Jurnal Kejuruteraan 36(4) 2024: 1365–1372
https://doi.org/10.17576/jkukm-2024-36(4)-03

Development of a Prototype Solar-Powered Autonomous Vehicle Prototype with Object Detection and Avoidance System using Raspberry-PI

Ogonye O. Solomon, Dagwa Ishaya Musa, Nurudeen Abdulhakeem Hassan*, Okonkwo Emmanuel & Kulutuye Precious

Department of Mechanical Engineering, University of Abuja, Nigeria.

**Corresponding author: Hassan.abdulhakeem@uniabuja.edu.ng*

Received 27 September 2022, Received in revised form 3 March 2024
Accepted 3 April 2024, Available online 30 July 2024

ABSTRACT

In this study, the development of a solar-powered autonomous vehicle prototype with an object detection and avoidance system was implemented and achieved using Raspberry Pi. The advancements in science and technology research have given rise to the robust adoption of smart means of transportation, from steam engines to energy-efficient means such as solar, electric, and hybrid-powered vehicles to ease transportation of people, goods, and services with increased human comfortability. Autonomous vehicles (AVs)offer a degree of self-control in driving in which a normal car requires a driver to execute such tasks e.g., braking, acceleration, and steering. An autonomous vehicle, requires sensors, controllers, algorithms, actuators, computers, and advanced software embedded in various locations on the vehicle to perform effectively. The study attempted to proffer solutions to the menace of human errors in decision-making while driving through the use of advances in scientific technology that have given rise to modern approaches to problem-solving. In Nigeria, almost 50% of road accidents were a result of poor decisions leading to the loss of lives and properties. The vehicle uses ultrasonic sensors and a USB webcam to detect and avoid obstacles on its path with the aid of a Raspberry Pie program that effectively executes decision-making changes to manoeuvre the vehicle away from objects on a free path. The study observed that as motor frequency is increased the speed of the AV increases and thus covers distances faster as compared to when the frequency is reduced. However, the increase in frequency also consumes energy faster. Charging rates were compared between the grid and solar photovoltaic, the grid system recorded faster charging rates when the vehicle was stationary while the solar photovoltaic charged the vehicle at stationary and in motion.

Keywords: Autonomous vehicle; sensors; solar vehicles; object detection; Raspberry Pie; smart cars

INTRODUCTION

The advancements in science and technology research have given rise to the robust adoption of smart means of transportation, from steam engines to energy-efficient means such as solar, electric, and hybrid-powered vehicles to ease transportation of people, goods, and services with increased human comfort Jamil and Domokos (2021). Also, the rise in driverless vehicles maximizes luxury and safety for the movement of people and goods, Jelena and Gyula (2021).

Autonomous vehicles (AVs) offer a degree of self-control in driving in which a normal car requires a driver to execute such tasks e.g., braking, acceleration, and steering. An autonomous vehicle, requires sensors, controllers, algorithms, actuators, computers, and advanced software embedded in various locations on the vehicle to perform effectively. The uses are enormous, from personal, transportation, and automation of processes as well to smart farming activities Rodrigo and Mohd (2021). This degree of autonomy in AVs ranges from one to four, which includes; driver assistance, partial automation, and high and full automation Debbie and Tim (2021). Driver assistance provides a fixed level of control in lateral (lane-keeping, overtaking) or longitudinal (speed choice, lane-following) control through the use of driver assistance systems such as adaptive cruise control (ACC) and cooperative adaptive cruise control (CACC) but is monitored by the driver at all time (Mishra et al. 2023). Partial automation also requires monitoring of the driver at all times. High automation does not require the driver to permanently monitor the longitudinal and lateral systems except in an emergency, and the control level is of limited time by the driver. Full automation has complete control over its system permanently without the intervention of a driver Toshiyuki and Thomas (2019), Gonçalo et al. (2016). Some of the advantages of AVs are; increased safety as it is a known fact that humans cause more car crashes as a result of reckless driving, and improper decisions among others Naz et al. (2022), reduction in pollution in urban areas, cheaper transportation, reduced accidents risks and fatalities, increased transportation access for disadvantaged social groups Fagnant and Kara (2015), in Nigeria, 47% of road crashes recorded in the second quarter (Q2) of 2020 were as a result of reckless driving, cars account for 28% of traffic accidents with motorcycles and minibus having 24 and 15% respectively NBS (2020). Meanwhile, (Umar & Gokcekus, 2019) argued that road accidents are prone to all modes of transportation in Nigeria, but the severity of road traffic accidents is high with injuries that sometimes could lead to deaths or permanent disablement of road passengers, pedestrians and other road users.

