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Review on traffic light control systems based on single-chip microcomputers and smart traffic light control systems

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Abstract. With the development of the economy and the improvement of living standards, the number of private cars is increasing, which brings about traffic congestion and increased traffic safety hazards. Although some cities have widened some urban roads, traffic congestion and traffic safety hazards have not been effectively alleviated, and the speed of road construction and urban construction is far from meeting the needs of citizens. Therefore, traffic congestion is the primary problem that needs to be solved at present. This paper introduces single-chip microcomputers with their functions and applications as well as designs for traffic light control systems based on microcomputers. By comparing previous research designs and models, this paper points out the comparisons between different models and provides research suggestions and future prospects.

Keywords: traffic light, single-chip microcomputers, intelligent transportation.

1. Introduction

Currently, traffic lights are erected at several intersections, as they have become the most prevalent and efficient method for directing traffic vehicles. This technology has a lengthy development history. On the main streets of London, UK, gas-powered red and blue mechanical wrench signal lights were erected in 1858 to direct the passage of carriages. This is the first traffic light in the world. In the United States, traffic lights powered by electricity appeared. This traffic signal is comprised of circular red, green, and yellow light projectors. 1914 saw its installation on a tower on Fifth Avenue in New York City. A red light indicates "stop", whereas a green light indicates "go".

After the design and transformation of the predecessors, the traffic lights have finally spread to the intersections of the whole city. The use of traffic lights has permitted the effective management of traffic. It has clear effects on dredging traffic flow, increasing road capacity, and decreasing traffic accidents. At this point in time, numerous designers have created numerous more modern traffic signal control schemes, such as intelligence, automation, and digitization, which are easier to maintain and administer and provide a more convenient traffic environment for drivers.

In order to ensure safer and faster traffic flow, better traffic light control systems are necessary today due to the increase in traffic congestion. Therefore, it is essential to build sophisticated traffic light control systems. This paper introduces single-chip microcomputers and how to use them to create traffic light control systems by comparing and contrasting the research papers of various scholars.

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2. Single-chip microcomputers

Microcontrollers are often incorporated within the single-chip microcomputer. The single-chip microcomputer is a type of integrated circuit chip that uses Very Large-Scale Integration (VLSI) technology to combine a central processing unit (CPU) with data processing capacity, random memory (RAM), read-only memory (ROM), multiple I/O ports and interrupt controllers, etc., as shown in figure 1. These components are integrated onto a silicon chip to create a microcomputer system that is compact but complete. They offer more basic capabilities but are considerably easier to use because they do not require extra chips. It is, in short, a compact computer system.

Because of its extensive application in industrial control, the single-chip microcomputer is also referred to as a single-chip microcontroller. A computer system is integrated into a chip, as opposed to a chip performing a particular logic function. It's the same as a microcomputer. In comparison to computers, single-chip microcomputers lack input/output (I/O) devices.

Microcontrollers completely transformed the computing industry. They were smaller, less expensive, and consumed less energy than their predecessors. This makes them suitable for usage in a wide range of electrical equipment, such as automobiles, appliances, and toys. As microprocessors have grown in power, microcontrollers have grown in complexity. They are able to accomplish increasingly complex jobs and gain in strength. Nowadays, microcontrollers are one of the most common and commonly utilized types of computer in the world. Practically every electronic and mechanical product utilized in contemporary human existence will incorporate a microcomputer on a single chip.

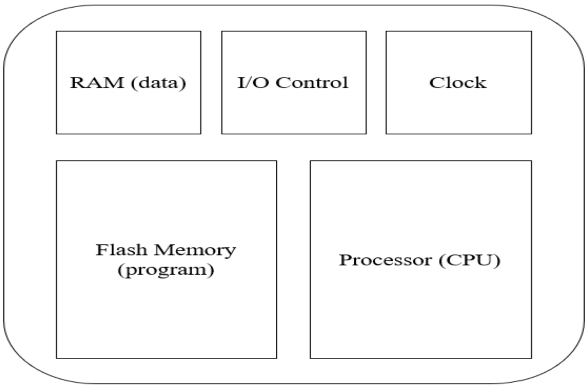

Figure 1. Schematic of a single-chip microcomputer [1].

