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Development of A Traffic Light Control System Using ARM-Based Microcontroller

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Abstract

Traffic lights are widely used at road intersections to regulate vehicle movement through red, yellow, and green signals. However, the absence of a clear time indication for each phase can cause driver uncertainty, sudden braking, and red-light violations. To address these issues, this project develops a traffic light control system with a single countdown timer as an indicator to road users while reducing implementation costs and simplifying hardware interconnections. The system is divided into two main parts: software development and hardware implementation. The C programming language is used to compute the traffic control program. The program is written, tested, debugged, and then programmed onto the NXP LPC1768 development board using the Keil uVision Integrated Development Environment (IDE). The developed program controls the timing sequence of the traffic lights, manages the countdown display, and determines the pedestrian crossing phase according to a predefined fixed-time schedule. The hardware part involves assembling components such as 7-segment displays, Light-Emitting Diode (LED) traffic lights, and the microcontroller development board. The traffic light system is designed to implement a 30s green light phase, followed by yellow and red light phases. During the final 10s, the countdown from 9 to 0 is displayed using a single 7-segment. In addition, a dedicated pedestrian crossing phase is activated at the end of each full cycle, during which all vehicle signals are red to allow pedestrians to cross safely. The project demonstrates a fully functional traffic control system with an effective countdown display and smooth integration of the software and hardware components. The novelty of this project is a low-cost traffic control system that uses a single 7-segment display for the countdown phase, which reduces hardware cost, simplifies the circuit design, and cutting required microcontroller pins.

1. Introduction

Traffic lights control vehicle flow and provide safe crossings for pedestrians, but most fixed-time signals do not indicate how much time remains in each phase [1-3]. As a result, drivers often guess the remaining green or red time, which can lead to sudden braking, rushing to “beat the light”, and red-light violations, while pedestrians may misjudge the safe time to cross [4-6]. In addition, previous studies have examined how countdown signal timers affect driving behavior and overall road safety [7]. Green signal countdown timers have also been studied for their influence on severe crash types related to red-light violations at signalized intersections [8]. In the Malaysian context, red-light running at signalized junctions remains an important safety issue, particularly among motorcyclists [9].

This project develops a four-way traffic light control system with a 7-segment countdown display and a dedicated pedestrian crossing phase. The controller is implemented on an ARM-based NXP LPC1768 microcontroller programmed in C and demonstrated on a small-scale prototype using 3D-printed traffic light models, light-emitting diode (LED), a 7-segment display and a buzzer.

The main objectives of this project are to design and develop a traffic light control system with a countdown timer and pedestrian crossing feature, using an ARM-based microcontroller platform. The traffic light control system prototype was developed using the NXP LPC1768 microcontroller [10]. The system control was coded in C, using the Common Microcontroller Software Interface Standard (CMSIS). The coding was tested, debugged and implemented on the development board using the Keil development tools. Earlier traffic light prototypes developed on microcontroller platforms also show that embedded controllers are suitable for implementing structured signal sequencing and simulation-based validation [11].

1.1 Traffic Light Technology

Table 1 compares traffic light control systems. Fixed-time traffic control uses preset signal timings and is simple and low-cost, but it cannot adapt to changing traffic conditions, which reduces efficiency. Density-based and actuated systems improve performance by adjusting signal timing based on vehicle presence or traffic density, making them more responsive and efficient under varying conditions, as they depend on sensor accuracy. Adaptive systems further enhance efficiency by leveraging real-time data and optimization algorithms, but they require more advanced, costly infrastructure. Intelligent Transportation Systems (ITS) integrate sensing, communication, and smart technologies to achieve the highest level of traffic management efficiency. The ITS is significantly complex and expensive. Manual traffic control is useful in emergencies and special situations, but is not practical for continuous use due to its reliance on human intervention. Countdown timers have also been evaluated in terms of intersection performance, indicating that they are relevant not only for safety but also for traffic operation efficiency [12]. Some studies further report potential environmental benefits of traffic signal countdown timers through their influence on driver response near intersections [13].

