

RESEARCH ARTICLE



Publisher: Daffodil International University
<https://journals.diu.edu.bd/index.php/jaiit>

Low-Cost Automated Zebra Crossing System with Actuated Safety Barrier

*A. T. Oyelam¹, A.O. Ajibodu¹, G.C. Ihenacho², and M.O. Olagunju³

¹Department of Mechatronics Engineering, Federal University of Agriculture Abeokuta, Nigeria

²Department of Mechanical Engineering, Pan Atlantic University Ibeju-Lekki, Lagos, Nigeria

³Department of Mechanical Engineering, Bamidele Olumilua University of Education, Science and Technology, Ikere Ekiti, Nigeria

*Email: oyelamiat@funaab.edu.ng

Abstract: Pedestrian safety is a key global concern due to increased urbanisation, traffic congestion, and a lack of pedestrian-friendly infrastructure. This paper presents a low-cost automated zebra crossing system that uses ultrasonic sensors and an Arduino-based control system to improve pedestrian safety. The system automates pedestrian crossing by recognizing pedestrian presence, initiating a safety flapping mechanism, and regulating traffic lights without requiring operator involvement. The performance evaluation revealed pedestrian detection accuracies of 98.57% (incremental) and 97.14% (decremental), with safety flapper reaction times of ± 50 ms. Power consumption analysis indicated a total load of 3.6 W, supporting solar-powered applications. Comparative assessment showed that the proposed system achieved accuracy levels similar to advanced sensor-based crosswalk systems while reducing cost by over 70%. The system offers a scalable and cost-efficient approach for deployment in resource-constrained urban environments, with future improvements directed towards IoT integration for adaptive, real-time traffic control.

Keywords: *Arduino microcontroller, ultrasonic sensors, zebra crossings, traffic congestion, pedestrian detection.*

1. Introduction

Walking is the most fundamental means of transportation and a key component of urban mobility. Despite its importance, pedestrian infrastructure is often overlooked in traffic policies, increasing the risk of pedestrian-related accidents. According to studies, pedestrians account for more than 20% of all traffic fatalities worldwide, with crossing incidents accounting for a sizable proportion [1]. Traditional pedestrian crossings, including signalised and zebra crossings, frequently lack efficient enforcement methods. Virtually every trip begins and ends with walking [1], making it a

fundamental form of mobility and a basic human activity [2–4].

This reality is often overlooked in transport and safety policy decisions. Pedestrians have been overlooked in the development of current traffic codes which have been concentrated on facilitating the flow of motorized traffic [2].

This neglect of pedestrian wellbeing is reflected in global crash statistics: more than one fifth of road fatalities happen among pedestrians; this proportion gets as high as two thirds in a few countries [1]. Pedestrians have been found to have the highest ratio of deaths to injuries among all the categories of people injured by motor vehicles: about two times that of motorcyclists and over four times that of motor vehicle occupants [4]. According to ITF [2], urban areas are where a majority of pedestrian injuries or fatalities occur and police reports showed that up to 80% of those in traffic collisions occur while crossing the road. The WHO estimates that annually, 1.35 million individuals perish and up to 50 million sustain non-fatal injuries due to traffic accidents, with schoolchildren and the elderly facing an elevated risk of pedestrian incidents, and children as young as 11 required to manage the challenge of road crossing [1]. A few attempts have been made to enhance the safety of pedestrians on the road, including a 5-phase signalization design [5] and evaluation of generic factors which singly or jointly influence the free flow of speed [6]. Over the years, several pedestrian crossing facilities have been introduced to aid pedestrians, but not all have been applied widely. Generally, two types have been the most common, 'signal-controlled crossings' and 'zebra crossings' [7–10]. Signal-controlled crossings also known as Pelican crossings are basically crossings operated by pedestrians through push buttons which activate traffic signals to stop motorized traffic allowing for safe pedestrian crossing. Zebra crossings on the other

hand, are typically zones on the road marked by stripes resembling the coat of a zebra which gives priority to pedestrians in that motorists are obliged to stop when someone has indicated their intent to cross by waiting by the crossing.