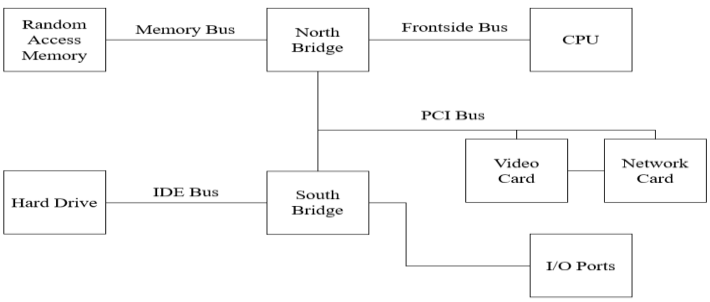

Figure 2. Schematic of traditional multi-chip computers [2].

The single-chip microcomputer's benefits in industrial control include its compact size, robust control functions, low power consumption, high environmental adaptability, expandability, and user-friendliness. Control systems, data acquisition systems, communication systems, signal detection systems, wireless perception systems, measurement and control systems, robotics, and other application control systems can all be built around the single-chip microcomputer. Intelligent management of plant assembly lines, intelligent control of elevators, various alarm systems, computer networking to establish a secondary control system, etc. can all benefit from the use of single-chip microcomputers.

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Electronic weighing scales, color televisions, audio/video equipment, rice cookers, washing machines, refrigerators, air conditioners, etc. all use single-chip microprocessor controls. The microcomputer manages the time, alarm, and display of domestic clocks and watches as well as the water and spin cycles in washing machines.

Communication interfaces are a standard feature of modern single-chip microcomputers, allowing for simple computer-to-computer data exchange and creating ideal physical circumstances for the implementation of networks and communication devices.

Instruments and meters typically use single-chip microcomputers. When combined with various sensors, it is possible to obtain readings for a wide range of physical quantities. Instruments that are controlled by single-chip microcomputers are digital, intelligent, and miniature; their function is superior to that of electrical or digital circuits.

The single-chip microcomputer integrates multiple functional components on the crystal chip, which has the highest level of integration and smallest volume as shown in figure 2. The chip is designed to meet the requirements of industrial measurement and control environments, the internal wiring is extremely short, and its anti-industrial noise performance is superior to that of a conventional CPU. Many signal channels of the single-chip microprocessor are included on the chip, resulting in excellent reliability. A microcontroller contains the components necessary for a computer to work effectively. Several three-bus lines and parallel and serial input/output pins exist outside of the system, allowing for the formation of computer application systems of varying sizes. The integrated use of a single-chip microprocessor determines that low voltage and low power consumption are extremely significant properties. As a result of the extensive usage of CMOS and other techniques, many single-chip microcomputers may now operate at lower voltages (1.2V or 0.9V), and their power consumption has been drastically lowered. Owing to the rise in system resources and system complexity, high-level programming languages (such as the C programming language) have been used to write software for single-chip microcomputers. The adoption of a high-level programming language can minimize development complexity, shorten the development cycle, increase the software's readability and portability, and simplify the enhancement and expansion of functionality. These characteristics allow the microcontroller system to operate longer with a smaller power source. Using these advantages of single-chip microcomputers, we can apply them to a variety of devices and utilize them to solve real-world problems, such as designing a traffic light control system that manages the flow of traffic.

3. Building traffic light control systems based on single-chip microcomputers

The scenario at this four-way intersection necessitates the construction of a traffic light control system that can regulate traffic flow in both the east-west and north-south directions, assuring the safety and efficiency of road traffic, as shown in figure 3. To address the issue, we must install a traffic light control circuit at the intersection of the crossroad and mandate that cars traveling in the north-south and east-west directions run alternately at the two intersections. In the case of each green light becoming red, the duration of the yellow light should be regulated, and the vehicle should only be allowed to restart after a brief period of pausing. In certain high-traffic highways, in addition to red, yellow, green, and other indicator lights, digital display tubes are needed to display the time of each light, primarily in the form of countdown displays that can serve as a reminder to drivers.