Table 1 *Comparison of traffic light control systems*

	System Type	Characteristic of Operation	Performance	Complexity and Cost
[14]	Fixed-time traffic control system	Uses preset signal timing with a fixed cycle.	Efficient for stable traffic and predictable traffic conditions.	Simple design, low cost, and minimal maintenance.
[15]	Density-based traffic control system	Adjusts signal timing based on traffic density detected by sensors.	More efficient for uneven traffic flow, performance depends on sensor accuracy.	Moderate complexity, cost depends on the number and type of sensors.
[16]	Actuated traffic control system	Responds to vehicle detector inputs by extending or skipping signal phases.	Efficient for varying traffic demand, it reduces unnecessary delays.	Moderate to high complexity, requires a reliable detection system.
[17]	Adaptive traffic control system	Uses real-time traffic data and optimization algorithms to continuously adjust timing.	Highly efficient in dynamic and congested traffic conditions.	High complexity, advanced hardware requirements, and higher cost.
[18]	Intelligent Transportation System (ITS)	Integrates sensing, communication, and smart-city technologies.	Very high efficiency with enhanced traffic management and coordination.	Very high complexity, requires advanced infrastructure, and high cost.
[19]	Manual traffic control	Controlled directly by traffic officers or trained personnel based on real-time observation.	Effective for emergencies and special situations, not suitable for continuous operation.	Low system cost, but high manpower dependency.

The objective of this project is to develop a simple, cost-effective four-way traffic light system using a CMSIS-based microcontroller. Therefore, a fixed-time traffic control approach was selected due to its low complexity, ease of implementation, and suitability for resource-constrained embedded systems.

1.2 Project Scope

The scope of this project is limited to a single four-way traffic light junction controlled by a microcontroller. The system manages four vehicle approaches and their traffic signals, together with the surrounding pedestrian crossings and a 7-segment countdown display at the junction.

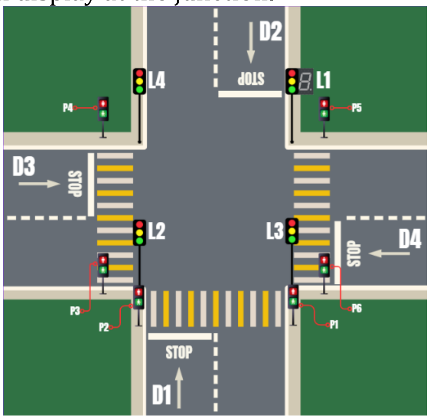

Fig. 1 *Top view of a four-way junction for the traffic light system*

Fig. 1 illustrates a top view of a four-way traffic light junction for this project. The junction layout features four main vehicle directions, labelled D1, D2, D3, and D4. Each direction is equipped with a traffic light (L1–L4), where L1 corresponds to D1, L2 to D2, L3 to D3, and L4 to D4. Each traffic light includes a 3-color LED (red, yellow, green) and a 7-segment display that shows a countdown timer during the green phase, providing drivers with a visual indication of how much time remains before the signal changes.

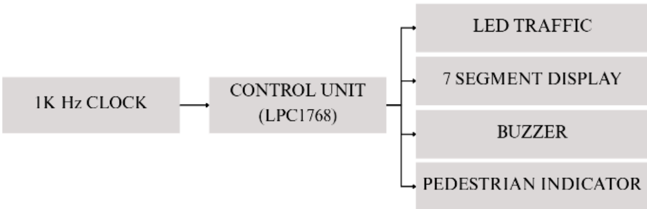

Fig. 2 *System block diagram*

As indicated by the system block diagram in Fig. 2, the 1 kHz clock provides the time base for the controller to generate precise delays for each traffic phase. The control unit, LPC1768, reads this clock and runs the state-machine program that decides which outputs should be ON or OFF. The LED traffic outputs drive the red, yellow, and green vehicle signals at each junction. The 7-segment display output shows the countdown time during the L1 phase. The buzzer activates during the pedestrian green phase to provide an audible warning, while the pedestrian indicator controls the red and green LEDs at the pedestrian crossings.