Some advanced countries through their unions have developed a framework for the European Green Deal to reduce their greenhouse gas emissions (GHG) by 50% by the year 2030 and hope to achieve carbon neutrality by 2050 European Commission (2019). Around 43% of greenhouse gasses are generated from passenger light-duty vehicles which are the most utilized transport mode that accounts for about 73% of the total passenger kilometres travelled across the European Union Andrea et al. (2022). This Commission is saddled with the development of decarbonization policies to cater to the sustenance of the human race through cutting global carbon footprints, AVs are regarded as the possible technology for the future to meet the multifaceted challenges of the future Fagnant and Kara (2015) and Richter et al. (2022).

The future of AVs is indeed not just a hypothesis, researchers have performed investigation on the various modes of integrating AVs into the transport and other sectors such as the economy, infrastructure, agriculture, and manufacturing among others, Krzysztof et al. (2022) developed a solar-powered small autonomous surface vehicle for environmental measurement and observed that AVs can be used to perform water quality measurements, contaminations and hazards detection, aquatic animal population control, garbage collection among others while his experimentation was on determining water pH, turbidity, purity and oxygen content of water using an autonomous solar-powered boat equipped with necessary sensors and actuators.

In a study conducted by Andrea et al. (2022) and his co-researchers analyzed the impact of mass-scale deployment of electric vehicles and the benefits of smart charging across 28 European countries, the study developed and validated a RAMP model against empirical data that simulates such patterns to investigate the impact of deployment of electric vehicles and smart charging locations, it was observed that an uncontrolled deployment of electric vehicles fleet will increase the demand of power system to 51%, while if smart charging strategies are distributed, the demand will reduce to around 41%. Also, researchers Ahsan et al. (2022) realized that around 40% of energy is consumed by residential or commercial buildings, and identified the need for synergy between smart buildings and electric vehicle fleets, elaborated a methodology to optimize power dispatch for smart buildings and electric vehicles with V2X operation and found that if this synergy is feasible, smart charging stations will provide residential buildings with up 62% profit for investing into solar photovoltaic, storage and charging systems, while commercial buildings will save around 20% energy costs, and electric vehicle owners will save 35-65% charging costs because these stations will provide energy for both the buildings and electric vehicles.

AVs are seen as the future of transportation, Ronik et al. (2022) explored the willingness to use shared AVs, the study showcased the tendency to shared AVs and integrate them into the current transportation infrastructure, the output indicated that AVs will reduce the cost of transportation, improve sociodemographic awareness, increase trust in technology and also serve as a guide to policymakers and transportation planners in developing effective and robust AV-related policies.

For this novel technology to function effectively, there is a need to fully understand how AVs function and what kind of sensors are needed, Henry et al. (2022) highlighted the importance and types of sensors used in autonomous vehicles, the study observed that for AVs to travel, avoid obstacles, detect changes in the environment, avoid accidents and increased passenger safety, sensors are needed to make effective decisions. The role of these sensors is to detect changes in the environment and convert them into numerical measurements that can be processed; they include internal sensors, and external sensors when classified according to the principle of operation with each having sub-classes such as encoders, locational sensors, inertial measurement units (IMU) as internal sensors while cameras, Radars, LiDARs, and ultrasonic sensors as a sub-division of external sensors. (Hyder et al. 2023) conducted a study to proffer solutions to traffic challenges, which often are neglected and the impact could lead to accidents, a situation common in most countries, as such YOLO-V3 was used to perform the study to detect vehicle speed and thereby eliminating human errors in manual traffic control. Similarly, potholes also contribute to road accidents, (Alayat & Ali, 2023) developed a distress detection algorithm using digital image processing to generate data. While researchers (Yaacob et al. 2020) integrated Geographic positioning systems (GIS) to extract a deeper understanding of how traffic accidents can be minimized and enable policymakers to develop strategies for reducing road accidents based on three road parameters; such as the number of lanes, level of service and slope. The researchers observed that the majority of road accidents were largely affected by the level of flow of vehicles, while the slope of the road has very little influence on road accidents.

