmanuel Oni[1*], *Nombuso* Zulu[1], and *Kazeem* Oyebode[1]
[1]University of Zululand, Department of Electrical & Computer Engineering, Richards Bay, 3900

Abstract. The emergence of wireless communication, sensing technologies and collision avoidance systems are ushering in the era of autonomous vehicles and revolutionizing today's transportation. AEVs provide greater safety, lower accident risk, better energy efficiency and environmental effects than traditional IC engines. A dual-mode (Manual and Autonomous) Electric Vehicle (EV) prototype design and implementation using sensor automation, wireless communication and obstacle avoidance control is presented. The system is based on an Arduino Uno microcontroller which is connected to front and rear ultrasonic sensors for real-time obstacle detection. The front sensor is servo mounted, allowing for scanning of the environment between left, centre and right. The control signals generated by the microcontroller control the DC motors by using an L298N motor driver module. The prototype can autonomously navigate in a predefined safety radius of 40 cm by use of a rule-based obstacle avoidance algorithm and remotely supervised by a smartphone application during manual operation. These are verified in the experiments, which show stable manoeuvring, reliable obstacle detection and good propulsion control. The results of the developed prototype validate the feasibility of low-cost electric propulsion in small-scale autonomous platforms and provide a practical educational framework for programming autonomous control, research in smart mobility.

1 Introduction

The world's shift to autonomous electric vehicles (AEVs) has been looked upon as a strategic measure to combat global climate change, urban air pollution, and growing fuel expenses, and has been seen as an economic catalyst for the automotive industry [1]. The Fourth Industrial Revolution (4IR) technologies such as artificial intelligence (AI), automation, and smart manufacturing have greatly improved the manufacturing and operation of today's electric vehicles (EVs) [2]. The need for this shift is demonstrated by the World Health Organisation's report that in 2016, 91% of the world's population spent part of their day breathing in polluted air, with the amount of pollution being around 2.5 times the recommended levels [3]. The situation is especially alarming from a South African point of view, where the country is listed 14th in terms of air pollution, with major emitters like Eskom and Sasol contributing significantly to air pollution. The development of the electric vehicle has not been a process of invention that can be credited to any single country, but was a result of multiple contributions from countries like The Netherlands, Hungary, and the United States, among others, in particular the battery systems, electric motors, chassis designs and charging procedures [4]. Mass-produced EVs were only introduced in South Africa many years later, and massive rollout is still restricted by poor infrastructure, frequent power failures, and lack of charging stations. Such structural problems pose significant questions about the practicability and scalability of EV adoption in the developing countries.

The advancement of AI based sensing, wireless communication and control technologies has also led to the emergence of intelligent and self-manoeuvring electric vehicles [5]. EVs can be broadly categorized according to the energy source and the way they are powered, such as Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Fuel Cell Electric Vehicles (FCEVs). The BEVs are battery electric vehicles that use battery electric propulsion, HEVs are hybrid electric vehicles utilizing a combination of internal combustion engine and electric motor, PHEVs are plug-in hybrid electric vehicles that are powered by an externally rechargeable battery with a fuel backup system, and FCEVs are fuel cell electric vehicles using hydrogen fuel cells to create electricity [6].

Nevertheless, due to the above, the use of autonomous electric vehicles is still restricted by the sensor cost, complex control algorithms and lack of accessibility of research, especially in developing countries. Thus this study explores the feasibility of electric propulsion and autonomous control in a South African context and a small scale AEV prototype was designed and built which was remotely controlled. The research considers application scenarios for urban mobility and last mile delivery, analyzes adoption trends and socio-economic impact, and shows how sensing systems, wireless communication and obstacle avoidance algorithms can be integrated to a dual-mode (manual and autonomous) service able to be