2. Schematic Diagram

Fig. 3 shows the full wiring diagram of the four-way traffic light system. The NXP LPC1768 microcontroller is connected to the LED traffic signals for junctions L1–L4 and the pedestrian LEDs (P) through current-limiting resistors. The same GPIO lines also drive the single 7-segment display, which displays the countdown timer.

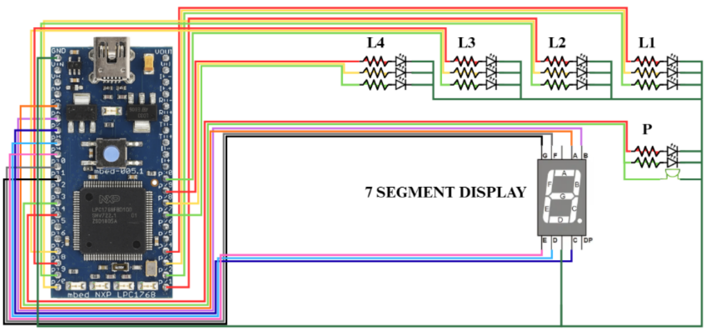

Fig. 3 *Schematic connection between LPC1768 board, traffic lights for each direction and the 7-segment display*

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This schematic defines the actual pin connections used when implementing the prototype on the breadboard, as given in Table 2.

Table 2 *Pin connections for the traffic control system*

Type	Feature	Function	Pin
Traffic control	LI Junction	L1 red	P2.2
		L1 yellow	P2.3
		L1 green	P2.4
	L2 Junction	L2 red	P2.5
		L2 yellow	P1.31
		L2 green	P1.30
	L3 Junction	L3 red	P0.26
		L3 yellow	P0.25
		L3 green	P0.4
	L4 Junction	L4 red	P0.5
		L4 yellow	P0.10
		L4 green	P0.11
Countdown display	7-segment display	Segment a	P0.9
		Segment b	P0.8
		Segment c	P0.7
		Segment d	P0.6
		Segment e	P0.0
		Segment f	P0.1
		Segment g	P0.18
Pedestrian control	Visual	P red	P0.16
		P green	0.15
	Audio	Buzzer	P0.15

The core controller is the NXP LPC1768, implemented with an ARM Cortex-M3 microcontroller. It executes a state-machine program written in C, controls the GPIO pins to drive the red, yellow, and green LEDs at each junction, updates the 7-segment module to show a 9-to-0 countdown during the final part of the L1 traffic phase, and activates the buzzer during the pedestrian green phase as an audio alert.

The prototype represents a plus-shaped four-way junction with four vehicle signal heads (L1–L4), each using red, yellow, and green LEDs, and pedestrian indicators at the crossing points, also using red and green LEDs. A single 7-segment countdown display is mounted near the active junction to show the remaining seconds, and a buzzer provides an audible warning during the pedestrian green phase.

3. Overall System Operation

Fig. 4 illustrates the overall system operation flow for the traffic light control. This system operates a one-direction-at-a-time traffic control cycle to prevent conflicts. After initialization, it continuously cycles through four vehicle phases (L1-L4), where only one direction receives a green light at a time while all other vehicle and pedestrian signals remain red. During the final seconds of each green phase, a 7-segment display shows a countdown, followed by a yellow interval before briefly returning all lights to red.

After completing all four vehicle phases, the system enters a dedicated pedestrian phase in which all vehicle lights remain red, and all pedestrian signals turn green for a fixed duration. Once the pedestrian phase ends, the cycle restarts from phase 1.