This study aimed to develop a prototype solar-powered autonomous vehicle with obstacle detection technology using Raspberry Pie for the identification of tracks and control of the robotic car using a systematic design process.

METHODOLOGY

DESCRIPTION OF THE PROTOTYPE SYSTEM

The concept of the solar-powered autonomous vehicle was designed based on the systematic design method Agbese et al. (2022), this approach is derived from the product development phase of product design, which classifies product design as a process into several levels of preoccupation. Different AVs require different level requirements regarding levels of technology to be incorporated to enable effective functioning. However, the systematic design method was adopted because of its elaborative and concise methodologies (Tijmen et al. (2010).

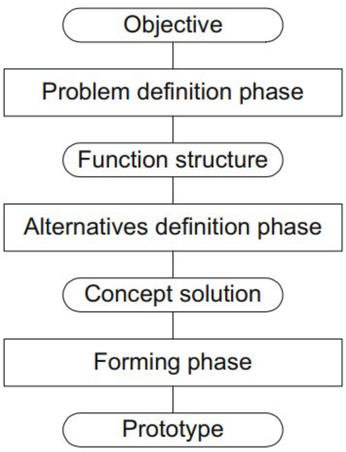

FIGURE 1. Systematic Design Method Tijmen et al. (2010)

Figure 1 shows a flowchart of the systematic design method. The phases are problem definition, alternatives definition, forming phase, and prototype.

The problem definition phase highlights the objectives of the design and classifies them into fixed and variable requirements, then sets each function of each requirement. Regarding this study, the objectives are to among other things move autonomously and detect and avoid obstacles along the path of movement.

Function structure comprises the grouping of functions identified from the problem definition phase that provide solutions and alternative principles to adopt in achieving the desired goal. The alternative definition phase covers the possible routes needed to achieve various functions, the selections of alternatives for each function, and the establishment of a concept solution. i.e., lane identification, detection of obstacles, recognition of obstacles, an obstacle within or outside the driving path, and avoidance of obstacles are regarded as functions the AV must incorporate to achieve its objectives. Then the forming phase selects the best concept solution and finally leads to the development of a prototype vehicle.

The prototype comprises of chassis, solar panels, a charge controller, Raspberry Pie, batteries, DC motors, a USB Web Camera, an ultrasonic sensor, and a servomotor.

The chassis was constructed using lightweight plywood to reduce cost and energy consumption. Solar panels used have an output power of 3W with a dimension 145*145mm and weigh around 0.025kg. Raspberry Pie (B+) is a microcomputer that has a 1.4GHz, 64-bit quad-core processor, a 40-pin general-purpose input/output handle, and a power output of 5V was used. It is equipped with the ability to produce complex computer programs using common language programs like Python, C++ can be used for audio and video processing and other related Internet of Things (IoT) based applications Yuhao et al. (2021). The Servo motor (Sg90) served as the actuator for the control of linear and angular motion Abdulhamid and Sheshai (2019).

USB Web Camera Module has a 5-mp sensor, 1080 pixels per 30 frames, 720 pixels per 60 frames, the camera produces crisp images of the surroundings by detecting light emitted by the surroundings on a photosensitive surface, it can detect both stationary and moving objects in its field of vision Henry et al. (2022). The ultrasonic sensor analyses the attributes of the target while the charge controller serves as a regulator that regulates the rate of electric current dissipation and prevents overcharging of batteries Abdulhamid and Achiki (2020).

The Operating Systems used were Open CV and Raspbian OS both have better user-friendliness characteristics than other operating systems offer free-to-use libraries, it has a cross-platform for the development of multiple programming languages Yuan et al. (2019).

