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Design and implementation of intersection traffic light control for optimal traffic flow

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Abstract. This paper delves into the pressing issue of enhancing urban transportation efficiency and introduces a design for a traffic light system tailored for intersections. Rooted in the foundations of digital logic circuits, the design seeks to masterfully regulate traffic flow using a sophisticated state-switching algorithm. Both the principle and intricate design of this system are thoroughly discussed in this paper, accompanied by a comprehensive circuit diagram. To tackle the pervasive challenge of traffic congestion, this document outlines several avant-garde techniques for traffic flow detection. One notable method employs infrared light detection, utilizing a light receiving tube to capture real-time vehicular movement. Another method harnesses the video detection approach, relying on pixel occupancy ratio computations to gauge traffic density. By adopting these techniques, urban traffic administrators can gain a deeper insight into the nuances of traffic flow. This enriched understanding paves the way for more informed adjustments to the traffic signal cycling system, promising to mitigate congestion and elevate overall traffic efficiency.

Keyword: Traffic Light System, Traffic Light Control Systems, Traffic Flow Detection, Infrared Light Detection.

1. Introduction

This paper delves into past research on traffic signal systems, proposing a bespoke set of traffic lights tailored for intersections. Concurrently, it contemplates methods to regulate traffic flow, aiming to mitigate traffic congestion.

In recent years, urban transportation has evolved into a critical challenge, characterized by frequent traffic congestion and accidents [1]. Traffic lights, pivotal for effective traffic management, are indispensable. Efficient traffic signal control strategies play a pivotal role in streamlining traffic flow and serve as one of the most effective means to reduce congestion at junctions [2]. A solution mentioned in the Baidu Library outlines a rudimentary Simulink-based traffic light design. However, implementing such a system in real-world intersections reveals its limitations in catering to genuine demands. This paper, therefore, aims to design a traffic signal control system, particularly suited for intersections, employing logical controls. Eom and Kim have delineated three primary control schemes for traffic signals: fixed-time, driven, and adaptive [3]. Nonetheless, the fixed-time control strategy, relying on a time counter, falls short in managing high traffic flows [4]. Hence, relying solely on a singular traffic signal control system proves insufficient for urban requirements. It becomes imperative to devise a method capable of detecting and adjusting to the nuances of traffic flow. Considering methods for traffic

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flow detection, distributed fiber-optic acoustic sensing proves effective for detecting individual vehicles. However, when multiple vehicles traverse the detection area swiftly, the results can be unrepresentative of the actual scenario [5]. A plausible alternative involves using ground magnetic sensors, which detect magnetic field alterations as vehicles pass the detection zone [6]. Additionally, the Vertical Virtual Road Induction Line (VVRIL) technique can quantify traffic volume through image analysis [7].

The subsequent sections of this article are structured as follows: Section 2 outlines the research objectives; Section 3 presents the conceptual design of the traffic signal control system for intersections. Section 4 illustrates the detailed circuit implementation, complemented by brief explanations. Section 5 offers a summary and suggests techniques for on-road traffic flow control. Lastly, Section 6 encapsulates the research findings, highlighting areas for further exploration.

2. Research objectives

Designing States and State Mapping: The cornerstone of our traffic signal control system lies in effectively designing its various states. By illustrating these states through well-structured state diagrams, we can showcase the intricate digital logic relationships between them, thereby facilitating a smoother system design process.

Setting State Duration and Crafting Digital Logic Circuitry: The amount of time each traffic state endures is crucial and should mirror real-life traffic situations and flow. With the incorporation of digital logic circuits, we can trigger transitions between these states based on predefined time intervals. This will require the integration of components like pulse clocks and counters, which will act as catalysts for these state transitions, ensuring signals evolve in the desired sequence.

Multisim Implementation and Analysis: By leveraging the capabilities of Multisim, we'll connect the digital logic circuit we've designed and delve into a comprehensive description. Through meticulous simulation, this endeavor not only validates the circuit's functionality but also ascertains its adaptability and reliability when implemented in real-world scenarios.