This organization ensures orderly, conflict-free traffic flow, clear visual timing indication and structured pedestrian crossing, making it suitable for embedded-system-based traffic management applications.

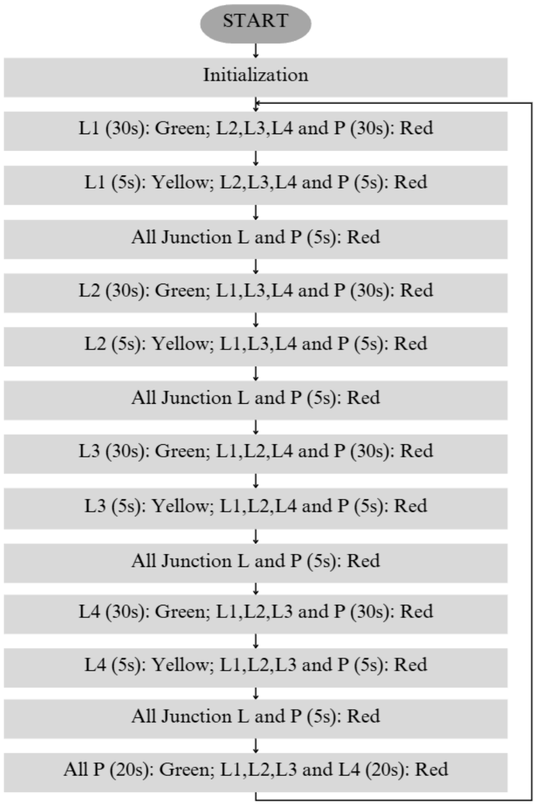


Fig. 4 *Traffic light flow chart*

4. Hardware Implementation

Fig. 5 presents the prototype of the traffic light system, which was developed using an NXP LPC1768 board connected to a breadboard to traffic-light LEDs, pedestrian LEDs, a 7-segment display, and a buzzer, forming a small four-way junction model that demonstrates the programmed timing, countdown, and pedestrian phase in real hardware. The LPC1768 microcontroller generates the timing and switching for all phases, the traffic-light LEDs indicate red, yellow, and green states for each junction, the pedestrian LEDs show when it is safe or unsafe to cross, the 7-segment display provides a countdown of the remaining time, and the buzzer gives a warning during the pedestrian green.

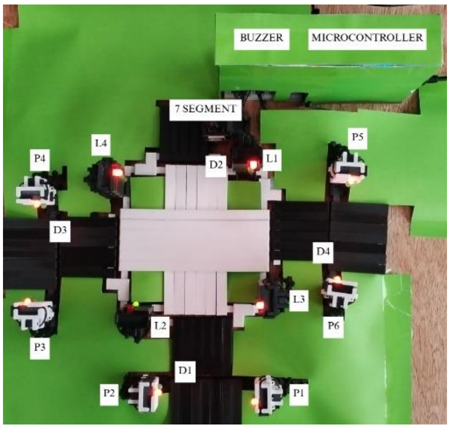


Fig. 5 *Top view of the traffic light system prototype*

The prototype interconnects each LED and its 7-segment segments to specific GPIO pins on the LPC1768 as provided in Table 2.

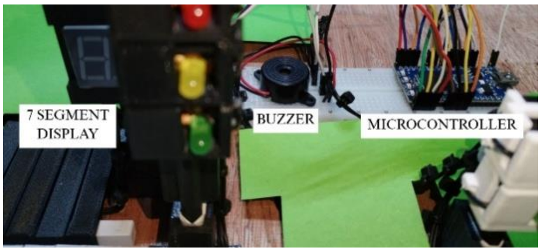
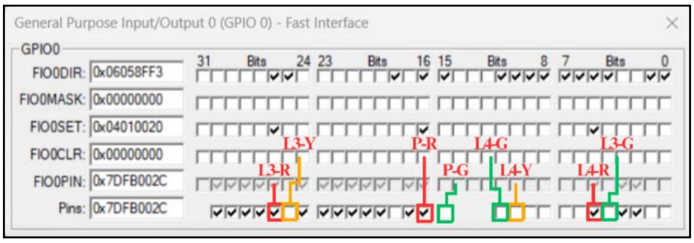