* Corresponding author: onio@unizulu.ac.za

implemented in developing areas. The design and implementation of small-scale autonomous electric vehicles (EVs) have been investigated recently, with various technologies including sensor-fusion localization, route planning algorithms, and real-time communication systems being explored. Advanced control and localization techniques have been applied to autonomous EVs to track trajectories even when they are not in a GNSS environment. Other studies have shown that dual-mode vehicles can use embedded controllers and sensor systems to switch between the two modes of operation—autonomous and manual [7]. There are also low-cost prototype AVs that have been created with features like navigation, object detection, and auto parking [8], and EV adoption studies that have identified other issues concerning the mobility and infrastructure system. Furthermore, a number of systems have been developed that include GPS and ultrasonic sensors for the purpose of obstacle detection and limited autonomous driving [9], and Bluetooth mobile apps for the remote control of small-scale EV prototypes [10]. While all these progress have been made, there is a notable absence in the research field about how to combine a low-cost remote-control platform with an autonomous navigation using a sensor system in the same prototype so that the system can easily switch between modes. Most current systems either prioritize navigation algorithms or consider a remotely driven vehicle but do not include a reliable collision avoidance process. To fill this void, this work involved the design and implementation of a small-scale autonomous EV prototype equipped with a mobile-app remote control system, ultrasonic sensor obstacle detection and collision avoidance algorithm to illustrate the electric propulsion and autonomous decision-making capabilities.

2 Autonomous Vehicles Technology

2.1 Automated Driving System Levels

Self-driving cars are made up of various sensors and controllers that helps achieve the degree of independence on drivers of these type of cars, and they come in 5 levels of self-governance, with single, dual or multiple powertrain setups. According to the Society of Automotive Engineers (SAE) many people still confuses autonomous vehicles with electric vehicles operated by human beings, therefore the National Highway Traffic Safety Administration (NHTSA) came up with a solution to have levels of automated systems [11]. Typically, vehicle automation is broken down into six levels. 0: Fully Manual – No Automation. At driver control Level 1, basic driver assistance features are introduced. At level 2, some of the driving tasks will be automated but driver supervision will still be required at all times. In Level 3, the system can make some driving decisions with minimal driver involvement to a certain degree. In Level 4, the vehicle has a high level of automation and can operate on its own in certain situations, but may still be able to be controlled by the driver. Level 5 is the highest level of automation, where the vehicle can operate with no human input.

2.2 Monitoring and Sensor fusion

In order to provide autonomous car with the environmental knowledge they need for route planning and decision-making, which is both crucial for controlling the vehicle movement, monitoring systems and sensors are important. Global Navigation Satellite System (GNSS) and the cars odometry sensors are examples of position tracking technology that aids in determining the vehicle's precise location coordinates and surrounding distances. To sense its environment, AV mostly uses sensors mentioned below:

- **LiDAR:** is a broad geographical view recognition and measuring device with a range of 100-300 meters. It generates precise data, target discrimination, excellent quality 3D pictures, and light-condition independence. Typical applications involve GPS and navigation, detection of barriers, and in cabin monitoring.
- **Radar:** Radar utilises the radio frequencies(EM) to identify things, enabling accurate monitoring in both daytime and night time driverless smart car. It gives information on moving bodies and maps in short, medium, or long range.
- **Multiple vision camera:** Cameras use a lens to detect light to take crisp, detailed pictures of their surroundings. They are affordable and can distinguish between moving and stationary objects. These abilities allow cars to identify roadblocks and traffic signals, among other impediments, both on and off the road.
- **Ultrasonic sensors:** they use sound waves to identify things, offering 3D visualization, accuracy, and resolution. Lift-gates, parking, blind-spot identification, and space detection all make use of them.

Sensor fusion is a crucial component in the majority of self-governing systems such as fully autonomous vehicles [12]. To reduce detection errors and overcome the limits of individual sensors functioning on their own, it combines sensory information collected from many sensing modes of transport. A key component of self-navigating cars is virtual sensing, which incorporates information from several detecting techniques to reduce detection inaccuracy and get around the drawbacks of independent sensor technology [13]. Probability principles are used by conventional multi-sensor data fusion techniques, including statistical, probabilistic, and knowledge-based techniques, to integrate sensor data [14]. Some of the techniques used in autonomous driving technology to incorporate the information coming from numerous sensors of the system includes the following:

- Kalman Filter
- Bayesian Network
- Fuzzy logic
- Convolutional Neutral Network (CNN)
- Recurrent Neutral Network (RNN)

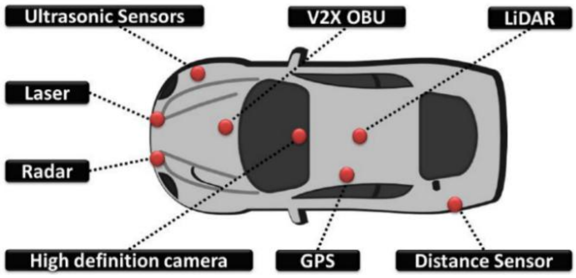


Fig. 1. Sensor fusion of an automated vehicle.