Intelligent Traffic Flow Detection: Merely controlling traffic signals based on fixed time intervals isn't the zenith of efficiency. This paper proposes exploring cutting-edge traffic flow detection solutions, equipping our system with the intelligence to dynamically adapt. By doing so, the system becomes more responsive, adjusting signal durations based on real-time traffic conditions, paving the way for smarter and more efficient road networks.

3. The Design of Intersection Traffic Light

Component Introduction: 74HC161: This is a 4-bit counter, which is mainly used in the design of the counting part of the control circuit. As shown in Figure 1.

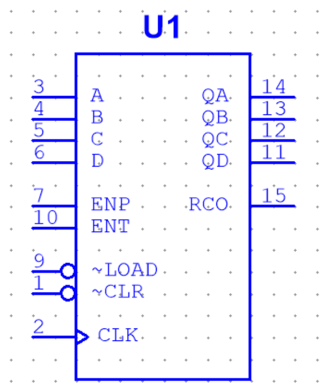

Figure 1. 74HC161(Photo/Picture credit: Original).

74HC138: This is a 3-8 decoder, mainly used with counters and logic gates to output control signals, As shown in Figure 2.

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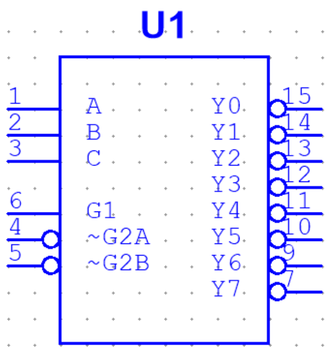

Figure 2. 74HC138 (Photo/Picture credit: Original).

74HC139: This is a 2-4 decoder, which is mainly used in the circuit to receive the output signal of the counter and thus control the switching of the traffic signal states [8]. As shown in Figure 3.

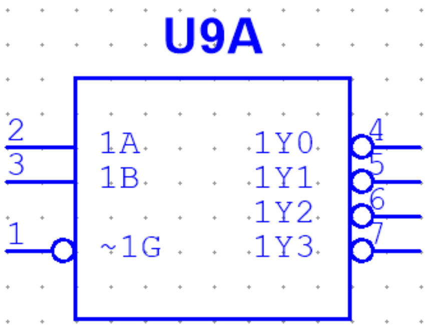

Figure 3. 74HC139 (Photo/Picture credit: Original).

States design: In the same intersection, traffic flows tend to be different in different directions, so here the road with higher traffic flows is called the main road, and the road with lower traffic flows is called the branch road.

There are thus four possible states of the intersection’s traffic lights: green in the direction of the main highway and red in the side road; yellow in that direction and still red in the side road; red in the direction of the main roadway and green in that direction; and finally, red in the direction of the main roadway and yellow in that direction. Here the four states can be denoted by D0, D1, D2, and D3 respectively. Meanwhile, since the traffic flow on main roads is higher, the passing time (that is, the duration of the green light) of main roads can be set at 45 seconds, while the passing time of branch roads can be set at 25 seconds, and the duration of the yellow light can be set at a uniform time of 5 seconds. This results in a state diagram as shown Table 1.

Table 1. State diagram.

State variable	Main road state	Branch road state	Time duration
D0	Green light on	Red light on	45s
D1	Yellow light on	Red light on	5s
D2	Red light on	Green light on	25s
D3	Red light on	Yellow light on	5s

Based on the same idea, it is possible in reality to adjust the duration of different states according to the need to obtain multiple traffic light state diagrams.

To obtain the truth table of this state diagram, the state of a signal of a certain color is 1 when it is lighted and 0 when it is not lighted, so this paper can obtain the truth table as shown Table 2.

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Table 2. The truth table of the traffic lights system.

