Design FSM Based Coordinated Four -Way Intersection Specific Automated Traffic Light Controller.

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ABSTRACT

Traffic congestion at urban road intersections has become a major challenge due to the increasing number of vehicles and inefficient fixed-time traffic signal systems. This paper presents an intelligent traffic light control system designed to improve traffic flow and pedestrian safety through adaptive signal management. The proposed system uses IR sensors to detect vehicle density on each lane and dynamically allocates signal timing based on traffic conditions. A sound sensor is incorporated to identify emergency vehicles such as ambulances and fire engines, enabling signal priority for rapid clearance. This feature reduces delay for emergency services and improves response efficiency. The controller is designed to operate with reliable timing control under varying traffic conditions. The complete system is implemented using Verilog to achieve hardware-level accuracy and efficient digital design. Functional verification is carried out using SystemVerilog through simulation-based testing. The results confirm correct signal switching, emergency prioritization, and adaptive operation. The proposed design offers a scalable and cost-effective solution for intelligent traffic management in densely populated regions such as India.

Keywords: Intelligent traffic control, IR sensor, sound sensor, emergency vehicle detection, adaptive traffic signal, Verilog, SystemVerilog, smart transportation

INTRODUCTION

Traffic congestion has emerged as a major challenge in urban environments due to rapid population growth and increased vehicle density. Conventional traffic signal systems based on fixed-time scheduling fail to adapt to real-time traffic conditions, leading to longer waiting times, fuel wastage, and increased emissions. To address these issues, Intelligent Traffic

Light Control Systems (ITLCS) have been proposed to dynamically regulate traffic flow at intersections. These systems utilize sensors and real-time decision-making algorithms to optimize signal timing and improve road efficiency. In densely populated countries, ensuring smooth passage for emergency vehicles such as ambulances remains a critical concern. Delays at intersections can result in severe consequences, including loss of life. The proposed system integrates sound sensors to detect ambulance sirens and automatically prioritizes their movement by clearing traffic signals. The system is designed using Finite State Machine (FSM) principles and implemented in SystemVerilog to ensure reliable and predictable control behavior. Functional verification is carried out to validate system performance under normal traffic, emergency scenarios, and pedestrian crossings. The proposed approach reduces congestion, minimizes delays, and enhances overall road safety. This work contributes to the development of smart and adaptive traffic management solutions for future urban infrastructure.

RELATED WORK

Several research efforts have been carried out to address traffic congestion and improve emergency vehicle prioritization using intelligent traffic systems. Traditional traffic signal systems rely on fixed-time control, which lacks adaptability to real-time traffic conditions and often results in inefficient traffic flow. To overcome this, various intelligent and adaptive approaches have been proposed. A significant number of studies focus on sensor-based traffic control systems. For instance, systems using infrared sensors dynamically adjust signal timing based on vehicle density at intersections, thereby reducing congestion and waiting time . These systems demonstrate improved traffic efficiency compared to conventional methods. Recent studies have explored the use of sound sensor-based detection systems to identify ambulance sirens and provide immediate signal clearance at intersections. These systems offer a cost-effective and practical solution, especially in densely populated region

LITERATURE SURVEY

Recent research in intelligent traffic management systems has focused on enhancing traffic efficiency and prioritizing emergency vehicles. FPGA-based implementations using Finite State Machine (FSM) models have been widely adopted due to their high-speed operation and reliability. Nor Shahanim Mohamad Hadis et al. (2025) proposed an FSM-based traffic controller using Verilog HDL with RFID and IR sensors to detect ambulances

and provide immediate green corridors, ensuring reduced response delays. Similarly, Supriya R J and P. B. Manoj (2023) developed an FPGA-based traffic system using RFID technology to dynamically control signals and improve traffic flow.IoT-based approaches have also gained attention for real-time adaptability. Systems utilizing Arduino, ESP8266, and RFID modules enable dynamic signal switching for emergency vehicles while maintaining low implementation cost. GPS and GSM-based systems further enhance scalability by tracking ambulance locations and preemptively controlling traffic signals across multiple intersections. Advanced techniques such as artificial intelligence and fuzzy logic have been introduced to improve detection accuracy and decision-making. Robinson Jimenez-Moreno et al. (2022) implemented a deep learning-based ambulance detection system combined with a fuzzy controller, achieving high accuracy and adaptive signal timing. However, such methods increase computational complexity and cost.

Several works also employ IR sensors for density-based traffic control, improving normal traffic flow but offering limited support for emergency prioritization. Literature surveys indicate that hybrid approaches combining FSM, IoT, and AI provide better scalability and flexibility. Despite these advancements, many systems depend on additional infrastructure such as RFID tags and communication networks. In contrast, sound sensor-based detection offers a cost-effective and infrastructure-free solution by identifying ambulance sirens directly.

