Automated Zebra Crossing Using Artificial Intelligence

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Abstract

Pedestrian safety remains a critical concern, particularly at zebra crossings where accidents often occur due to poor visibility and a lack of driver awareness. This project presents an Automated Zebra Crossing System that integrates Artificial Intelligence (AI) with Raspberry Pi technology to enhance pedestrian safety. The system utilises a webcam and a YOLO-based object detection model to identify pedestrians in real-time. When a pedestrian is detected, the Raspberry Pi triggers a flashing light and buzzer alarm to alert both pedestrians and drivers, ensuring a safer crossing experience. To improve efficiency and sustainability, the system is powered by a 12V lithium-ion battery, recharged via a solar panel, making it energy-efficient and environmentally friendly. The hardware components, including the microprocessor, relay module, and output devices, are enclosed in a waterproof electrical box to withstand various environmental conditions. Additionally, the implementation of the COCO dataset in the YOLO algorithm ensures high detection accuracy, with a confidence score threshold set above 70% to minimise false positives. The results demonstrate that the system effectively detects pedestrians and activates the warning signals in real-time, enhancing road safety. With its high commercial potential, this system can be implemented in industrial areas and later expanded to urban roads with further enhancements. Future improvements include upgrading to more advanced microprocessors, optimising image processing, and increasing public awareness through educational campaigns. Overall, this project contributes to the development of smart transportation systems, promoting safer and more efficient urban mobility.

Keywords: Artificial Intelligence, Pedestrian Detection, Raspberry Pi, Smart Transportation System, YOLO Object Detection

1.0 Introduction

Pedestrian safety remains a significant concern in Malaysia, as pedestrians account for the third-highest fatality group in road accidents, following motorcyclists and passenger car occupants. According to the Ministry of Transportation Malaysia (MOT), an average of 542 pedestrian fatalities occurs annually, translating to approximately 45 deaths per month. Data from the Traffic Investigation and Enforcement Department (JSPT) indicate a downward trend in pedestrian fatalities, with 394 recorded in 2019, 266 in 2020, and 266 in 2021 [1]. Despite this decline, pedestrian-related accidents continue to be a serious issue, highlighting the need for improved safety measures at road crossings.

Traditional zebra crossings and pedestrian traffic lights depend heavily on driver compliance and pedestrian caution. However, such systems are often ineffective, particularly in high-traffic areas where driver inattentiveness and poor visibility pose significant hazards [2]. These challenges are even more pronounced for People with Disabilities (OKU), the elderly, and children, who face mobility, sensory, and reaction-time limitations. Existing systems largely lack intelligent features that dynamically adapt to real-time pedestrian activity, exposing users to avoidable risks.

Several prior studies have proposed sensor-based interventions to improve crossing safety. For instance, Patil et al. [3] developed an Arduino-based system that activates pedestrian lights when motion is detected near a zebra crossing, while Kumar et al. [4] implemented a PIR sensor to alert both pedestrians and vehicles. Although such systems improve visibility, they operate on basic motion detection and do not adapt dynamically to varying pedestrian behaviours or traffic conditions.

Recent research has explored the use of Artificial Intelligence (AI) to enhance detection and decision-making in traffic environments. Kulhandjian et al. [5] introduced an AI-powered pedestrian detection system using thermal imaging and radar to improve visibility in low-light scenarios. El Habchi et al. [6] employed drone-based surveillance to detect crowd movement and pedestrian clustering. While these systems demonstrate technological advancement, they are often hardware-intensive, expensive, or focused on surveillance rather than direct intervention at pedestrian crossings.

However, the majority of current smart crossing systems rely on static sensor-based triggers and lack integration of AI-driven, real-time automation [7], [8]. Many fail to address critical limitations such as driver non-compliance, adaptive response to diverse pedestrian profiles (e.g., OKU), or long-term sustainability through renewable energy sources. While previous studies have proposed sensor-based pedestrian alert systems, few have explored fully automated, AI-driven systems capable of real-time detection and autonomous decision-making. This gap limits the practical deployment of adaptive safety solutions in dynamic urban environments, especially in regions requiring cost-effective and energy-efficient infrastructure.

To bridge this gap, this study proposes an AI-powered Automated Zebra Crossing System that integrates computer vision and sensor fusion for real-time pedestrian detection. The system autonomously triggers visual and auditory alerts for both drivers and pedestrians, significantly improving crossing safety and accessibility, particularly for OKU communities. The integration of solar energy not only enhances sustainability but also supports long-term deployment in urban and semi-urban settings. This research contributes a novel, cost-effective, and adaptive solution to pedestrian safety challenges by advancing the current state of AI-based traffic control systems. By addressing both technical and social dimensions, including accessibility, real-time decision-making, and energy efficiency, it holds potential for wide-scale adoption in smart city initiatives.