State variable	Main road			Branch road		
	RED	YELLOW	GREEN	red	yellow	green
D0	0	0	1	1	0	0
D1	0	1	0	1	0	0
D2	1	0	0	0	0	1
D3	1	0	0	0	1	0

The diagram uses capital RED, YELLOW, and GREEN to indicate the status of signals on main roads, and small letters to indicate the status of signals on branch roads.

The red light of the main road is on in the D2 and D3 states, while the green light is on in the D0 state and the yellow light is on in the D1 state, so the following logical expression can be obtained.

$$RED = D2 + D3$$
$$YELLOW = D1 \tag{1}$$
$$GREEN = D0$$

Similarly, the logical expression for the signals of the branch roads is:

$$red = D0 + D1$$
$$yellow = D3 \tag{2}$$
$$green = D2$$

In this case, the logic expressions for controlling the entire traffic light system are clear, and the next step is to design the counting part and how to implement these logic expressions in a circuit.

In the previous design, the reason for setting the duration of each state to a multiple of 5 in this paper is so that the period of the clock pulse can be set to 5 seconds, thus making it convenient to trigger a switch between different states. In this way the circuit requires a total of 16 clock pulses to complete a cycle, so a 3-8 decoder is chosen here. As shown in Figure 4.

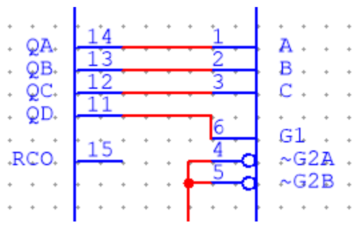

Figure 4. Connection between 74HC161 and 74HC138 (Photo/Picture credit: Original).

The output of the 74HC161 is connected to the 74HC138 as shown above, which allows the 74HC138 to operate from a counter output of 1000, resulting in 8 outputs of 9-16 clock pulses respectively. Name the 16 output states of the counter as P0-P15, according to the duration of each state in the state diagram, switching will take place at P8, P9, P14, and P15. The logical expression for the control signal is:

$$control\ signal = P8 + P9 + P14 + P15 \tag{3}$$

4. Circuit Implementation

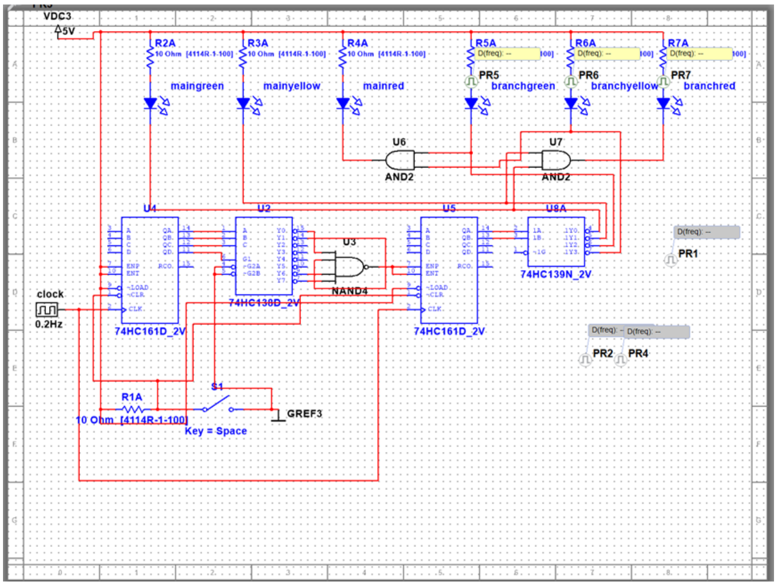

Figure 5. The entire circuit of traffic lights control system (Photo/Picture credit: Original).