EXISTING METHOD

Traffic management plays a crucial role in regulating vehicle flow at road intersections. Traditional manual traffic control relies on personnel, road signage, and hand signals to direct vehicles, ensuring orderly movement and safety. However, manual systems often suffer from inconsistencies and delayed responses due to human limitations. This paper presents a traffic signal control system based on a Finite State Machine (FSM) with six operational states. The system utilizes three timers: long timer (TL = 25 s), short timer (TS = 4 s), and transitory timer (Tt = 1 s), along with a side-road vehicle detection sensor. Initially, the main road is given priority with a green signal, while the side road remains red. Based on timer expiration and vehicle presence, the system transitions through sequential states, including yellow and red phases, ensuring safe signal switching. Buffer states are incorporated to prevent conflicts during transitions. The FSM design simplifies implementation and enhances reliability compared to manual

control. Despite its advantages, manual traffic control is prone to human error and slower adaptability, highlighting the need for automated solutions.

PROPOSED METHOD

The proposed system presents the design and functional verification of an intelligent traffic light control system using SystemVerilog, integrated with ambulance detection through sound sensors. The system is specifically designed for a four-way road intersection, where each direction is equipped with traffic signals for vehicles and dedicated pedestrian crossing indicators. In this system, four sound sensors are strategically placed at each side of the intersection to detect the presence of ambulance sirens. These sensors are capable of identifying specific siren frequencies and generating a trigger signal when an emergency vehicle is approaching. The detected signal is then forwarded to the central controller unit. The core component of the system is a Finite State Machine (FSM), which governs the operation of traffic lights. Under normal conditions, the FSM operates in a predefined cyclic sequence, managing transitions between red, yellow, and green signals for all directions. This ensures smooth traffic flow, fairness, and reduced waiting time at the junction

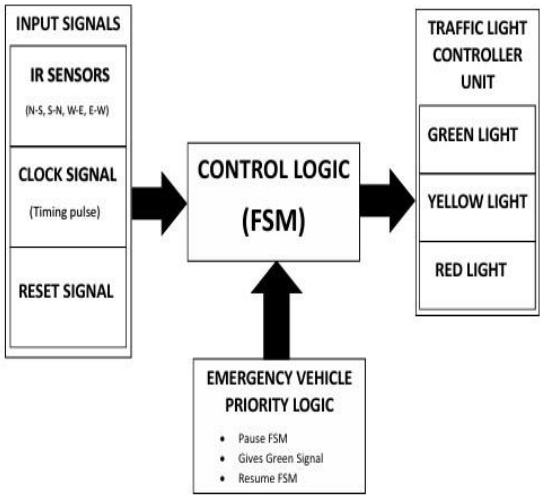
When an ambulance is detected, the system enters an emergency mode. In this mode, the FSM immediately overrides its normal operation and prioritizes the direction from which the ambulance is approaching. The corresponding traffic signal is turned green, while all other directions are set to red.

This mechanism ensures a clear and unobstructed path for the emergency vehicle, significantly reducing response time and enhancing public safety. After the ambulance has passed, the FSM automatically resumes its normal traffic signal sequence without manual intervention. Additionally, pedestrian safety is incorporated into the system by allocating dedicated crossing intervals, synchronized with traffic signal transitions to avoid conflicts between vehicles and pedestrians. The FSM used in this system can be implemented using either a Moore or Mealy state machine model. In the Moore model, outputs depend only on the current state, ensuring stable and predictable signal changes. In contrast, the Mealy model produces outputs based on both current state and inputs, allowing faster response to emergency conditions. Based on system requirements, an appropriate model can be selected to optimize performance.

Overall, the proposed system enhances traffic management efficiency by

combining automation, real-time emergency detection, and reliable state-based control. It offers advantages such as low power consumption, high operational speed, and ease of implementation, making it suitable for modern smart city applications.

ARCHITECTURE



METHODOLOGY DESCRIPTION

The proposed system is an intelligent traffic light controller based on a Finite State Machine (FSM). It operates using inputs from IR sensors, a clock signal, and a reset signal. The IR sensors detect vehicle presence in all directions of the intersection. The clock signal ensures proper timing and synchronization of traffic light transitions.The FSM acts as the core control unit, managing the sequence

of traffic signals such as red, yellow, and green. Under normal conditions, the FSM cycles through predefined states to ensure smooth traffic flow. Each state corresponds to a specific traffic direction being allowed to move. An emergency vehicle priority logic is integrated into the system. When an ambulance is detected, the normal FSM operation is paused. The system immediately gives a green signal to the ambulance direction while all other signals turn red. After the emergency vehicle passes, the FSM resumes its normal operation. The output from the FSM is sent to the traffic light controller unit, which drives the signal lights. This methodology ensures efficient traffic control, reduced congestion, and quick emergency response.

SOFTWARE REQUIREMENTS

Software Tools:

Questa Sim is a powerful simulation and functional verification tool used for designing and testing digital circuits using languages like Verilog and VHDL. Developed by Siemens EDA, it helps detect errors early through simulation before hardware implementation. It also provides debugging, waveform analysis, and coverage features to ensure accurate and reliable system performance.

Languages:

Verilog – Hardware design and implementation

System Verilog – Verification, testbench, and simulation

RESULTS AND DISCUSSION

The outputs represent the simulation and functional results obtained after successful implementation and testing of the proposed system "Design FSM Based Coordinated Four Way Intersection Specific Automated Traffic Light Controller". These outputs verify correct operation of sensors, control logic, under different conditions.

