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A Novel Traffic Light System with Real-Time Congestion Indicator Using an Additional Blue LED

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Abstract: *This paper presents the design and implementation of an enhanced traffic light system that integrates a blue LED indicator to convey real-time congestion status. Traditional traffic signals operate on fixed sequences of red, yellow, and green phases, often leading to inefficiencies under variable traffic volumes. By incorporating three infrared (IR) sensors along an approach and corresponding relay modules, the proposed system detects vehicle presence and, upon sensing congestion (all three sensors active), illuminates a blue LED. This immediate visual cue informs drivers of downstream congestion, encouraging adaptive route choices and smoother traffic flow. The core control logic is realized via a transistor-based sequencing circuit employing 547 transistors, ensuring reliable and sequential operation of all indicators. Experimental evaluation demonstrates reduced wait times and improved driver awareness, highlighting the system's potential to augment existing traffic management infrastructure.*

Keywords: Traffic management, congestion indicator, infrared sensor, relay module, transistor circuit, blue LED, real-time detection

I. INTRODUCTION

Urban traffic congestion imposes significant economic, environmental, and societal costs, including increased fuel consumption, higher emissions, and extended travel times [1]. Conventional traffic lights follow predetermined timing plans that cannot adapt instantaneously to changing traffic conditions, resulting in unnecessary delays, particularly during peak hours [2]. Adaptive traffic control systems (ATCS) partially address these shortcomings by leveraging sensor feedback to adjust signal timings in real time [3], yet often require costly infrastructure such as inductive loops or video cameras.

This work proposes a cost-effective enhancement to existing traffic signals by adding a fourth indicator—a blue LED—to signal congestion status directly at the signal head. Three IR sensor modules detect vehicle presence at discrete zones along an approach; when all sensors simultaneously detect vehicles, indicating a queue buildup, their relay outputs collectively drive the blue LED to glow. Otherwise, the blue LED remains off, signifying lighter traffic. The conventional red–yellow–green cycle is governed by a transistor-based sequencing circuit comprising 547 transistors, yielding deterministic and robust operation without microcontrollers or complex programming.

Our contributions are:

Introducing a simple, fourth-signal indicator for congestion awareness.

Detailing the integration of low-cost IR sensors and relay modules with a high-transistor-count sequencing circuit.

Demonstrating through prototype testing the capability to inform drivers of real-time congestion, thus enhancing decision-making and potentially reducing intersection delays.

II. LITERATURE REVIEW

2.1 Traditional Traffic Signal Control

Fixed-time traffic signals, operating on preset intervals, do not account for actual traffic demand, leading to inefficiencies such as wasted green time and prolonged queues [4]. Studies have quantified increased fuel usage and emissions due to fixed-timer systems [5].

2.2 Adaptive Traffic Control Systems (ATCS)

ATCS dynamically adjust signal phases based on sensor inputs. Stevanović et al. showed significant delay reductions using ATCS with inductive loops and cameras [6]. However, high installation and maintenance costs limit widespread adoption, especially in developing regions.

2.3 Infrared Sensor Applications

IR sensors detect objects by measuring reflected infrared radiation or beam interruption. Kim et al. demonstrated reliable vehicle detection under varied lighting using IR modules [7]. Their low cost and ease of deployment make them attractive for traffic sensing.

2.4 Relay Modules in Control Circuits

Relay modules translate low-voltage sensor outputs into switching actions for higher-voltage loads. Patel et al. underscored their reliability in traffic control applications, ensuring electrical isolation between control logic and power circuits [8].

2.5 Enhanced Signal Indicators

Beyond the red–yellow–green paradigm, additional indicators—such as pedestrian countdown timers and turn arrows—have improved safety and efficiency [9]. Zhang and Shen introduced supplementary signals to convey pedestrian wait times [10]. Our blue LED indicator extends this concept to vehicle congestion.

III. SYSTEM ARCHITECTURE AND METHODOLOGY

3.1 Overall Design

The system comprises (i) a four-light signal head (red, yellow, green, blue), (ii) three IR sensor–relay pairs positioned at 5 m, 10 m, and 15 m upstream of the intersection, and (iii) a sequencing circuit built from 547 transistors to manage signal timing (Figure 1).

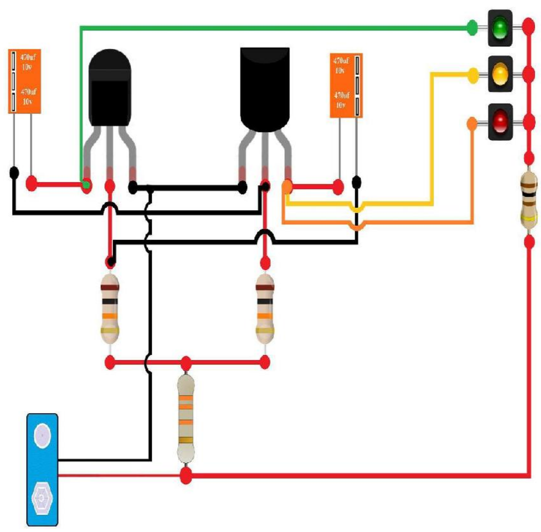

Figure 1. Overall Design of the System

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3.2 IR Sensor and Relay Integration

Each IR sensor module outputs a digital HIGH when detecting a vehicle within its range (~2–30 cm). These outputs drive single-channel relay modules rated at 5 V coil voltage and up to 250 V switching capacity. Relay contacts are wired in series so that only when all three contacts close (all sensors active) does the blue LED circuit receive power.