3 System Overview

The overall system proposed here is based on the use of a microprocessor as the main control element, which oversees the sensing, decision-making and actuation. It operates on real-time information received from the collision avoidance subsystem and performs navigation commands based on this. Two ultrasonic sensors are placed in front and rear of the vehicle prototype to implement the obstacle detection. The front ultrasonic sensor is attached to a servo motor to allow angular scanning (left, right and forward), thus providing the environment with more perception to realize autonomous path planning and obstacle avoidance. In manual mode, the motor driver acts as a power buffer between the low-level control signals produced by the microprocessor (through the receiver) and the DC propulsion motors, while in autonomous mode, it buffers the low-level control signals produced by the autonomous logic. It controls voltage and current delivered to the motors, which can be used to control the movement of the vehicle, such as forward, reverse and steering.

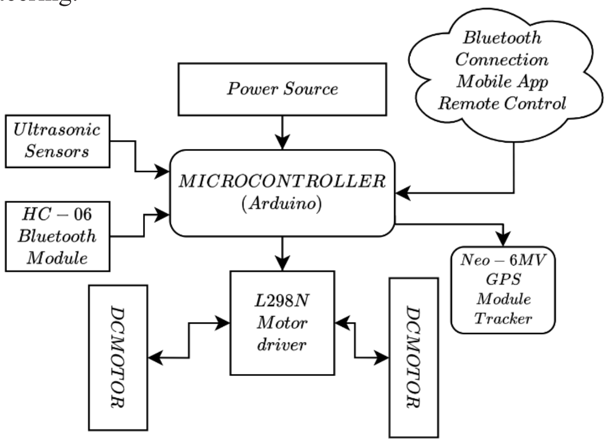


Fig. 2. System overview block diagram for a remotely controlled autonomous vehicle.

3.1 Design Modelling and Governing Equations of an Autonomous Electric Vehicle

To design an Autonomous Electric Vehicle (AEV) with manual (app based) control and autonomous (algorithms based on collision avoidance) control, a complete dynamic and energy-based modelling framework is needed. Newton's Second Law that links the net tractive effort to the forces resisting the movement of the vehicle body is the equation governing the longitudinal dynamics of the vehicle. If the motion is on an inclined plane of angle α, the fundamental force balance is:

$$\sum F = ma = F_t - F_a - F_r - F_g \qquad (1)$$

where $m$is the vehicle mass (kg), $a$is longitudinal acceleration (m/s^2), $F_t$is tractive force (N), $F_a$is aerodynamic drag (N), $F_r$is rolling resistance (N), and $F_g = mg\sin\alpha$is the gravitational component along the slope (N). The aerodynamic drag force is given by:

$$F_a = \frac{1}{2}\rho C_d A(v - v_w)^2 \qquad (2)$$

where ρ is the air density in kg/m³, $C_d$is the drag coefficient typically somewhere between 0.25 and 0.35 for most modern EVs with reasonably streamlined bodies. A_f is the frontal area of the vehicle in m², v is the vehicle velocity in m/s, and $v_w$is the wind velocity in m/s. Rolling resistance is then modelled as:

$$F_r = C_r mg\cos\alpha \qquad (3)$$

where the rolling resistance coefficient (C_r) captures tyre friction losses against the road surface. Together, these equations define the total traction demand under both manual and autonomous driving conditions.

The propulsion subsystem is where wheel dynamics and motor torque meet. The mechanical power reaching the wheels is:

$$P_w = F_w v \qquad (4)$$

where F_w the wheel tractive force acts in Newtons. From this, the torque the wheel must deliver works out to:

$$T_w = F_w r \qquad (5)$$

where the wheel radius $r,$ is measured in metres. Accounting for the gear reduction ratio G and drivetrain efficiency η_d, the required motor torque becomes:

$$T_m = \frac{T_w}{G\eta_d} \qquad (6)$$

These relationships directly inform how the motor is sized and controlled, both during acceleration and when recovering energy through regenerative braking in autonomous navigation.