OBSTACLE DETECTION AND AVOIDANCE

Since the program was developed based on two functions of Raspbian OS; setup () and loop (), the setup () function is the initiation stage of all variables while the loop () function is used to control the microcontroller. The USB camera captures the image sequences and then analyses them through the codes developed using libraries such as Numpy and OpenCV2. The ultrasonic sensor measures the distance between the vehicle and the obstacle using ultrasonic waves then translated into executable functions to enable the vehicle to adjust appropriately. Figure 2 shows the flowchart for object detection and avoidance.

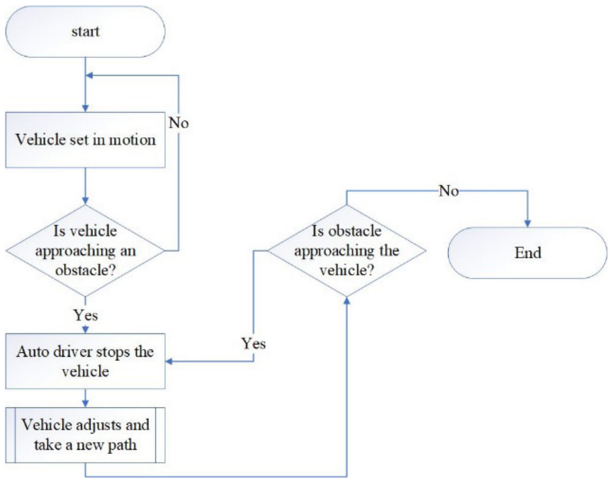

FIGURE 2. Flowchart of vehicle obstacle detection and avoidance

HARDWARE ARCHITECTURE

The system hardware architecture illustrated the method of connection with each module to make the AV. Figure 3 highlighted the system architecture, from the Figure, it can be seen that the power supply (solar) and batteries were interfaced with the H-Bridge driver motor and DC motors then linked with the Raspberry Pie controller, USB webcam is linked to the Raspberry Pie through the USB input of the Raspberry, the ultrasonic sensor and servo motor were also connected to the raspberry pie through various input ports.

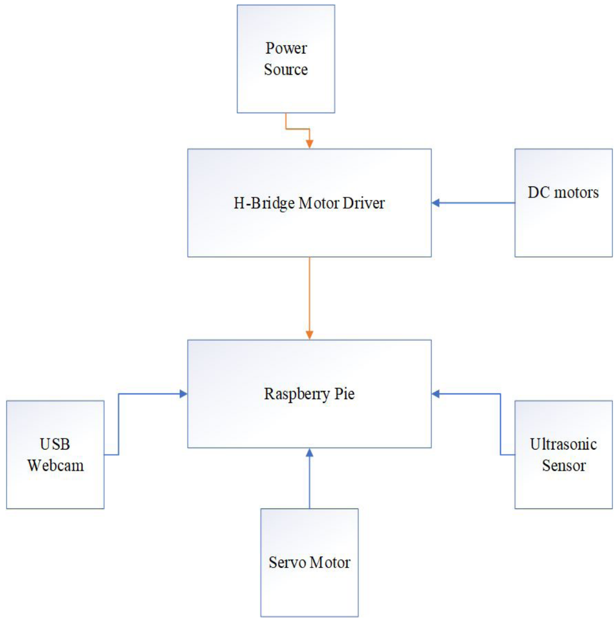

FIGURE 3. Block diagram of the solar autonomous vehicle

RESULTS AND DISCUSSION

OBJECT DETECTION AND AVOIDANCE

The solar AV prototype with an obstacle detection and avoidance technology was developed using the sequence from Figure 2, series of codes were computed to align with the flowchart shown in Figure 2 above, and these codes were then downloaded to the microprocessor to enable the vehicle to function autonomously. The AV comprises solar photovoltaic, charge controller, batteries, motor driver, DC motors, USB Webcam, servo motor, ultrasonic sensor, Raspberry Pie, and vehicle chassis. Figure 4 shows the lane detection sequence that enabled the autonomous driving of the vehicle, detection, and avoidance processes.