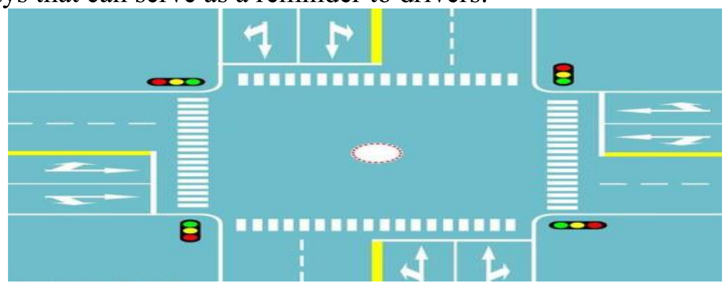

Figure 3. A four-way crossroad intersection with traffic lights [3].

As the fundamental controller for this system, designers can choose from a variety of single-chip microcomputers. Frequently picked microcomputers from previous research and design include AT89C51, AT89S51, STC89C52, STC89C51, AT89C52, AT89C52, and so on.

Standard features offered by the AT89C51/52 include: A full-duplex serial communication port, on-chip oscillator, and clock circuit, as well as 4k of Flash memory, 256 bytes of on-chip data memory (00H-7FH is on-chip RAM, 80H-FFH is special function register SFR), 32 I/O lines, two 16-bit timer/counters, a 5-vector, two-level interrupt structure, and an on-chip oscillator. In addition to its ability to switch to static logic operation at 0Hz, AT89C51 also features two additional power-saving modes that can be toggled in software. The central processing unit's activity is suspended during idle mode, however the Memory, timer/counter, serial communication port, and interrupt system all keep running as usual. Power-down mode saves RAM data but disables the oscillator, so nothing else can function until the next hardware reset [4]. The AT89S51/52 is essentially an improved version of the AT89C51/52, with a higher operating frequency (33MHZ, translating to faster computation speeds), a larger power range (4-5.5V), and improved anti-interference performance. The single-chip microcomputers with STC are superior than the other types. Keil and Proteus are two widely used programs for software and simulation, respectively.

As shown in figure 4, the model of a traffic light control system created by Huang Yongcheng, Yang Bin, Li Zhiyong, and Liu Shunpeng consists of a clock circuit, a reset circuit, a single-chip microcomputer, and an analog traffic signal light circuit [5]. Nonetheless, the reset circuit can initialize the internal circuit of the AT89C51 microcontroller, resulting in a fresh state for the central processor unit. This paper's reset circuit consists of capacitors and resistors and employs power-on reset. The clock circuit employs internal oscillation, and an external crystal oscillator is utilized to build its own oscillator so that the oscillation frequency can be stabilized and the oscillation beat can be controlled.

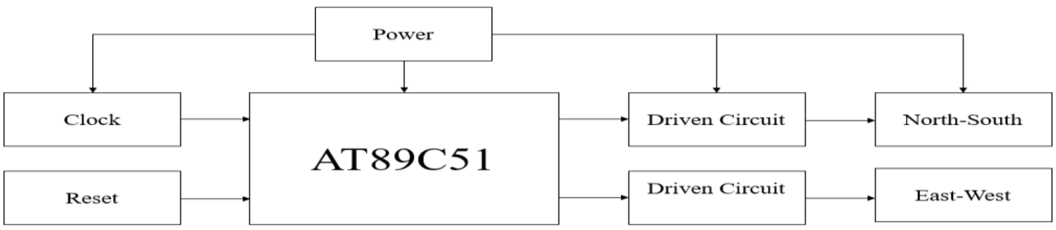

Figure 4. The basic structure of Huang Yongcheng, Yang Bin, Li Zhiyong, and Liu Shunpeng's model [5].

As shown in figure 5, the team led by Huang selected C language programming on a single-chip microcomputer. The C programming language offers obvious advantages in terms of readability and reusability. With the introduction of Keil C51 in recent years, C51 is increasingly used for MCU programming. In addition to fast editing speed and high code generation efficiency, Keil's C51 features an integrated development environment (IDE) and a real-time operating system (RTX51). The selection statement uses the switch case statement to execute branch selection control on the east-west green light and the north-south red light on, the east-west yellow light begins to flash, the green light turns off, and the east-west red light and the north-south green light on.