The battery subsystem determines how far the vehicle can travel and how sustainably it manages energy. The total energy the battery must supply over a given driving range R_{car}(km) is:

$$E_B = \frac{(E_1 + E_2)}{\eta} \times R_{car} \qquad (7)$$

where E_1represents traction energy per kilometer (kWh/km), E_2denotes auxiliary system consumption (kWh/km), and $\eta$is overall drivetrain efficiency. The dynamic State of Charge (SoC) of the battery is modelled as:

$$\mathrm{SoC}(t) = \mathrm{SoC}(t_0) - \frac{1}{C_b}\int_{t_0}^{t} I(\tau)\, d\tau \qquad (8)$$

where the battery capacity C_b is expressed in ampere-hours and the discharge current $I(t)$ in amperes. This formulation makes real-time energy management possible — something that matters equally whether the vehicle is being controlled remotely by a human operator or navigating autonomously to avoid obstacles.

Taken together, these equations lay the groundwork for everything that follows: the design, simulation, and optimisation of a dual-mode electric vehicle capable of switching between manual and autonomous operation.

3.1.1 Coding and Design Software

Following the assembly of the hardware components for the vehicle prototype, the next stage involves the development and configuration of the control software. This process includes implementing the Arduino-based control program and integrating it with a mobile application that functions as the remote controller. The mobile application enables the user to send control commands to the vehicle, while the onboard sensors support the automation features incorporated into the electric vehicle (EV) prototype.

The Arduino Integrated Development Environment (Arduino IDE) is used for developing and uploading the control algorithms (sketches) to the microcontroller. The programmed microcontroller facilitates communication between system components, including sensors, motor drivers, and control modules, thereby enabling automated and remote-controlled operation of the vehicle. Figure 3 presents the flowchart of the Arduino program used to control the vehicle prototype based on commands received from the mobile remote controller.