2.0 Methodology

This study implements an automated zebra crossing system utilising artificial intelligence (AI) technology integrated with a Raspberry Pi 4B microcomputer. The system uses a webcam and a pre-trained YOLOv5 (You Only Look Once version 5) object detection model to identify pedestrians in real-time. Upon detection, the Raspberry Pi activates a buzzer and flashing light to alert both pedestrians and approaching vehicles, thereby enhancing crossing safety and visibility.

The development process encompasses hardware installation, software integration for real-time object detection, and automated control logic for output responses. The methodology includes four main components: (i) system design and data flow; (ii) hardware configuration and installation; (iii) software programming and AI model setup; and (iv) system logic and pseudo-code implementation.

2.1 System Architecture and Workflow

The overall system workflow is presented in Figure 1, combining both the project flow and functional block components for clarity and to avoid redundancy. The webcam continuously monitors the crossing zone and sends video input to the Raspberry Pi, which runs the YOLOv5 model for pedestrian detection. Once a "person" is identified, the system triggers two outputs: a flashing light and a buzzer alarm. If no pedestrian is detected, the system reverts to an idle state.

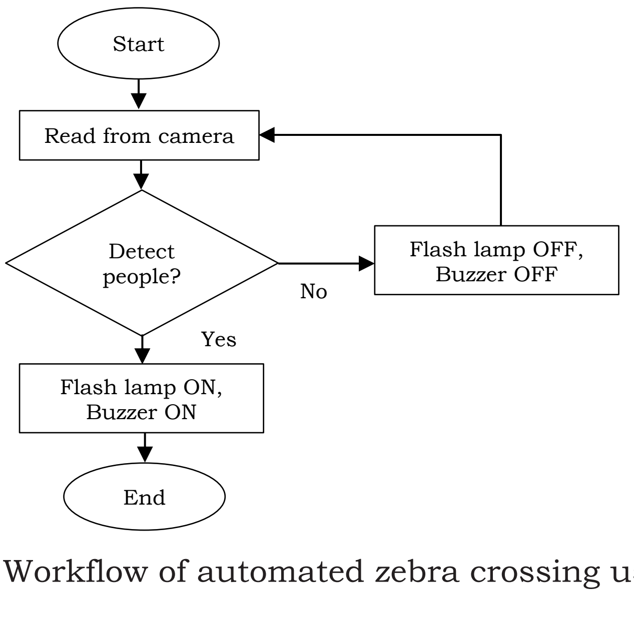

Figure 1: Workflow of automated zebra crossing using AI

The system is composed of the following key components:

i. Input: Webcam (captures real-time pedestrian movement).
ii. Processing unit: Raspberry Pi 4B (executes YOLOv5-based pedestrian detection, controls the output).
iii. Output: Flashing light (alerts pedestrians that the crossing is active) and buzzer alarm (notifies both pedestrians and drivers of crossing activity).

The integration of these components enables a fully automated pedestrian crossing system that enhances safety, accessibility, and efficiency using AI-based object detection.

2.3 Hardware Configuration

Figure 2 shows the circuit wiring between the microprocessor and connected components. The Raspberry Pi 4B is used due to its better performance and energy efficiency compared to previous models [9]. A 12V DC lithium-ion battery supplies power, supported by a solar panel to ensure uninterrupted, eco-friendly operation. A relay module is used to control the 12V buzzer and flashing light through the Raspberry Pi's GPIO outputs.