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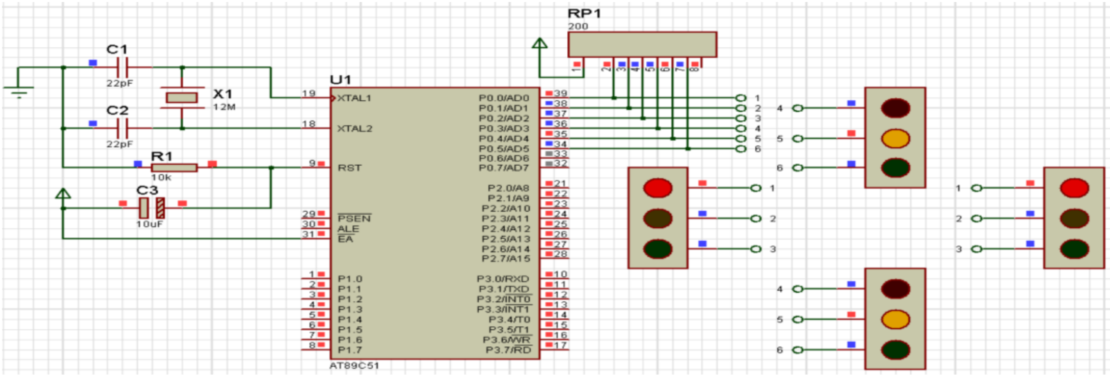

Figure 5. Simulation of Huang Yongcheng, Yang Bin, Li Zhiyong, and Liu Shunpeng's model [5].

Another model set by Chen Dongyang also introduces stoppage due to traffic accidents, with a similar design to Huang's team [6], shown in figure 6.

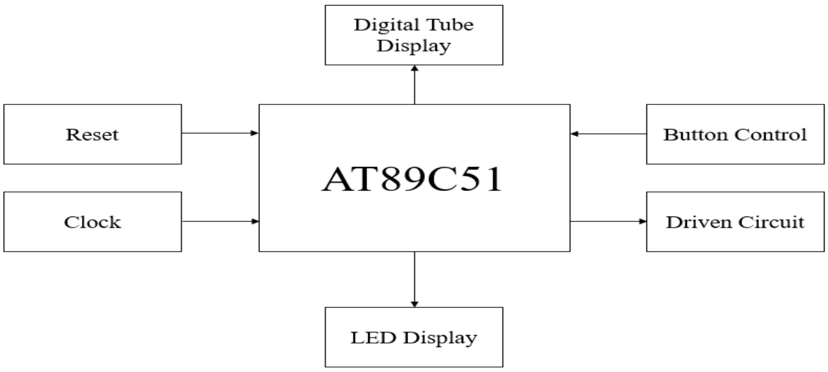

Figure 6. The basic structure of Chen Dongyang's model [6].

As displayed in figure6, a LED display module and a digital tube display module constitute the majority of the display circuit. Red, yellow, and green signal lights are displayed by LED traffic lights using light-emitting diodes. The pin is connected to a low voltage, which causes the diode to illuminate and show various colors for traffic management. Use P0.0–P0.6 on port P0 to control six LED lights. A light-emitting diode is the basic unit of a digital tube. Common anode digital tubes are utilized, the common pole is connected to the high-level +5V, the digital tube is a seven-segment digital tube, and when the cathode of a particular field is connected to the low level, the field is illuminated; otherwise, the field is not illuminated. Control the digital tube using the whole P0 port.

When +5V is charged, the capacitor is charged in the reset circuit after the MCU has been running for some time. Currently, the voltage at both ends of the 10K resistor is close to 0 and the reset pin is connected to a low level, allowing the system to operate normally. When the reset button is depressed, the switch closes and the capacitor discharges its previously stored energy. After some time, the voltage across the capacitor diminishes. In accordance with Kirchhoff's law, the 10K resistor will experience a significant voltage drop at this moment. The reset pin is connected to 1 at this time, and the microcomputer is reset, shown in figure 7.