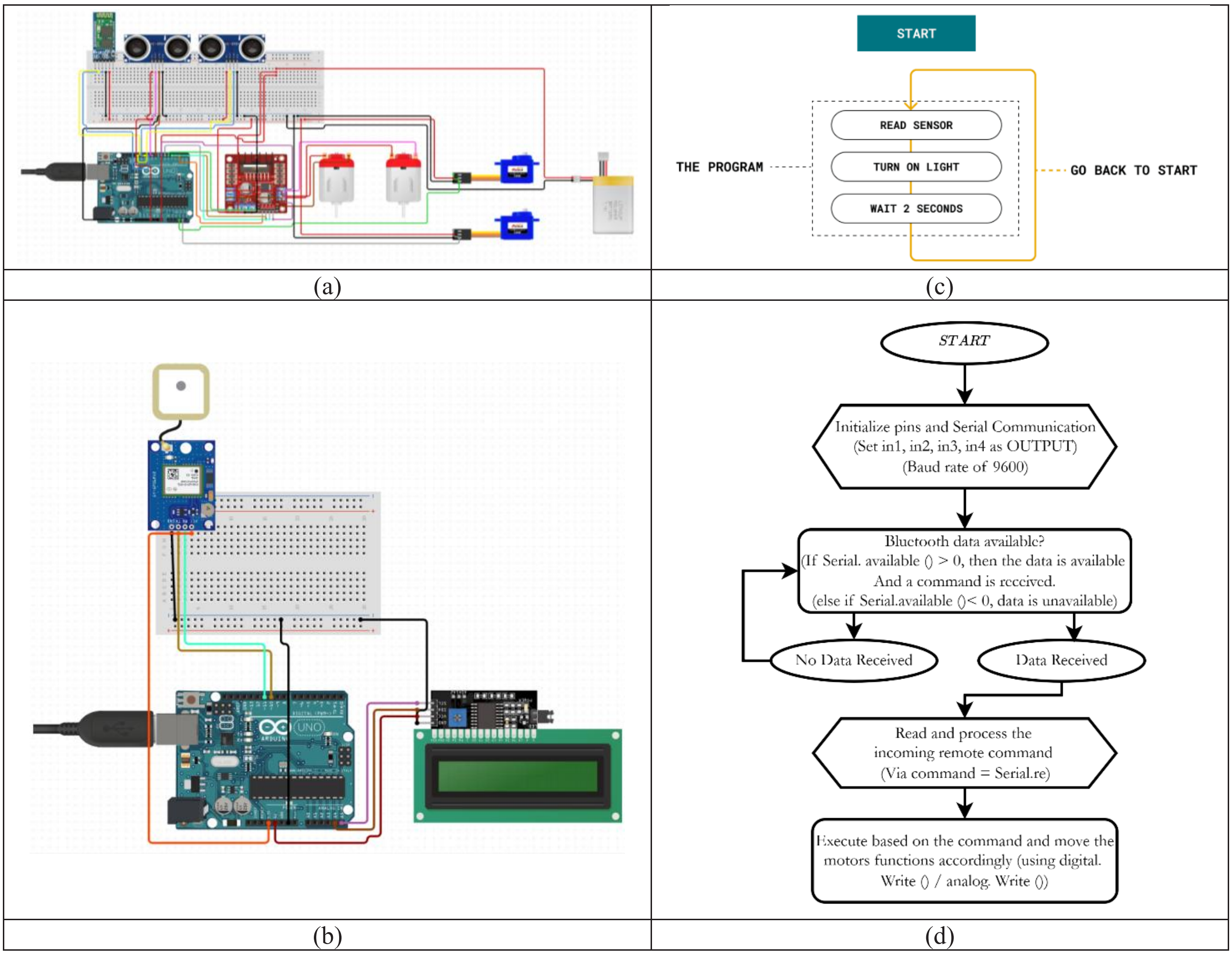


Fig. 3. Core circuit of the design, (b) GPS Tracker connection, (c) An example of the basic operation of the Arduino program (d) Arduino program flow used in the design

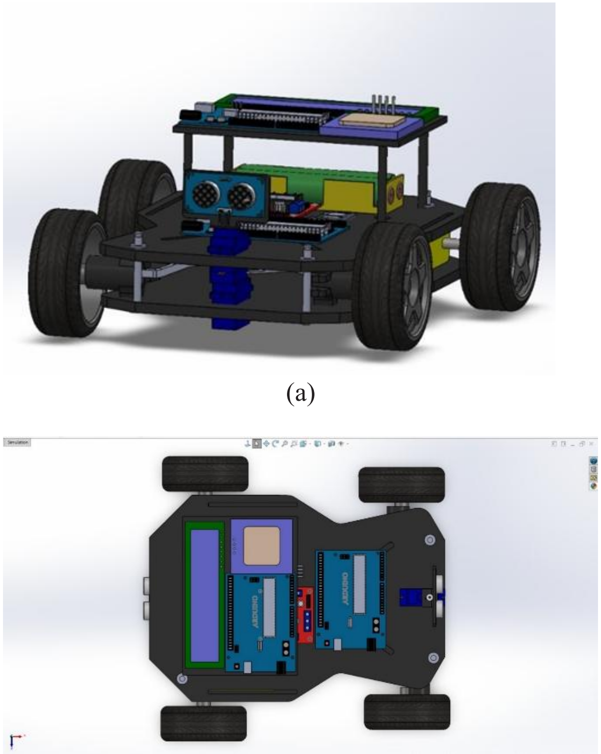
3.1.2 Design Implementation.

A mobile application was implemented to enable wireless communication between a smartphone and the autonomous electric vehicle (AEV) prototype. The application functions as a remote controller, allowing the user to command the vehicle to move forward, backward, left, right, stop, or switch between manual and automatic operating modes. The mechanical structure of the vehicle was designed using SOLIDWORKS CAD software, which allowed the creation and assembly of the vehicle's components through 3D modelling techniques.