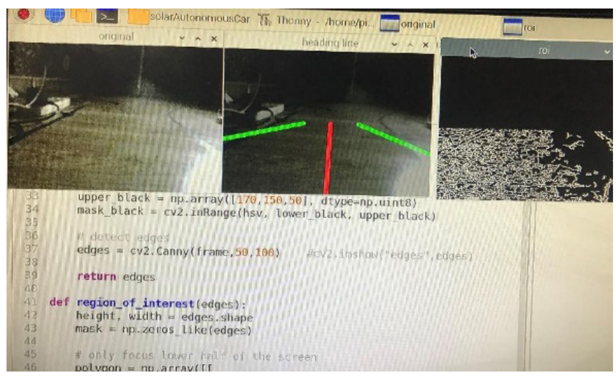

FIGURE 4. Lane Detection of the Preview

Figure 5 highlighted the images captured using the USB webcam to enable object detection and avoidance along its path. Figure 6 showcased a collage of images (1-5) highlighting the sequence of object detection and avoidance of the AV at an average distance of (0.025m) with the aid of the ultrasonic sensor and the USB webcam independently.

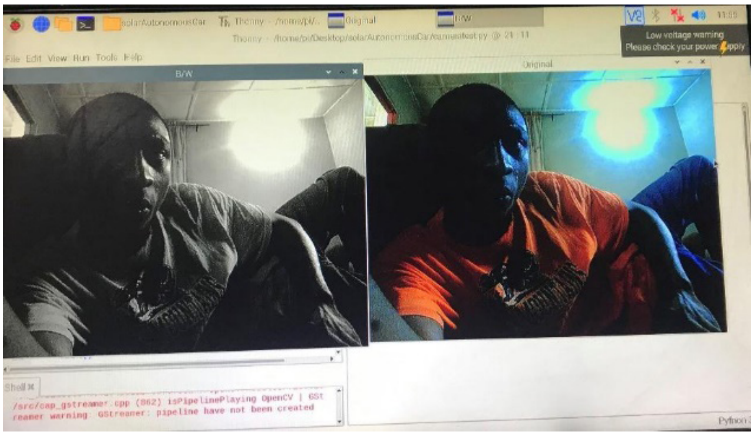

FIGURE 5. Images Captured from the USB webcam

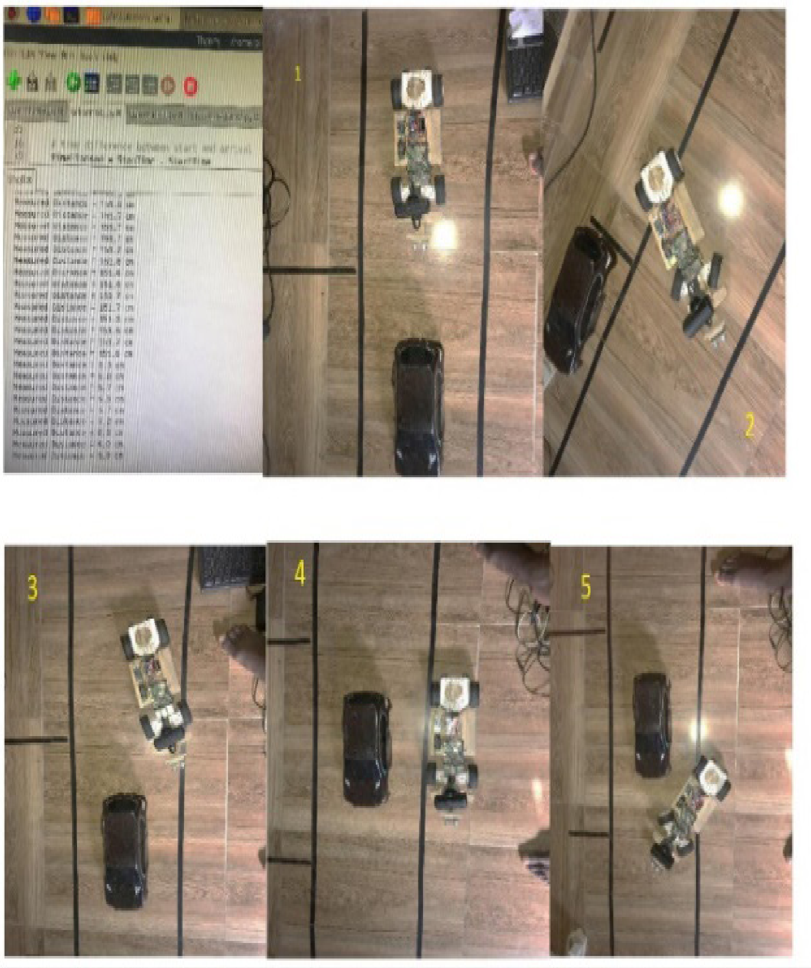

FIGURE 6. Preview of Autonomous Object Detection and Avoidance of the Solar AV

PERFORMANCE EVALUATION

The performance of the developed prototype AV was tested through the experimentation runs as shown in Figure 6. The results showed the duration of power dissipation over variation of motor frequency, and battery charging rates were also compared using the grid and solar photovoltaic system.

TABLE 1. Average time taken to reach peak charging (seconds)

S/N	Number of Tests	Charging rates Grid	Charging rates for Solar PV
1	1	9000	28,440
2	2	11,160	27,000
3	3	10,080	29,160
The average time taken to reach peak charge seconds		10,080	28,200
Mean		720	800
Standard Deviation		1080	1099.82

Table 1 showed the variation in time taken to reach peak charge from the two different sources of energy. The Table showed that using electricity to charge was faster than when the vehicle was charging with solar energy.