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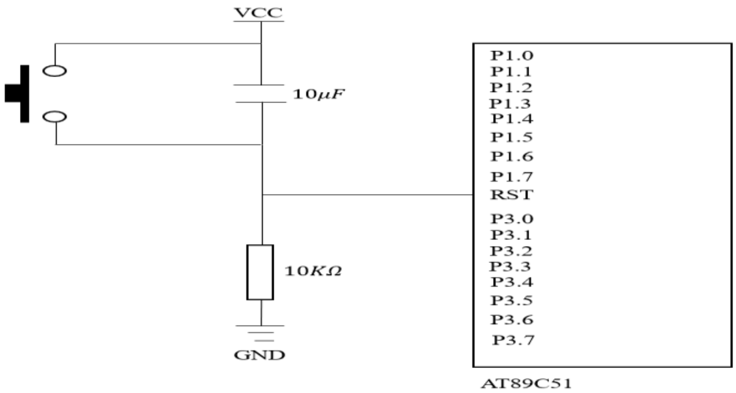

Figure 7. The reset circuit of Chen Dongyang's model [6].

The suggested traffic light control system utilizes three buttons for separate control. A traffic accident has happened in the east-west direction, and east-westbound traffic has been stopped. The second button indicates that an accident has happened in the north-south route and that traffic in that direction has been stopped. The third button indicates that there is an accident in the middle of the intersection and that all traffic has been stopped.

Both methods create an outstanding traffic light control system, with Chen's model additionally incorporating a manual stop option for traffic accidents. Yet, neither strategy adequately addresses the issue of transportation congestion. There is a need for an intelligent traffic light control system.

4. Constructing smart traffic light control systems

Modern types of intelligent traffic signal control systems all account for the impact of traffic density on traffic congestion and use real-time control to achieve intelligent traffic control.

As depicted in figure 8, Hu Zhijie and Shen Ruibing's model detects the volume of road traffic using an infrared sensor detection circuit [7]. In this type, the HJS18-M14DNK infrared photoelectric switch is employed to detect traffic flow. Cars that pass through the photoelectric switch automatically send a signal to the microprocessor, which is then added to the traffic statistics. Figure 9 depicts Zhang Yuye and Yan Weisheng's design, which employs infrared signals. This type contains infrared remote sending and receiving circuits [8].

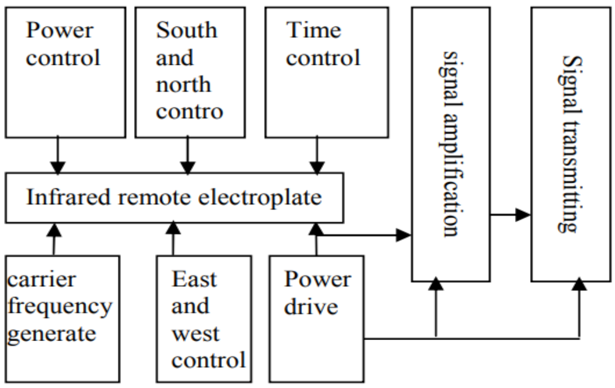

Figure 8. The infrared remote transmitting circuit design of Zhang Yuye and Yan Weisheng's model [8].

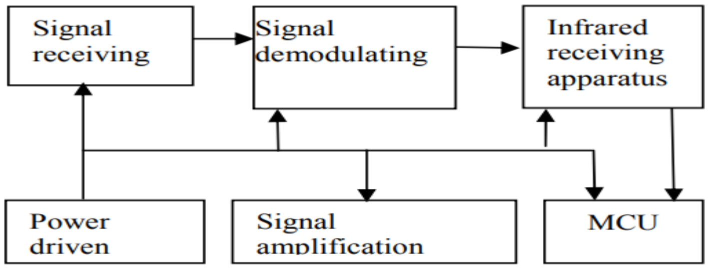

Figure 9. The infrared remote receiving circuit design of Zhang Yuye and Yan Weisheng's model [8].

The group led by Lin Chunyu utilized the infrared photoelectric switch E18-D50NK to mimic and detect traffic flow [9]. As a vehicle passes the photoelectric switch once, a signal is generated, and the single-chip microcomputer counts once, thereby completing the traffic flow statistics. The traffic flow at the intersection is sampled, and the timing of the traffic lights is adjusted based on the sampled traffic flow. By default, east-west traffic is prioritized, the green light period is 20 seconds, and the red light time is 25 seconds. If 10 or more vehicles pass within 20 seconds, the east-west green light time in the next cycle will be 25 seconds; if fewer than 10 vehicles pass within 20 seconds, the east-west green light time will be 15 seconds (minimum value). Likewise, in the north-south direction.