Fig. 6 *Arrangement of 7-segment display, buzzer and microcontroller*

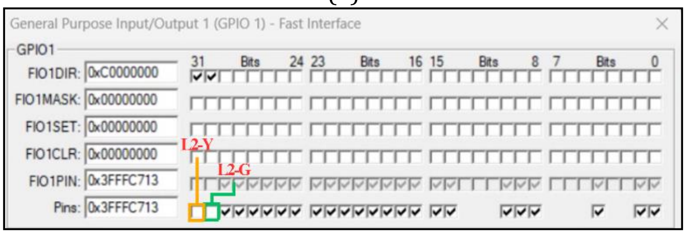
Fig. 6 shows the physical arrangement of the system in Fig. 3. The microcontroller on the breadboard is connected to the 7-segment display and buzzer using the same pin assignments as in the schematic, demonstrating that the theoretical full wiring diagram is realized in the actual prototype.

5. Result and Analysis

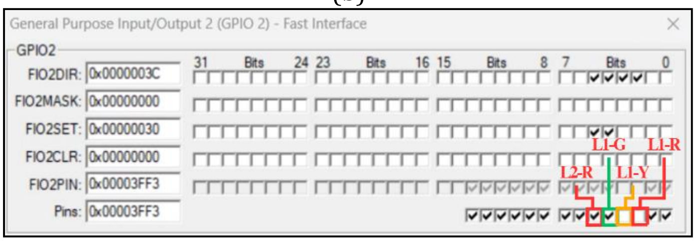
Fig. 7 illustrates the pin allocation for all traffic lights, representing the system prototype LEDs configured through the Keil general purpose input/output (GPIO) fast interface. The GPIO fast interface was used to simulate and verify the program functionality before downloading the code to the LPC1768 microcontroller.



(a)



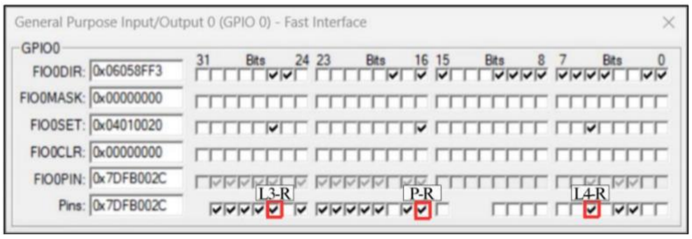
(b)



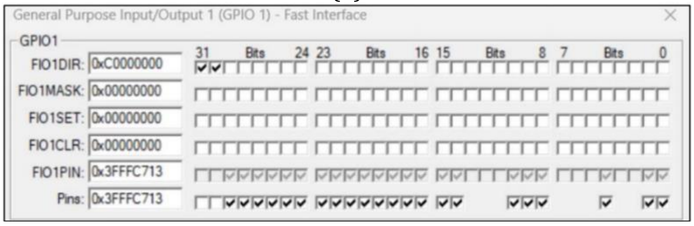
(c)

Fig. 7 *Pin assignment for all the traffic lights on GPIO fast interface; (a) Port 0; (b) Port 1; (c) Port 2*