An average of 10080 seconds was recorded using the grid to charge the batteries while it took 28200 seconds to fully charge the 3000mAh batteries using solar energy the delay was due to the weather conditions that affect the rate of generation of energy from the sun.

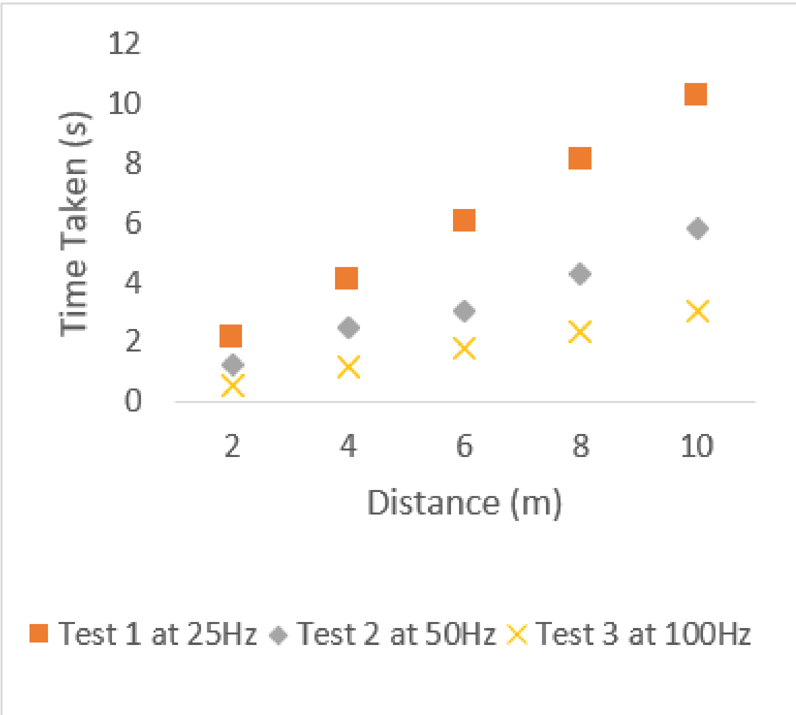

FIGURE 7. Motor Frequency against Distance and Time

Figure 7 highlighted a graph of time taken over distance travelled as motor frequency is varied, from the chart, it could be observed that Test 3(100Hz) recorded the quickest time (3.03 seconds) taken to travel over distances (2,4,6,8, and 10m) this is due to the higher motor frequency of 100Hz while the lowest was recorded for Test 1 at 25Hz. The graph showed that as the motor frequency increased, the less time taken to travel to a distance of 10 meters was recorded meanwhile when the frequency was reduced to 25Hz, the speed of the vehicle drastically reduced, and thus 10.3 seconds was exhausted to reach a distance of 10 meters. The intermediate frequency was recorded for Test

2 at 50Hz the motor frequency recorded 5.80 seconds to cover a distance of 10 meters and 1.23 seconds to cover a distance of 2 meters. However, the rate of energy dissipation is higher when the motor frequency is increased. Figure 8 shows the image of the fully assembled solar-powered autonomous vehicle.