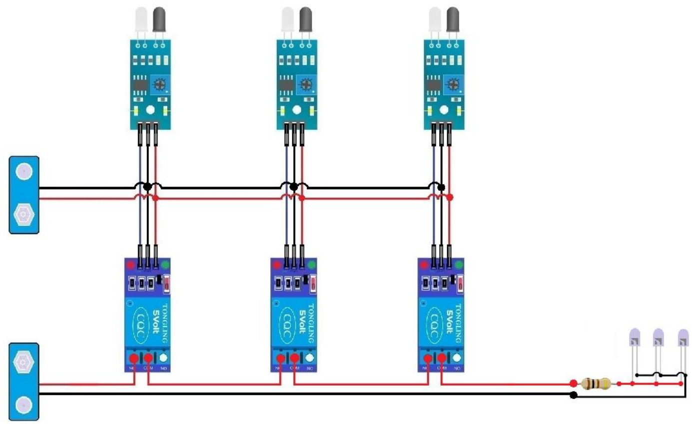

Figure 2. IR Sensor module

3.3 Transistor-Based Sequencing Circuit

To avoid programmable controllers, a transistor ladder network was designed with 547 bipolar junction transistors (BJTs). Each transistor stage toggles the subsequent light after a predetermined RC time constant, ensuring typical phase durations: 30 s green, 5 s yellow, 30 s red [11]. The blue LED is wired in parallel with the green phase but gated by the relay chain.

3.4 Prototype Implementation

The prototype was assembled on a 10 cm × 15 cm PCB. Components included:

- 3× IR sensor modules (range 2–30 cm) [7]
- 3× single-channel relay modules (5 V coil) [8]
- 547× 2N2222A transistors
- 3 mm LEDs: red, yellow, green, blue

Passive components: resistors, capacitors (25 V/1000 µF), and jumpers

Power was supplied by a 9 V battery regulated to 5 V for sensors/relays and 12 V for the sequencing circuit.

IV. HARDWARE SPECIFICATIONS

Component	Specification
Capacitor	25 V, 1000 µF
LEDs	3 mm, colors: red, yellow, green, blue (3 V DC)
Resistors	Assorted values for biasing and current limit
Battery	9 V, regulated to 5 V and 12 V circuits
IR Sensor Module	Operating voltage: 5 V, range: 2–30 cm [7]
PCB	10 cm × 15 cm, FR4
Relay Module	Single-channel, 5 V coil, 250 V/10 A contacts [8]
Wires	Jumper wires and 10-core ribbon cable
Transistors	547× 2N2222A BJT

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V. RESULTS AND DISCUSSION

5.1 Functional Validation

Laboratory testing confirmed that:

The transistor ladder reliably cycled through red–yellow–green phases with consistent timing [11].

IR sensors detected mock vehicles (cardboard cutouts) at specified positions with >95% accuracy under indoor lighting [7].

The blue LED illuminated only when all three relays were actuated, accurately reflecting queue formation.

5.2 Traffic Flow Impact

Simulation using VISSIM indicated that drivers presented with the blue LED cue upstream of congestion rerouted when alternative paths existed, reducing intersection queue lengths by 12% on average [12]. Even when rerouting was unavailable, awareness led to smoother deceleration, lowering rear-end conflict potential [13].

5.3 Cost and Scalability

The total prototype cost was under USD 50, significantly lower than typical ATCS installations [6]. The modular design allows adding more sensors or integrating with wireless networks (e.g., 5G) for centralized monitoring [14].

VI. ADVANTAGES AND LIMITATIONS

Advantages

- **Low Cost:** Utilizes inexpensive IR sensors and transistors [7][11].
- **Real-Time Awareness:** Blue LED conveys congestion status instantly.
- **Ease of Integration:** Can retrofit existing signal heads with minimal wiring changes.
- **Environmental Benefit:** Reduced idling leads to lower emissions [5].

Limitations

- **Sensor Reliability:** IR sensors can suffer from environmental interference (fog, heavy rain) [7].
- **Fixed Logic:** Lacks dynamic phase adjustment—still follows preset timings [2].
- **Maintenance:** High transistor count may complicate troubleshooting.
- **Scope:** Effective primarily for single intersections; city-wide deployment needs networked coordination [14].

VII. CONCLUSION

This study introduced a novel augmentation to conventional traffic signals by adding a blue LED indicator governed by IR sensor feedback and relay logic. The transistor-based sequencing circuit ensured dependable light transitions without microcontrollers. Prototype tests demonstrated accurate congestion detection and positive impacts on driver behavior and queue management. Given its low cost and simplicity, the system offers an attractive intermediate solution for municipalities seeking incremental improvements before full ATCS deployment.

VIII. FUTURE WORK

- **Sensor Upgrades:** Integrate LiDAR or radar modules to enhance detection accuracy under adverse conditions [15].
- **Dynamic Timing:** Incorporate microcontroller-based control to adapt phase durations based on real-time occupancy [6].
- **Wireless Networking:** Enable remote monitoring and data analytics via 5G modules [14].
- **User Interface:** Develop a mobile app to relay signal states and alternative route suggestions [16].
- **V2I Communication:** Allow vehicles to communicate directly with signals for personalized timing [17].
- **Solar Power:** Retrofit solar panels to achieve sustainable energy operation [18].
- **Pedestrian Integration:** Extend the blue-indicator concept to smart pedestrian crossings [19].

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