Recent advancements in smart-crosswalk technologies — including radar, thermal imaging, LiDAR, and computer-vision systems — have demonstrated strong safety improvements in pilot deployments [11-13], but these solutions often remain costly and complex for wide adoption in resource-constrained urban areas. This work proposes a pragmatic alternative: a low-cost Arduino-based pedestrian detection and actuation system using affordable ultrasonic and proximity sensors, together with servo-driven safety barriers (flappers), designed to provide mechanical enforcement of pedestrian priority at zebra crossings.

The project aims at the integration of automation into the system at minimal cost through the introduction of sensor controlled flapping mechanism serving as a vehicle barricade to protect people indicating their intentions to cross at Zebra crossings. An evaluation of existing relatively affordable pedestrian crossing systems revealed some notable limitations including limited accuracy in real-world conditions [6], lack of pedestrian safety mechanism, and limited throughput [14-19]. While advanced solutions incorporating specialized sensors such as LiDAR [12, 20-23] and use of thermal imaging offer high precision [16], this paper presents a relatively efficient solution by leveraging ultrasonic and proximity sensors, which provide reliable pedestrian detection while maintaining a low-cost framework.

In addition, low-cost embedded systems using ultrasonic and proximity sensors [8–10] offer affordability but often lack enforcement mechanisms and robustness. This work bridges this gap by integrating low-cost sensing with physical enforcement (actuated flappers), providing both detection and compliance.

2. METHODOLOGY

The automated system was designed to operate in a sequential logic framework where pedestrian detection, traffic light regulation, and flapper actuation are synchronized. The detection stage consists of the first ultrasonic sensor detecting pedestrians approaching the crossing while the second sensor confirms presence and increments the pedestrian count. This dual confirmation reduces false positives. The second stage is the control phase whereby when the threshold pedestrian count X is

reached, the Arduino initiates a yellow-to-red light transition. The last stage is the actuation stage where servo motors rotate the flappers by 90° to block vehicles by triggering a mechanism that ensures physical stoppage.

All power pins of Ultrasonic Sensor and Servo Motors are connected to the board which takes the power input pins in from the Arduino 5V pin and GND pin. This causes the servo to rotate anticlockwise at 90 degrees for the flappers to open for the passerby(s) to safely cross the street. After “X - R” (where X represents the desired number of people for red light prompt and R for the number of desired people for yellow light prompt), the number of people passing the sonars and waiting in the lobby the system will turn on the yellow light, while the subsequently additional “R” number of people crossing and waiting in the lobby triggers the red light. The system waits “T1” for a specific amount of time according to the traffic regulations of the localization for “R” more people to come and after timeout it turns on the red light and signal and repeats the due programmed process.

2.1. Hardware, Design and Assembly Phase

Some of the hardware components used for the development of the prototype include Flappers Arduino UNO, Servo Motor (SG90), Power Supply Unit, LCD Screen, Traffic Light Module, Ultrasonic Sensor, I2C LCD adapter, Male-Female Jumper Wires, Proximity Sensor, Resistors, Buttons and LED Lights. The hardware implementation of the model is done according to the block diagram in Fig.1 while 3D model of the developed prototype is shown in Fig. 2.

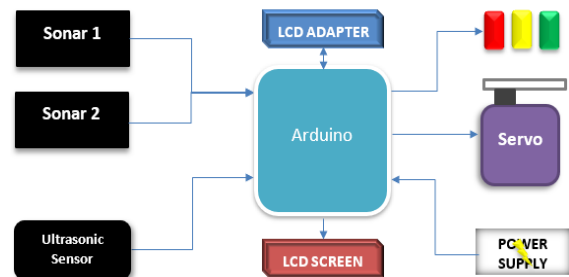


Fig. 1. Hardware Implementation Block Diagram

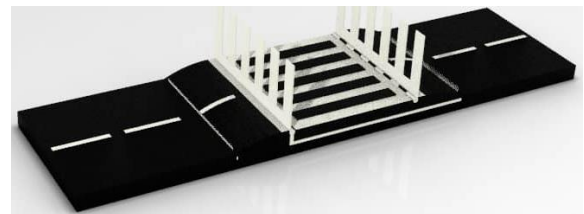


Fig. 2. Model Design of Automated Zebra Crossing System with Flapping Mechanism

Detailed wiring schematics and dimensional specifications of the prototype structure will be included in future revisions to enhance reproducibility.