The mass properties of the designed components were tested to estimate parameters such as mass distribution, volume and surface area, and then analysed the expected dynamic performance of the prototype. Various aspects of key performance elements such as chassis loading, torque, wheel load distribution and centre of mass were evaluated to assess the stability and manoeuvrability of the vehicle during operation. The steering mechanism was also done by a servo-motor, so that the front wheels could be turned at will. The chassis was structurally simulated to check the stress, displacement, strain and factor of safety under the applied load and the material chosen was found to be able to withstand the operational forces. A collision avoidance algorithm using ultrasonic sensing was developed to allow the robot to navigate and operate independently and safely. The system employs ultrasonic sensors that determine the distance between the vehicle and other objects by measuring the time it takes for ultrasonic waves to echo back. If an obstacle is detected within a specified safety distance, the control algorithm will decide whether to stop or turn the vehicle to the side that was further away from the obstacle. The hardware part consists of an Arduino Uno microcontroller, ultrasonic sensors, a motor driver of type L298N to control the motors, a Bluetooth module for wireless communication and lithium ion batteries as power supply. The GPS module was also incorporated to help monitor the vehicle's location and to show the coordinates on the LCD screen for verification on mapping services. The prototype underwent various experiments such as the ability of the remote control to respond, the Bluetooth range of the remote, the avoidance of obstacles, the behaviour of the discharge of the remote's batteries, the GPS accuracy of the remote, and the speed of the remote under indoor and outdoor environments. The overall performance of the system was assessed through the use of data gathered from the Arduino serial monitor, signal monitoring applications and measurement equipment.

4 Results

This research had the primary goal of the design and validation of an electric propulsion system for a small scale vehicle powered with battery packs, electric motors and embedded control units. In order to improve the autonomy function of the prototype, the ultrasonic sensors were added to detect and avoid obstacles, so that the prototype could realize the simple path decision function in operation. The test results of the developed prototype as shown in Figures 4a, 4b and 5 are presented in this section. The evaluation of the vehicle was carried out in the real-time operating conditions in the indoor and outdoor environment. The tests took place on a smooth surface inside to check the stability and response of the system in a confined environment, and on a rough surface outside to assess the vehicle behaviour under more realistic environmental conditions. The distance travelled to obstacle vs Reaction and Detection Time are shown in Figure 6 and 7. The experimental results show that the ultrasonic sensing system can detect the obstacles at a distance of about 40cm. The approach towards the obstacle is performed, and the detection is performed at first and the vehicle is still in the forward motion for a small period of time. Avoidance response is triggered by the control system when it is at a distance of 5-10 cm, by stopping, backing up slightly and choosing an alternate direction (left or right). This behaviour illustrates the simple decision making ability of the obstacle avoidance algorithm. It was noted though that some obstacles had irregular surfaces or sound absorbing characteristics that could cause the ultrasonic sensor to be less effective at detecting the obstacle and sometimes miss the obstacle altogether, causing possible collisions. The vehicle is able to avoid collision with obstacles as shown in the experimental result in figure 8, however as the number of obstacles increased the success rate of avoiding obstacles decreased. This means that the current sensing configuration works well in moderately cluttered environments but isn't quite as reliable in highly cluttered environments. This finding shows that only ultrasonic sensing is not sufficient for the perception of the environment and that more sophisticated sensing technologies or sensor fusion could be needed to accurately navigate complex environments.



(a)

(b)

Fig. 4. Prototype design on SolidWorks (a) Front view, (b) Top view.

Fig. 5. Assembled prototype

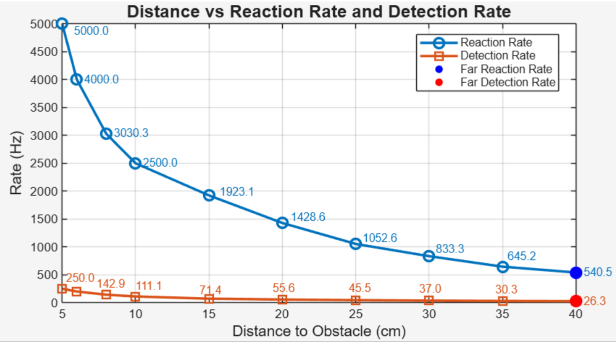


Fig. 6. Distance vs Reaction and Detection Graph

The nRF Connect mobile application was used to observe the RSSI (dBm) of the Bluetooth module as the vehicle distance from the controller was increased to test the vehicle's ability to connect to the remote application controller via Bluetooth. In figures 9 and 10 the recorded BLE RSSI values during the experiment are shown. The observations reveal that the signal strength decreased gradually as the distance between the vehicle & controller increased. After a while, the communication link was lost and the vehicle stopped functioning. This finding validates the natural limit of Bluetooth communication and its limitation for long-range control in an autonomous vehicle application.