As shown in Figure 5, a NAND gate was chosen to be used here in order to realize the logic expression of the control signal (since the output of the 74HC138 is active low). Since the output of the 74HC139 is also actively low, the logic expression for controlling the status of the main and branch signals needs to do the following conversion:

$$\begin{gathered} RED' = (S2 + S3)' = S2'S3' \\ YELLOW' = S1' \\ GREEN' = S0' \\ red' = (S0 + S1)' = S0'S1' \\ yellow' = S3' \\ green' = S2' \end{gathered} \tag{4}$$

Therefore, two AND gates were chosen for the red light status control of the main and branch roads, also due to the output being actively low, the direction of connection of the LEDs in the diagram is reversed compared to the normal situation. The S1 switch in the figure functions as a clearing operation for this system.

5. The Method of Realizing Traffic Flow Control

The methodology of the last section of this paper makes it possible to obtain a number of different traffic light control systems, the next question is how to detect the traffic flow so that different traffic signal systems can be selected.

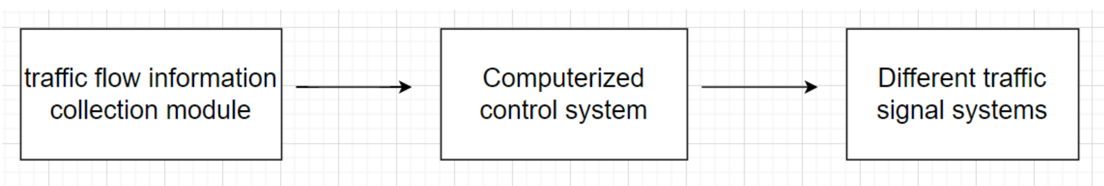

Figure 6. Traffic signal control flow chart (Photo/Picture credit: Original).

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The process of traffic signal control through traffic flow detection is generally shown in the figure 6, and the computer in the background can choose different pre-designed traffic signal systems based on different traffic flow information collected.

Video Measurement System (VMS) is a technique for detecting traffic flow based on the tracking detection method and the YOLOv2 (You Only Look Once) algorithm, which can achieve an accuracy of more than 90% [9]. In addition, a detection scheme based on the YOLOv3 algorithm and deep learning can achieve a similar accuracy to the above methods [10].

This paper considers that since the resistance of the light-receiving tube is significantly changed when it receives infrared light, the infrared light detection scheme could be a possible option. The specific scheme is to input the high and low-level conversion of the circuit caused by the resistance change into the control system to identify and thus intelligently select different traffic signal cycling systems.

Furthermore, it is difficult to select different traffic signal systems in the most efficient way if the traffic flow is measured in terms of the number of vehicles, Yong Zhao and Huaiyu Li mentioned that the image of a road with no passing cars can be used as the background, and the subsequent photos taken by the camera can be directly subtracted with the background image to obtain the traffic flow. This method chooses to calculate the traffic density based on the pixel occupancy ratio so that the traffic signal system can be set up for different traffic densities based on the analyzed examples, which is more efficient than the method of directly figuring out how many vehicles there are.

6. Conclusion

In this paper, a traffic signal system for intersections is proposed and designed, and some effective traffic flow detection methods are also explored with the aim of solving the problem of traffic congestion and improving the efficiency of road traffic. Several important summaries can be obtained from this research as follows:

First of all, this research has successfully developed an intelligent traffic signal system that utilizes integrated chips and logic circuits to design the state cycle of traffic signals to solve the problem of different traffic flow between main roads and branch roads. This system can effectively reduce traffic congestion and thus improve road safety.

Second, several traffic flow detection methods are summarized and proposed, including infrared light detection and image recognition analysis techniques. These methods show good feasibility and accuracy in different situations and can provide strong support to traffic management by monitoring traffic flow in real-time and selecting suitable traffic signal cycling systems. However, in this study, the feasibility of the intersection traffic signal system in real life has not yet been verified, in addition the precision with which the traffic flow detection scheme and the specific method of controlling the traffic signal system are yet to be discovered by further research. In conclusion, this study provides a powerful solution to improve the urban traffic situation and reduce traffic congestion, and the traffic signal system and traffic flow detection method in this paper have a wide range of application potential, but further research and improvement is needed before they can be practically applied to real life.

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