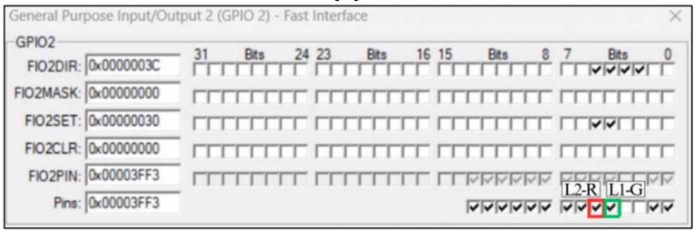
Testing was conducted by observing the LED states and 7-segment display outputs over multiple complete operating cycles. Initial observation confirmed that the traffic phases follow the intended sequence, with only one junction displaying a green signal at any given time and an all-red interval enforced between successive phases. The pedestrian phase is correctly executed at the end of the vehicle cycle, during which all vehicle lights remain red, and the buzzer is activated. The 7-segment display counts down from 9 to 0 during the final part of the L1 green phase, providing a clear visual indication of the remaining time before the signal transition. Furthermore, the simulation timing diagrams generated are consistent with the observed behaviour of the hardware prototype, verifying the correctness of the program logic and GPIO configurations.



(a)



(b)



(c)

Fig. 8 *GPIO status during the L1 GREEN phase; (a) Port 0; (b) Port 1; (c) Port 2*

Fig. 8 shows the GPIO Fast Interface status during the 30-second GREEN phase of Junction L1. Bit P2.4 is set high to activate the L1 green LED, while P2.5 is high to keep the L2 red LED ON. Simultaneously, pins P0.26 and P0.5 are driven high to maintain L3 and L4 in the red state, respectively, and P0.16 is high to keep the pedestrian red indicator ON. This result confirms that only L1 is granted right-of-way during the 30-second green interval, while all other vehicle directions and pedestrian movements remain stopped.

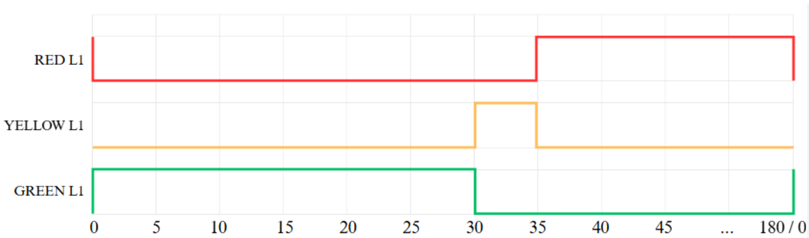


Fig. 9 *Timing diagram for junction L1 over a complete cycle*

Fig 9 shows the timing waveform for Junction L1. The L1 GREEN signal is active from approximately 0 to 30 seconds, followed by the L1 YELLOW phase from 30 to 35 seconds. After 35 seconds, the L1 RED signal remains ON until the cycle completes. This confirms that Junction L1 is allocated a 30-second green phase, followed by a 5-second yellow transition period before handing over control to the next junction.

The controller operates on a fixed 180-second cycle, with only one direction receiving a green signal at any given time. Each vehicle phase at L1, L2, L3, and L4 consists of 30 seconds of green, followed by 5 seconds of yellow, and a subsequent 5-second all-red clearance interval before the next junction is activated. After completing all four vehicle phases, the system enters a 20-second pedestrian green phase, during which all vehicle signals remain red, and the buzzer is activated. During the L1 phase, the 7-segment display provides a visual countdown, showing 9 to 5 during the final 5 seconds of the green interval and 4 to 0 during the 5-second yellow transition.

Fig. 10 shows the traffic light at Junction L1 together with its dedicated 7-segment display. When L1 is in the red state, the countdown display is disabled to prevent confusion for drivers. As the L1 green phase approaches its end, the 7-segment display begins showing a countdown starting from 9, as shown in Fig. 10(b). After that, the countdown continues into the yellow phase, as illustrated in Fig. 10(c), until it reaches completion. Finally, Fig. 10(d) indicates the return to the red phase, during which the 7-segment display is again disabled.