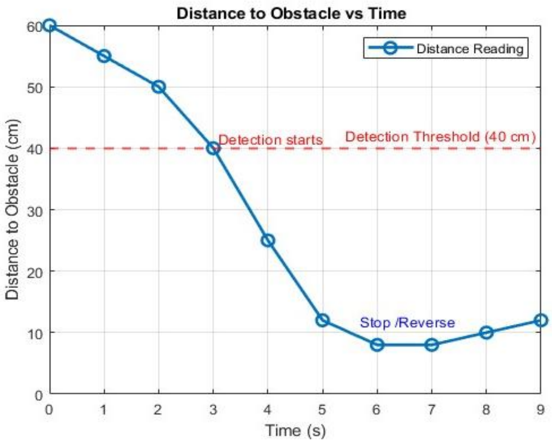


Fig. 7. Distance to Obstacle vs Time graph

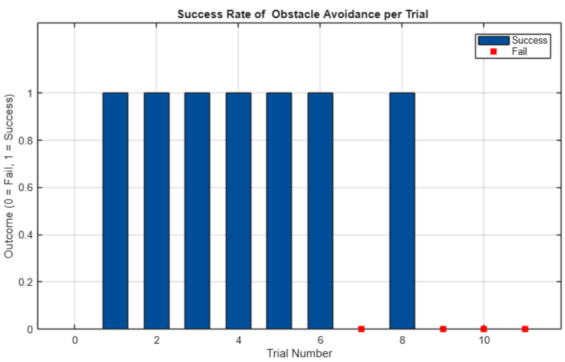


Fig. 8. Success Rate of Obstacle Avoidance per Trial

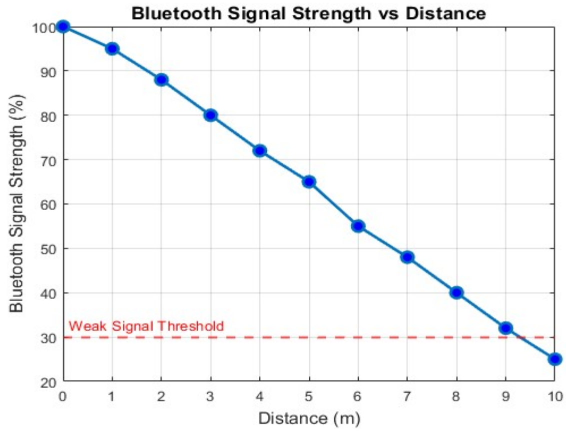


Fig. 9. Bluetooth Signal Strength Vs Distance

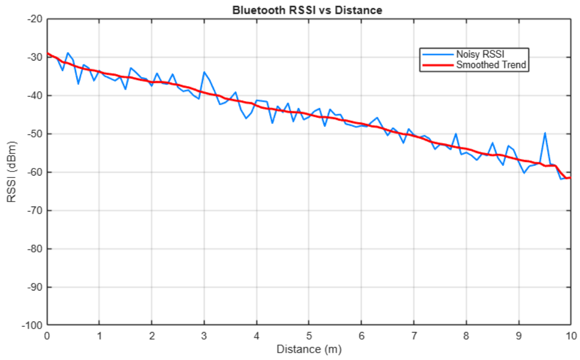


Fig. 10. Bluetooth RSSI vs Distance Graph

The vehicle prototype was connected to the circuit with two 18650 3.6 V Li-ion batteries which gave a combined voltage of ~7.20 V, and the voltage was measured by a voltage sensor and checked with a multimeter in order to analyse the performance of the batteries. The obtained data is shown in Figures 11 and 12. When the battery was working, the voltage level was gradually lowered with the increasing distance of driving, which was normal discharge. Meanwhile, the amount of current flowing through the system rose marginally to ensure the set motor torque and speed. From the gradual discharge profile, it can be observed that the lithium-ion battery pack supplied stable and reliable power during the experimental tests.