2.2. Electrical/Electronic Components

The major components of the system include: the Arduino Uno, the HC-SR04 ultrasonic sensors, the Proximity sensors, Servo Motors, LCD Screen, L293D motor Driver Module. The Arduino Uno is the brain of the system. It serves the purpose of processing the data which is fed by the sensors and providing control signals to activate or deactivate the flappers of the system after predetermined conditions have been met.

The HC-SRO4 ultrasonic sensors and proximity sensors are devices that are used in the system for both detecting the presence of pedestrians near the zebra crossing as well as activating a count of the number of individuals present at the crossing. This data is sent to the Arduino Uno for processing. The ultrasonic sensor makes use of sonar for distance measurement whilst the proximity sensor makes use of infrared rays to detect the presence of pedestrians. Servo motors are rotary actuators that allow for precise control of linear position, velocity and acceleration. They are used in this work for the activation of the systems crossing safety mechanism – flappers, serving as guards against vehicle for the pedestrians across the zebra crossing lane.

The L293D motor driver module is a module for motors that allows for the control of the working speed and direction of two motors simultaneously. The device functions in the system as the signal transmitter for the controlling of the two servo motors controlling the crossing flapper’s position. The LCD screen uses liquid crystals to display information on a screen and serves as a means for indicating the pedestrian count in the automated zebra crossing system. An I2C LCD adapter is also used in the system to facilitate easy communication of data between the microcontroller and the LCD screen with the use of only two pins of the microcontroller (SDA and SCL) freeing up other pins for use elsewhere.

2.3. Design Calculations

a) Servo Torque Requirement

$$T = F \times r = (mg) \times r \tag{1}$$

$$= (0.25 \times 9.81) \times 0.15 = 0.368$$

The SG90 servo provides a rated torque of 1.8 N·m at 5V, giving an approximate safety factor of 5, which is adequate.

b) Power Consumption Analysis

The analyzed power consumption of the prototype setup is contained in Table 1.

Table 1: Developed Prototype Power Consumption Analysis

Component	Qty	Current (mA)	Voltage (V)	Power (W)
Arduino Uno	1	50	5	0.25
Ultrasonic Sensors (HC-SR04)	2	15 each	5	0.15
Proximity Sensor	1	20	5	0.10
Servo Motors (SG90)	2	250 each	5	2.50
LCD + I2C Adapter	1	40	5	0.20
Traffic Light Module	1	80	5	0.40
Total	–	–	–	3.60

c) Detection Range Justification

The ultrasonic sensor measures distance using:

$$d = \frac{v \times t}{2} \tag{2}$$

With $v = 343$ m/s (air at 20°C), a range of 1–5 cm was chosen to minimize false triggers from distant objects.

d) System Modelling

The system’s behavior is modeled as a discrete event system with the following notations:

- $N(t)$ = number of detected pedestrians
- X = threshold for red signal
- R = intermediate threshold
- T_1 = waiting time

The decision logic is then given as follows:

- If $N(t) \geq X$ □ Red Light+Barrier Activation
- If $R \leq N(t) < X$ □ Yellow Light
- If $t > T_1$ □ Force Transition to Red

3. Results and Discussions

To ensure comprehensive evaluation, the developed system was tested under various conditions:

- Lighting Conditions: Daylight, dusk, nighttime, and artificial lighting scenarios.
- Weather Conditions: Clear and simulated adverse conditions (reduced visibility and moisture interference). Due to environmental constraints, snowfall conditions were not physically tested.
- Traffic Conditions: Low, medium, and high pedestrian traffic densities.

Testing was conducted in controlled environments, simulated conditions, as well as in real-world settings to validate performance.