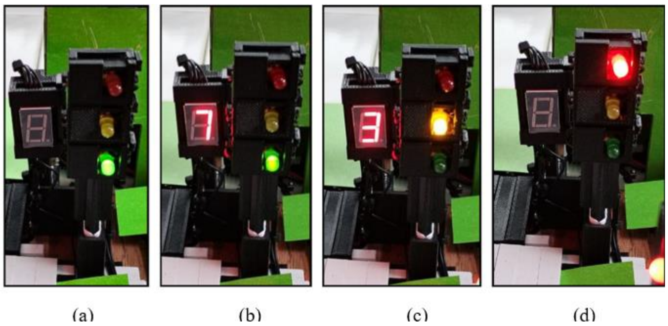


Fig. 10 *Operation of 7-segment display during the final 10-second countdown of each phase; (a) Green phase with the display disabled; (b) Green phase with the countdown starting from 9 seconds; (c) Yellow phase with the countdown continuing; (d) Return to the red phase with the display disabled.*

Table 3 *Overall data status for each junction*

	L1	L2	L3	L4	P
Phase 1	G/Y	R	R	R	R
Phase 2	R	G/Y	R	R	R
Phase 3	R	R	G/Y	R	R
Phase 4	R	R	R	G/Y	R
Phase 5	R	R	R	R	G

Table 3 summarizes the overall signal status at each stage of the 180-second cycle. In each phase, only one junction or the pedestrian phase shows a green signal, while all other approaches remain red. During the first phase, L1 is green while L2–L4 and the pedestrian signal (P) are red. In the second phase, L2 turns green; in the third and fourth phases, L3 and L4 are activated, respectively. In the fifth phase, all vehicle approaches remain red while the pedestrian phase (P) turns green. This confirms that the system follows a one-direction-at-a-time control strategy, followed by a dedicated pedestrian phase to ensure orderly and conflict-free operation.

6. Conclusion and Recommendation

This project successfully developed and implemented a traffic light control system using an ARM-based LPC1768 microcontroller programmed in C. The system coordinates four-way vehicular traffic, incorporates a dedicated pedestrian crossing phase, and integrates a 7-segment countdown timer to indicate the remaining green time. The prototype demonstrates that a relatively simple microcontroller-based design can enhance safety and improve user awareness at signalized intersections. It also provides a solid foundation for further enhancements. Such as adaptive timing and sensor-based traffic control. This design also offers the advantage of lower implementation cost and reduced system complexity, since using only one 7-segment display eliminates the need for an additional display unit, simplifies circuit connections for showing tens digits, and reduces the total number of required microcontroller pins.

However, several limitations were identified. The controller operates on a fixed-time schedule and does not adapt to real-time traffic density, limiting its ability to respond to varying vehicle or pedestrian demand. Using a single-digit 7-segment display limits the visible countdown to 10 seconds. Additionally, the hardware implementation is constructed on a breadboard with multiple jumper wires, which is suitable for laboratory demonstration but lacks the mechanical robustness required for real-world deployment.

Several improvements can be considered for future development. Traffic sensors, such as infrared or ultrasonic devices, can be integrated to enable adaptive signal timing based on queue length or real-time demand, allowing green intervals to adjust dynamically to actual traffic conditions. The countdown feature could be enhanced by upgrading to a two-digit or multiplexed 7-segment display to support longer and more informative timing intervals. From a hardware perspective, the prototype should be migrated from a breadboard implementation to a dedicated printed circuit board (PCB) with a proper enclosure to improve mechanical robustness, electrical reliability, and suitability for field deployment. For future enhancement, smart traffic signal control approaches for smart city applications suggest that this prototype can be expanded with sensing, communication, and intelligent control features [20].

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Muhammad Asyraf Hakim Mohd Zaki, King Lee Chua;* ***data collection:*** *Muhammad Asyraf Hakim Mohd Zaki;* ***analysis and interpretation of results:*** *Muhammad Asyraf Hakim Mohd Zaki, King Lee Chua, Kim Seng Chia;* ***draft manuscript preparation:*** *Muhammad Asyraf Hakim Mohd Zaki, King Lee Chua, Kim Seng Chia. All authors reviewed the results and approved the final version of the manuscript.*

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