FIGURE 8. Fully assembled solar-powered autonomous vehicle

CONCLUSION

The conceptualization and development of a Prototype solar autonomous vehicle with an object detection and avoidance system were successfully implemented; it comprises solar panels, a USB webcam, an ultrasonic sensor, a Raspberry Pie microcontroller, DC motors, Driver motors, batteries, servo motor, and chassis. The implementation and experimental runs were conducted and showed the vehicle could detect and avoid objects on its path autonomously. However, there is a need for improved solar charging capacity as it takes a long time to charge the batteries as compared to using electricity as a power source. Adopting smart technology in buildings will reduce the 40% of global energy consumed by residential and commercial buildings, also reducing our carbon footprint. Smart innovative technology like autonomous solar-powered vehicles rely on renewable energy, reducing dependence on fossil fuels and minimizing greenhouse gas emissions. By harnessing the power of the sun, they contribute to a cleaner and more sustainable transportation system, helping combat climate change, and providing an unlimited and free source of power. By integrating this energy source into autonomous vehicles, we can maximize energy efficiency and reduce overall energy consumption, making transportation more sustainable, can potentially reduce or eliminate the need for fossil fuel consumption, leading to long-term cost savings for owners. is seen as the necessary tools for increasing overall energy efficiency, smart vehicle policy-related matters should be enforced and incorporated into the urban and regional planning units to cater to this global rise into energy-saving autonomous vehicle fleets by creating smart charging stations that use the grid and solar photovoltaic to provide, store energy and also supply energy to the vehicles as well primary and secondary buildings which increases the return on investment for investors of energy systems.

The authors also further recommended the following for further work; the vehicle should be designed on a larger scale, adopt improved sensors such as LIDARs, PIR sensors, and GNS to enable proper navigation of the vehicle, and a deep learning technology to effectively process and classify objects.

ACKNOWLEDGEMENT

The authors would like to thank the Management University of Abuja and the Federal College of Horticulture Gombe for their financial support.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

Abdulhamid, M., & Achiki, M. 2020. Car Security System Based on Raspberry Pi. *Scientific Bulletin of the Electrical Engineering Faculty 1*(42).

Abdulhamid, M., & Sheshai, S. 2019. Design of Security System Based on Raspberry-Pi. *Scientific Bulletin of the Electrical Engineering Faculty 2*(41).

Agbese, R., Dagwa, I. M., Nurudeen, A. H., & Adekunle, J. 2022. Development of an Arduino-Based Robotic Arm Yam Heap Maker. *Journal of Mechatronics and Robotics*, 84-89.

Ahsan, S. M., Khan, H. A., & Naveed-ul-Hassan. 2022. Optimized power dispatch for smart building(s) and electric vehicles with V2X operation. *Energy Reports 8*: 10849–10867.

Alayat, A. B., & Ali Omar, H. (2023). Pavement Surface Distress Detection Using Digital Image Processing Techniques. *Jurnal Kejuruteraan 35*(1): 247–256. https://doi.org/10.17576/jkukm-2023-35(1)-24.

Andrea, M., Francesco, L., Sanvito, F. D., Matija, P., Quoilin, S., & Emanuela, C. 2022. Impact of mass-scale deployment of electric vehicles and benefits of smart charging across all European countries. *Applied Energy, 312*(118676).

Debbie, H., & Tim, S. 2021. Talking about automated vehicles: What do levels of automation do? *Technology in Society*.

European Commission. 2019. *The European Green Deal.* Brussels: European Commission. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52019DC0640.

Fagnant, D. J., & Kara, K. 2015. Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice, 77*, 167-181.