To check the validity of some components the following tests were equally performed using the Arduino IDE:

- i. Servo test to check 90° opening of the safety flappers.
- ii. Servo test to check 90° closing of the safety flappers.
- iii. Push button test by checking if it activates an LED upon being pressed.

A prototype of the final assembly including all the necessary sensors were implemented and the system’s performance accordingly tested as shown in Figure 3:

- i. In order to test for pedestrian detection accuracy, an object representing a pedestrian was made to pass by the sensor for a total of 70 incremental and decremental test trials each within the detection range of 1cm to 5cm away from the sensors. Although 70 trials provided preliminary validation, larger datasets are required for statistical robustness.
- ii. Also, to test the safety flappers and traffic light mechanism, the number of people required for the yellow light to turn on was set to 3 and also an extra number of 1 or more people to ignite the red light. A delay value of 5000ms for yellow-light activation and also a 10000ms delay for the red-light activation was set and the system response time tested.
- iii. The number of delays in seconds for the flappers to remain open before closing begins and the yellow light changes back to green was set to 5000ms
- iv. Testing of the override open/close button just in case of emergency.

In addition, it can be stated that there is a significant cost reduction when compared with LiDAR-based smart crosswalk systems with estimated price range of \$800–\$1500 per unit and vision-based systems with estimated price range of \$500–\$1200 [24-25],

whereas the developed prototype costs approximately \$90–\$120. The comparative analysis done is tabulated in Table 2

Table 2: Performance Comparative Analysis

System Type	Accuracy	Cost	Complexity
LiDAR-based	~99%	High	High
Vision-based	~98%	Medium	High
Proposed System	97–98%	Low	Low

Table 3 shows the accuracy of the pedestrian detection sensors in incremental and decremental counting.:

Table 3: Sensor accuracy for pedestrian counting

Case	Total Trials	Number of Successful Trials	Accuracy (%)
Incremental Counter	70	69	98.57
Decremental Counter	70	68	97.14

From the table the accuracy of sensors for incremental counting is found to be 98.57% and that of Decremental counting to be 97.14% which is satisfactory for its application. The observed error in the accuracy may have stemmed from false movement of the item used to represent pedestrians away from the specified detection range of 1cm to 5cm detection range.

As for the safety flappers functioning, the flappers responded within ±50ms of the delay set which is also a satisfactory result. The resulting model is shown in Figure 3.

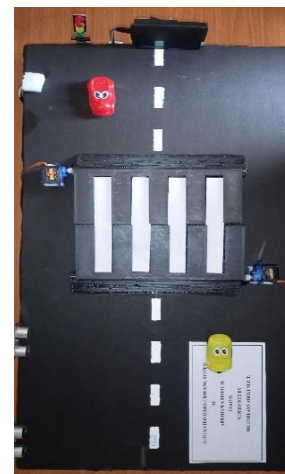


Fig. 3: Model of Low-cost automated zebra crossing system

4. Conclusion

This work developed a low-cost automated zebra crossing system with ultrasonic and proximity sensors, Arduino-based control, and servo-driven flapper enforcement. Performance evaluation demonstrated high detection accuracy (97–99%) and safety flapper actuation occurring within ± 50 ms of the programmed delay, and modest power requirements (3.6 W), validating its suitability for low-resource urban environments

The proposed design is suitable for pilot deployments in resource-constrained settings and serves as a foundation for future IoT-enabled, multi-sensor smart-crosswalk systems. Future work includes IoT integration, multi-sensor fusion, adaptive timing algorithms, and large-scale field trials to validate long-term reliability and user acceptance. The system achieves up to 70% cost reduction while maintaining over 97% detection accuracy, making it suitable for deployment in low-resource environments.