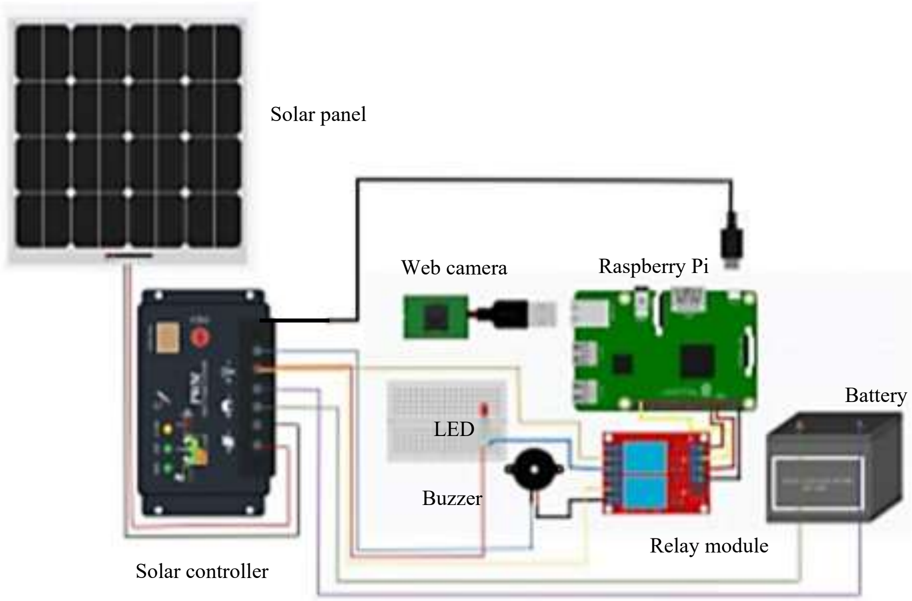

Figure 2: Circuit schematic of Raspberry Pi with output controls via relay

To ensure durability in outdoor conditions, all electronic components are housed in a waterproof enclosure as shown in Figure 3. The box is mounted at a 45-degree tilt, which was determined based on optimal solar irradiance angles for Malaysia's latitude (~4°N), as recommended in photovoltaic deployment studies. This orientation maximises solar energy absorption for battery charging.

Figure 3: Waterproof electrical box for the electrical components

2.4 Software Implementation

The software component is implemented in Python and runs on the Raspberry Pi OS. The system uses:

i. OpenCV – An open-source computer vision library for image processing and camera interfacing [10].
ii. YOLOv5 – A real-time object detection model developed by Ultralytics, known for its balance between accuracy and computational efficiency.

YOLO was initially introduced by Redmon et al. [11] and has undergone multiple updates. At the time of this research, YOLOv11 was the latest version, offering enhanced detection speed and accuracy [12]. YOLOv5 was selected in this study due to its compatibility with low-power edge devices like Raspberry Pi. The dataset used for detection is Microsoft COCO (Common Objects in Context), which consists of 80 pre-trained objects as presented in Table 1.

Table 1: COCO dataset

No	Item	No	Item	No	Item	No	Item	No	Item
0	Person	16	Dog	32	Sports ball	48	Sandwich	64	Mouse
1	Bicycle	17	Horse	33	Kite	49	Orange	65	Remote
2	Car	18	Sheep	34	Baseball bat	50	Broccolo	66	Keyboard
3	Motorcycle	19	Cow	35	Baseball glove	51	Carrot	67	Cell phone
4	Airplane	20	Elephant	36	Skateboard	52	Hot dog	68	Microwave
5	Bus	21	Bear	37	Surfboard	53	Pizza	69	Oven
6	Train	22	Zebra	38	Tennis racket	54	Donut	70	Toaster
7	Truck	23	Giraffe	39	Bottle	55	Cake	71	Sink
8	Boat	24	Backpack	40	Wine glass	56	Chair	72	Refrigerator
9	Traffic light	25	Umbrella	41	Cup	57	Couch	73	Book
10	Fire hydrant	26	Handbag	42	Fork	58	Potted plant	74	Clock
11	Stop sign	27	Tie	43	Knife	59	Bed	75	Vase
12	Parking meter	28	Suitcase	44	Spoon	60	Dining table	76	Scissors
13	Bench	29	Frisbee	45	Bowl	61	Toilet	77	Teddy bear
14	Bird	30	Skis	46	Banana	62	TV	78	Hair drier
15	Cat	31	Snowboard	47	Apple	63	Laptop	79	Toothbrush

A detection confidence threshold of 70% was empirically selected after preliminary testing. Thresholds below 70% resulted in false positives (e.g., shadows or background objects being detected as people), while thresholds above 80% occasionally missed actual pedestrians. Thus, 70% were chosen to balance precision and recall, ensuring reliable activation without over-sensitivity.

Once a person is detected with ≥70% confidence, the Raspberry Pi triggers the output components via GPIO pins 17 (buzzer) and 26 (flashing light), maintaining the active state for one minute to allow safe crossing. Thus, this output pin is declared before the main program as shown in Figure 4.

```
from pathlib import Path
import RPi.GPIO as GPIO
import time

LED_PIN =17
BUZZER_PIN = 26
GPIO.setmode(GPIO.BCM)
GPIO.setup(17, GPIO.OUT)
GPIO.setup(26, GPIO.OUT)
```

Figure 4: Code for setting the buzzer and flashing light

The program initialises these outputs and follows a conditional activation process. This logic ensures the system only activates upon high-confidence detection of a pedestrian, thereby reducing false activations and improving energy efficiency. The pseudo-code for this operation is presented in Figure 5 below:

```
while True:
    read image from web camera
    Import YOLO library
    object detection code
    if (object == "person")
        wait for 2 minutes
        buzzer on for 3 minutes
        flashing lamp on for 3 minutes
    else
        buzzer off
        flashing lamp off
```

Figure 5: Pseudo-code of the program

3.0 Results and Discussion

The AI-powered automated zebra crossing prototype was successfully developed and tested under real-world conditions. The hardware integration of Raspberry Pi 4B, webcam, relay module, buzzer, flashing light, and solar panel demonstrated operational stability. The waterproof casing ensured protection against environmental factors, while the 45-degree solar panel mounting angle ensures optimal sunlight absorption and energy conversion.