Similar models measure traffic density using ultrasonic transmitters and receivers. As seen in figure 10, Hu Ruinan's model consists of a collection of ultrasonic sensing modules on the highways in the four cardinal directions (east, west, north, and south) [10]. Each group contains numerous ultrasonic detectors, with two per lane. One is positioned at the intersection, while the second is placed 100 meters distant. The sensors detect the passing vehicles and use the difference between the counts to calculate the number of vehicles in each direction's waiting area. This system utilizes the ultrasonic range control module WT81B003-0202. The module transmits ultrasonic pulses through the ultrasonic probe, which propagate to the measured object through the air medium, return to the ultrasonic probe after being reflected by the object, and calculate the distance of the object based on the difference in time between transmission and reception. The ultrasonic detector has a maximum identification distance of 18 meters, a working period of 125 milliseconds, an operating temperature range of -25 to 70 degrees Celsius, and is resistant to dirt. It functions normally and meets the requirements for urban road detection.

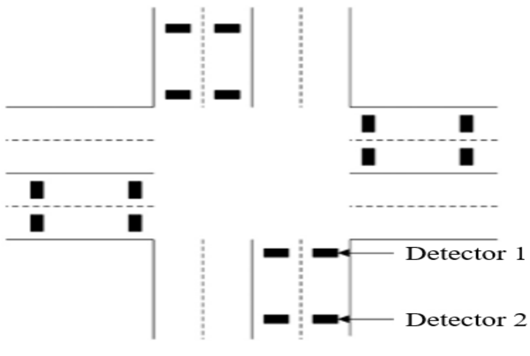

Figure 10. The ultrasonic detector schematic of Hu Ruinan's model [10].

Modern models, like the aforementioned models, address the issue of traffic flow head-on by using various detection methods to monitor traffic flow and real-time control to adjust the timing of green and red lights, thereby lowering the likelihood of traffic jams.

5. Possible solutions

Currently, there are four primary methods for detecting road vehicles: video detection, infrared detection, ground sensing coil detection, and ultrasonic detection [11]. Using the camera to evaluate the input traffic photos, identify passing vehicles, and determine the number of vehicles constitutes video detection. The benefits include simple installation and maintenance, steady operation, and a high rate of

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recognition. The downside is that it is susceptible to adverse weather. Light emission and reception are utilized for vehicle detection. It is simple to install and resistant to the elements, but it is also costly and its service life may be impacted by environmental variables [12]. The detection of the ground induction coil involves altering the inductance of the ground induction coil through the metal parts of the car to determine whether a vehicle is passing. This technology counts precisely, has consistent performance, and is not affected by the external environment, but its installation necessitates the destruction of the road surface and its maintenance is difficult. Reflection is the underlying basis of ultrasonic detection. Compared to other technologies, this technology's performance is more consistent and weather-resistant [13]. Unfortunately, the energy of ultrasonic waves diminishes as their propagation distance in the air increases, and huge mistakes occur when determining a great distance. In addition, ultrasonic waves are impacted by temperature, which causes variations in propagation speed, hence diminishing detecting precision. All of these methods of detection have advantages and downsides, thus it is essential to carefully analyze the disadvantages. Existing models require an update, such as the incorporation of temperature sensors that could alleviate the problem of ultrasonic wave temperature [14].

The density of pedestrians should also be taken into account, and designs incorporating pedestrian-specific traffic signals should be used. Additional considerations, like the presence of emergency vehicles such as fire engines and ambulances, should also be taken into account. In addition, intelligent traffic light control systems based on FPGA and PLC can be considered, as these models could have faster calculation speeds and reduced latency, hence enhancing the system's power and precision.

6. Conclusion

The design of intelligent traffic light control systems has an impact on the traffic infrastructure of the cities of the future. This study explains the structure and applications of single-chip microcomputers, as well as their potential application in the construction of traffic light control systems. This report also examined and assessed historical designs, compared alternative systems and made recommendations, and outlined potential future research directions for traffic flow sensing. This study report is not flawless since it lacks practical research and circuit building to illustrate the traffic light control system. In addition, research conducted on different platforms, such as FPGA and PLC, is not considered. FPGA and PLC have greater advantages than microcomputers with a single chip, including higher speeds and reduced delay. These aspects will be explored and completed in the future.

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