References

- [1] World Health Organization (WHO). Pedestrian safety: a road safety manual for decision - makers and practitioners. Geneva: World Health Organization; 2013 [cited 2025 Oct 6]. Available from:
- [2] http://apps.who.int/iris/bitstream/10665/79753/1/9789241505352_eng.pdf.
- [3] International Transport Forum (ITF). Pedestrian safety, urban space and health. Paris: OECD Publishing; 2012 [cited 2025 Oct 6]. Available from: https://www.oecd.org/content/dam/oecd/en/publications/reports/2012/08/pedestrian-safety-urban-space-and-health_g1g13e6c/9789282103654-en.pdf
- [4] Zegeer CV, Stutts J, Huang H, Cynecki MJ, Van Houten R, Alberson B, et al. Guidance for implementation of the AASHTO strategic highway safety plan. Volume 10: A guide for reducing collisions involving pedestrians. Washington: Transportation Research Board; 2004 [cited 2025 Oct 6]. Available from: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_500v10.pdf
- [5] National Technical University of Athens (NTUA). Measures for pedestrian safety and mobility problems. Promotion of Measures for Vulnerable Road Users (PROMISING) project, deliverable D1. Brussels: European Commission; 2001 [cited 2025 Oct 6]. Available from: <https://carrefour.vivreenville.org/storage/app/media/publications/Articles-de-fond-Encyclopedique/intersection-conviviale/promotion-mobility-and-safety-vulnerable-road-users.pdf>
- [6] Shukla S, Sahu V, Sharma S, Patel VK. Intelligent traffic signal with zebra crossing stoppage. *Int J Adv Res Electr Electron Instrum Eng*. 2018;7(4):1771-4.
- [7] Ysaswin BAOS, Jinasena TMKK. Automated low -cost pedestrian crossing carriage for efficient traffic control and pedestrian safety. In: Proceedings of the International Research Conference on Smart Computing and Systems Engineering (SCSE); 2019.
- [8] Prasad SJS, Yuganath P, Kumaravelan R, Kumar RS, Aravindan V, Harish VA, et al. Automatic barrier control in the zebra crossing of roads for pedestrian safety. *IOP Conf Ser Mater Sci Eng*. 2021; conference proceedings.
- [9] Rahman AM, Hossain R, Mehdi Q, Nirob EA, Uddin. An automated zebra crossing using Arduino -UNO. *International Journal of Advance Research Innov Ideas Educ*. 2023; 9(4):2910 -6.
- [10] Patil KT, Salunkhe DA, Chauhan ST. Automatic zebra crossing using Raspberry PI. *International Journal of Innovative Science Research Technology* 2024; 9(6): 729-36
- [11] T. J. Mateo Sanguino, J. M. Lozano Domínguez, M. J. R. González, et al., "New Approach to Intelligent Pedestrian Detection and Signaling on Crosswalks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 25, no. 12, Dec. 2024.
- [12] S. Nayagi, D. Prashant Jamwal, M. Vasudeva Reddy, P. Narasimha Royal, and B. Teja Karthik Reddy, "Arduino-Powered Smart Crosswalk Signal System," in Proc. of the Second Congress on Control, Robotics, and Mechatronics (CRM 2024), Singapore: Springer, 2024, pp. 371-376.
- [13] M. Jabłoński, J. Iwaniec, and W. Zabierowski, "Comparison of Pedestrian Detectors for LiDAR Sensor Trained on Custom Synthetic, Real and Mixed Datasets," *Sensors*, vol. 22, no. 18, 7014, Sep. 2022.
- [14] Sixu Fei, "Design and Implementation of an Autonomous Pedestrian Detection System Based on CFT," *Applied and Computational Engineering*, vol. (Proceedings of the 3rd Int'l Conf. on Software Engineering & ML), 2025.
- [15] D. Yang, H. Zhang, E. Yurtsever, K. A. Redmill, and Ü. Özgüner, "Predicting Pedestrian Crossing Intention With Feature Fusion and Spatio-Temporal Attention," *IEEE Transactions on Intelligent Vehicles*, vol. 7, no. 2, pp. 221-234, Jun. 2022.
- [16] Z. Wei, Y. Liu, L. Zhao, S. X., "Pedestrian Crossing Intention Prediction from Surveillance Videos for Over-the-Horizon Safety Warning," *IEEE Transactions on Intelligent Transportation Systems*, 2023.
- [17] V. Liu, S. Chen, N. Zheng, Y. Wang, J. Ge, K. Ding, Z. Guo, W. Li, and J. Lan, "Ground Pedestrian and Vehicle Detections Using Imaging Environment Perception Mechanisms and Deep Learning Networks," *Electronics*, vol. 11, no. 12, 2022.
- [18] S. El Hamdani, N. Benamar, and M. Younis, "PedCross: Pedestrian Crossing Prediction for Auto-Driving Bus," *IEEE Transactions on Intelligent Transportation Systems*, Dec. 2024.
- [19] O. T. Ajayi and J. O. Olusina, "Vehicle Detection, Tracking, Counting and Classification Using Deep Learning," *Nigerian Journal of Technology*, vol. 43, no. 4, pp. 738-742, 2024.
- [20] K. Kaya, M. Y. Çodur, and E. Mustafaraj, "Automatic Detection of Pedestrian Crosswalk with Faster R-CNN and YOLOv7," *Buildings*, 2023.
- [21] Jialai Liu, Kai Liu, Feiyu Jin, et al., "Toward Robust and Adaptive Pedestrian Monitoring Using CSI: Design, Implementation, and Evaluation," *Neural Computing and Applications*, 2022.
- [22] "Pedestrian-Liveness Detection Based on mmWave Radar and Camera Fusion," in 2022 IEEE SECON (Conference), for sensor fusion and safety contexts.
- [23] O. Bayode, O. Aiyelokun, O. Osanyinlokun, and A. Adanikin, "Enhancing Road Crash Prediction: A Comparative Study of Machine Learning Algorithms and Safety Performance Functions on the Lagos-Ibadan Expressway," *Nigerian Journal of Technology*, vol. 44, no. 2, pp. 215-221, 2025.
- [24] C. CPJRobot, "LiDAR pricing across different applications in 2025: Key trends and insights," *PoE LiDAR*, Apr. 30, 2025.