Gonçalo Homem de Almeida, C., Dimitris, M., Bart van, A., & Raymond, H. 2016. Vehicle automation and transport system performance. In *Handbook on transport and urban planning in the developed world* (pp. 498-516). https://www.researchgate.net/publication/299467997

Hyder, S., Gul, M., Hussain, S., Ahmed, S. I., Nazeer, A., & Ahmed, F. (2023). Implementation of A.I. Vehicle Detection for Traffic Analysis Using In-situ Surveillance Infrastructure. *Jurnal Kejuruteraan*, *35*(3): 779–787. https://doi.org/10.17576/jkukm-2023-35(3)-25

Henry, A. I., Hesham-El-Sayed, & Manzoor, K. 2022. An overview of sensors in Autonomous Vehicles. *International Workshop on Smart Communication and Autonomous Driving. 198*: 736–741.

Jamil, H., & Domokos, E.-K. 2021. Modeling travel behavior onboard of privately autonomous vehicle and shared autonomous Vehicle. *International Scientific Journal"Trans and Moauto World", 6*(2): 57-61.

Jelena, P., & Gyula, M. 2021. The Future of Autonomous Vehicles. *FME Transactions, 49* , 29-35.

Krzysztof, S., Jakub, W., Dominika, K., Rafał, F., Bartłomiej, W., Maciej, B., & Mateusz, W. 2022. Development of a solar-powered small autonomous surface vehicle for environmental measurements. *Energy Conversion and Management, 267*.

Mishra, A., Purohit, J., Nizam, M., & Gawre, S. K. (2023). Recent Advancement in Autonomous Vehicle and Driver Assistance Systems. *2023 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS):* 1–5. https://doi.org/10.1109/SCEECS57921.2023.10063089

Naz, N., Ehsan, M. K., Amirzada, M. R., Ali, M. Y., & Qureshi, M. A. 2022. Intelligence of Autonomous Vehicles: A Concise Revisit *Journal of Sensors, 2022*.

NBS. 2020. *Road Transport Data.* Abuja: National Bureau of Statistics.

Richter, M. A., Markus, H., Oliver, B., Vinit, P., & Joakim, W. 2022. Smart cities, urban mobility and autonomous vehicles: How different cities needs different sustainable investment strategies. *Technological Forecasting & Social Change, 184*.

Rodrigo, A., & Mohd, T. K. 2021. Sensors in Autonomous Vehicles: A Survey.

Ronik, K. P., Etminani-Ghasrodashti, R., Kermanshachi, S., Rosenberger, J. M., & Ann, F. 2022. Exploring willingness to use shared autonomous vehicles. *International Journal of Transportation Science and Technology*, 1-14.

Tijmen, B., Van, K. A., Jan, B., Joachim, M., & van, G. S. 2010. Systematic design of an autonomous platform for robotic weeding. *Journal of Terramechanics, 47*, 63–73.

Toshiyuki, I., & Thomas, B. S. 2019. A critique of the SAE conditional driving automation definition,. *Cognition, Technology & Work, 21*, 569–578.

Umar, I. K., & Gokcekus, H. 2019. Modeling Severity of Road Traffic Accident in Nigeria using Artificial Neural Network. *Jurnal Kejuruteraan*, *31*(2): 221–227. https://doi.org/10.17576/jkukm-2019-31(2)-06

Yaacob, N. F. F., Rusli, N., Bohari, S. N., Mat Yazid, M. R., & Muhammad Das, A. 2020. Integrated GIS Tool for Investigating the Relationship of Road Characteristics with Road Traffic Accidents. *Jurnal Kejuruteraan*, *32*(4): 683–691. https://doi.org/10.17576/jkukm-2020-32(4)-18.

Yuan, Y., Huang, J., & Yan, K. 2019. Virtual Reality Therapy and Machine Learning Techniques in Drug Addiction Treatment. *10th International Conference on Information Technology in Medicine and Education (ITME).*

Yuhao, H., Binggang, X., Jiaying, L., Kaiyi, W., Wang, W., & Jiabin, Y. 2021. Design and Implementation of Face Recognition System Based on Raspberry Pie. *2021 IEEE Intl Conf on Dependable, Autonomic and Secure Computing, Intl Conf on Pervasive Intelligence and Computing, Conf on Cloud and Big Data Computing, Intl Conf on Cyber Science and Technology Congress* 673-678.