3.1 Real-Time Pedestrian Detection Performance

The system was programmed to detect only the "person" class from the Microsoft COCO dataset with a confidence score threshold above 70% to ensure high detection reliability and avoid false positives. During laboratory trials, the system was able to detect pedestrians with this criterion and trigger the buzzer and flashing light accordingly, as shown in Figure 6.

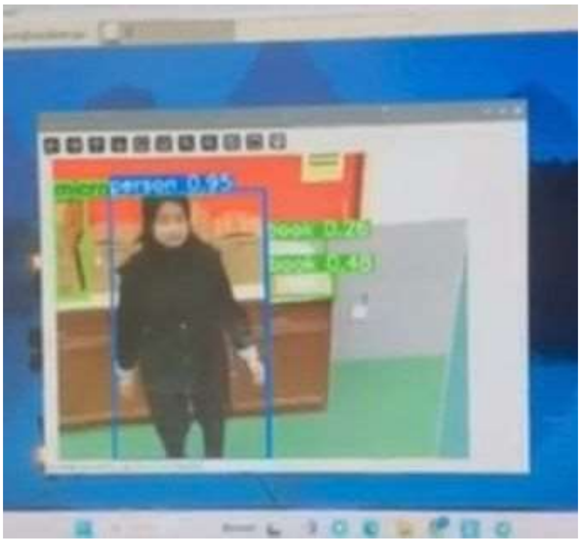

Figure 6: Detection of "person" during lab test session

However, during these lab tests, it was observed that there was a noticeable time lag between detection and system response. This delay is attributed to the limited processing capacity of the Raspberry Pi, which affects real-time image processing speed compared to more powerful hardware. Table 2 presents the recorded detection latency across five trials.

Table 2: Detection latency during lab testing

Trial	Detection Rate (s)	Average Detection Rate (s)
First	7.61	
Second	7.38	
Third	7.43	7.54
Forth	8.04	
Fifth	7.25	

The average detection latency was 7.54 seconds, indicating that while the system successfully identifies pedestrians, the current hardware limits the speed of actuation. For future improvements, the use of mini-PCs or NVIDIA Jetson Nano is recommended to reduce latency and enhance real-time responsiveness.

3.2 Power Efficiency and Operational Stability

Solar energy was the primary power source, with a 12V lithium-ion battery supporting the system. Field measurements showed that a fully charged battery sustained the system for approximately 18 hours, proving it suitable for continuous daily operation without grid dependence.

4.0 Conclusion

This project successfully developed and implemented an AI-powered automated zebra crossing system powered by solar energy. The system detects pedestrians in real time and autonomously activates visual and auditory alerts, enhancing safety at crossings without relying on manual control or grid electricity. The main contribution of this study lies in its integration of real-time object detection using YOLO and sustainable energy through solar power, offering a cost-effective, modular, and autonomous solution for pedestrian safety, particularly in low- to medium-traffic environments such as industrial zones and suburban roads. This system fills a notable gap in existing infrastructure, which often lacks automation or sustainable power sources. Compared to conventional and earlier smart crossing systems, this prototype operates more intelligently and independently, distinguishing itself through its AI-based detection, renewable energy use, and adaptability to underserved areas. To further improve system performance, future work should focus on reducing detection latency, improving accuracy in crowded or low-visibility conditions, and enhancing hardware resilience in outdoor environments. Upgrading to more powerful processors like Jetson Nano and using weatherproof, high-resolution cameras is recommended. Quantitative targets such as reducing latency below 3 seconds and achieving over 95% detection accuracy under various lighting conditions should guide future iterations. In conclusion, this research presents a practical and scalable contribution to smart transportation initiatives, addressing real-world challenges in pedestrian safety with a sustainable and intelligent solution.

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Author Contributions

Noor Azlyn Ab Ghafar: Data Curation, Software, Hardware, Formal Analysis, Visualisation; **Nur Raihana Sukri**: Conceptualisation, Supervision, Writing-Review & Editing; **Ninie Farahana Kamarulzaman**: Investigation, Validation, Writing-Original Draft.

Conflicts of Interest

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have reviewed and approved the manuscript, consent to its submission, and declare that there are no conflicts of interest.

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