[Online]. Available: <https://www.poelidar.com/lidar-pricing-across-different-applications-in-2025-key-trends-and-insights/>

- [25] M. F. Şen, H. Gümüşkaya, and Ş. Pazar, "Video detector: A dual-phase vision-based system for real-time traffic intersection control and intelligent transportation analysis," arXiv preprint arXiv:2603.14861, 2026.



A.T. Oyelami received the Ph.D. degree in Mechanical Engineering from the Federal University of Agriculture, Abeokuta, Nigeria in Year 2012. He is currently an Associate Professor of Computer Integrated Manufacturing Engineering. His research interests include automation technologies and Digital Manufacturing. He has published several research articles in reputed international journals and conferences



A.O. Ajibodu received the B.Eng. degree in Mechatronics Engineering from the Federal University of Agriculture, Abeokuta, Nigeria in Year 2021. He is currently working as an Academic Consultant at Croydon, London in the United Kingdom. His research interests include artificial intelligence, data science, intelligent systems, and robotics.



G.C. Ihenacho received the Ph.D. degree in Automotive Engineering from the Moscow Central Automobile and Engine Research Institute in Year 1986. He is currently the head of department of Mechanical Engineering at the Pan Atlantic University Ibeju-Lekki, Lagos, Nigeria. His research interests include Thermo-Fluids and Internal Combustion Engine Technologies. He has published several research articles in reputed international journals and conferences



M.O. Olagunju received his B.Tech. degree in Mechanical Engineering from Ladoko Akintola University of Technology (LAUTECH) Ogbomoso, Oyo State in year 2001 and M.Eng. degree in Mechanical Engineering (Production Option) from Federal University of Technology, Akure (FUTA) in Year 2018. He is presently working as Lecturer II at Bamidele Olumilua University of Education, Science and Technology Ikere Ekiti (BOUESTI). His research area includes Renewable Energy, Industrial / Production Engineering (IPE), Environmental Engineering, maintenance of power plants for mechanical, electrical and environmental engineering fields for reliability, efficiency, sustainability.