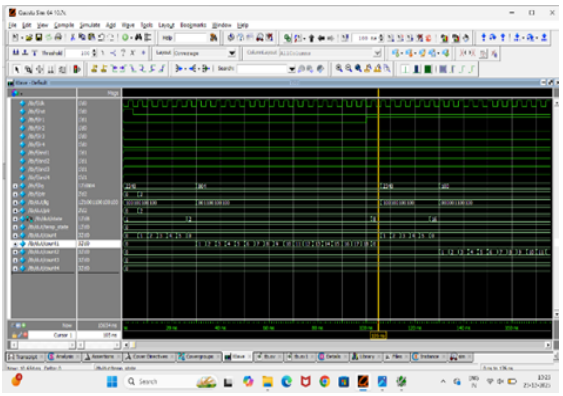


Fig1 Detects the emergency vehicle in north direction

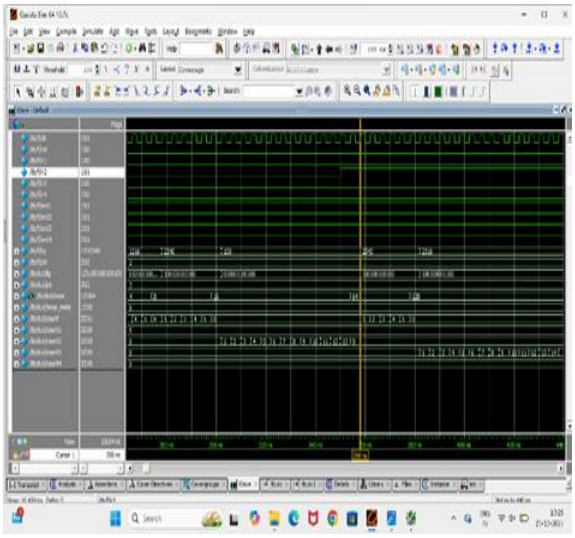


Fig2 Detects the emergency vehicle in south direction

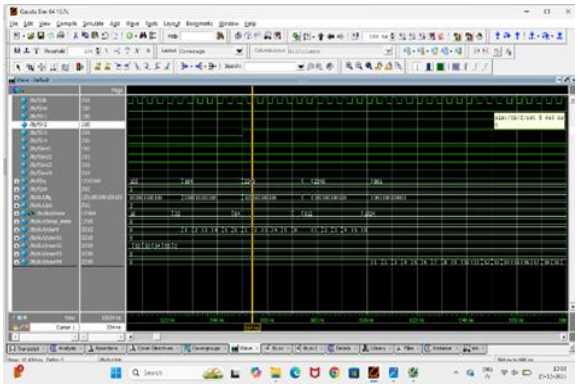


Fig3 Detects the emergency vehicle in east direction

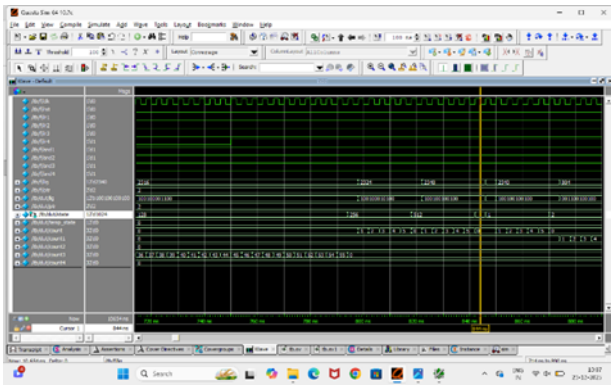


Fig4 Detects the emergency vehicle in west direction

These waveforms illustrates the operation of the FSM with clock, reset, and sensor inputs. It shows state transitions and timing control through counters during normal traffic conditions. Upon emergency detection, the FSM prioritizes the corresponding direction by enabling the green signal. The results confirm correct functionality and efficient emergency handling of the system.

CONCLUSION

The proposed intelligent traffic light control system based on a Finite State Machine (FSM) successfully improves traffic

management at a four-way intersection. By integrating IR sensors and emergency vehicle detection, the system ensures smooth traffic flow under normal conditions while providing immediate priority to ambulances. The FSM-based design enables reliable state transitions, efficient timing control, and quick response to real-time inputs. Simulation results verify that the system operates correctly without conflicts or delays. Overall, the project offers a low-power, cost-effective, and scalable solution suitable for modern smart traffic management systems.

FUTURE ENHANCEMENT

The proposed system can be further enhanced by integrating advanced technologies to improve efficiency and scalability. Camera-based vehicle detection using image processing can replace IR sensors for more accurate traffic density analysis. The system can be upgraded with IoT connectivity to enable real-time monitoring and control from a central traffic management system.

Machine learning algorithms can be incorporated to predict traffic patterns and dynamically adjust signal timings. GPS-based ambulance tracking can be added for more precise and early emergency vehicle detection. Additionally, solar-powered modules can be used to reduce energy consumption. Integration with smart city infrastructure and mobile applications can further improve user awareness and overall traffic management efficiency.

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