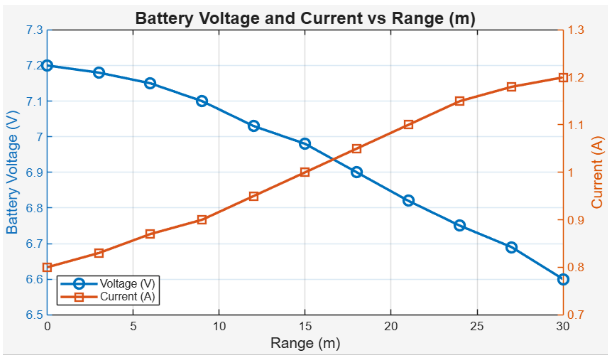


Fig. 11. Battery Voltage and Current vs Range graph

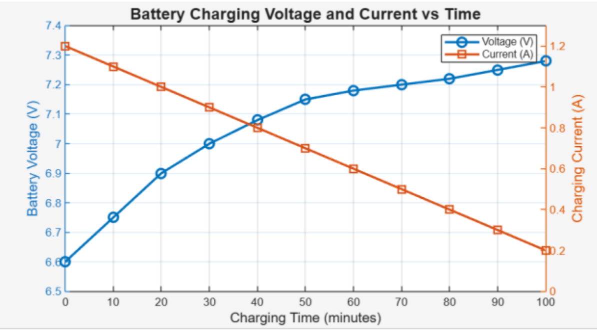


Fig. 12. Charging Rate of the battery

The vehicle also had a GPS tracking system set in place using an Arduino based configuration to find and track its location. The GPS coordinates shown on the LCD screen were compared to the Google Maps coordinates to check the accuracy of the GPS measurements as seen in Table 1. The GPS coordinate on the LCD screen was shortened because of its small screen size as is shown in figure 13, but the full coordinates were retrieved from the Arduino serial monitor to check the accuracy. The difference between the measured coordinates and those recorded in Google maps was very little. The differences between these can be due to signal noise, power fluctuations, or RF interference disrupting the Neo-6M GPS module. Even with these small inaccuracies, the GPS system proved to be a successful demonstration of the possibility of implementing low-cost localization and tracking in small-scale autonomous vehicle prototypes.

Table 1: GPS Tracker and Google Maps Coordinates

No.	**GPS Tracker**		**Google Map**	
	Lat (^{0})	**Long (^{0})**	**Lat (^{0})**	**Long (^{0})**
1	-28.7397	32.053741	-28.7397	32.05374
2	-28.7397	32.053741	-28.7396	32.05404
3	-28.7397	32.053737	-28.7399	32.05422

Fig. 13. GPS tracker Displace on AEV LCD screen

5 Conclusion

The design, implementation and experimental testing of a small-scale prototype of an autonomous electric vehicle (AEV) that combines electric propulsion, wireless remote control, obstacle avoidance and GPS localization is presented. The developed system has confirmed the feasibility of integrating embedded sensing, control, and wireless communication technologies in a low-cost prototype system. The experimental results showed the reliability of the obstacle detection, path adjustment and autonomous navigation abilities of the vehicle using ultrasonic sensors, and reliable remote control with acceptable response delay by using the Bluetooth communication technology. Moreover, the GPS tracking module successfully showed the ability of real-time localization, which provided the information on position, speed and travel distance of the vehicle, proving the positioning system's capacity to play a vital role in monitoring and guiding the autonomous vehicles. The results of these tests, conducted in both indoor and outdoor environments, validated the stability of the propulsion, the ability to sense, and the stable behaviour of the wireless communication, demonstrating the feasibility of electric propulsion systems for small-scale autonomous systems. Although the proof-of-concept implementation was successful, there were some limitations found that will impact the scalability to real-world autonomous mobility systems. The perceptual range was limited by ultrasonic sensing, and the communication distance and robustness was limited by Bluetooth communication. Furthermore, the prototype mainly showed simple obstacle avoidance, and not actual autonomous navigation and route planning. The restrictions suggest the need for more sophisticated sensing and control architectures such as multi-sensor fusion with LiDAR, RADAR, cameras and better localization technologies like Simultaneous Localization and Mapping (SLAM). In addition, advancements in battery management, communication technology, and intelligent decision-making algorithms will play a crucial role in boosting reliability and operational efficiency. The overall results show that small-scale autonomous electric vehicle prototypes are effective experimental facilities for investigation of fundamental concepts in electric propulsion, sensing and autonomous control, and can serve as a valuable experimental base to develop smart mobility and last-mile applications.

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