Adaptive Traffic Light Controller Project

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December 8, 2024

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1 Introduction

This project involves designing an **adaptive traffic light controller** for a four-way intersection. The system adapts dynamically to real-time traffic conditions to ensure collision-free operation and prioritize heavily congested lanes.

The traffic light controller is modeled as a **Finite State Machine (FSM)** with 16 states corresponding to each lane's traffic light conditions, including **primary green**, **extended green**, and **yellow** states.

2 Problem Statement

The goal is to develop a **traffic control system** with:

1. **Dynamic Timing:** Extend green light duration for congested lanes based on sensor inputs.
2. **Collision Avoidance:** Only one lane can have a green or yellow light at any time.
3. **Timer-Based States:** States remain active until the timer expires if no next state is defined.
4. **Skipping Idle Lanes:** If no cars are detected in a lane, the FSM skips to the next lane in sequence.
5. **Efficient Lane Priority:** Ensure a fair balance between lane priorities while dynamically adjusting for congestion.

3 FSM Overview

3.1 States

The FSM has **16 states** encoded using Gray Code to minimize transitions:

1. `NS_RED`, `NS_PRIMARY_GREEN`, `NS_EXTENDED_GREEN`, `NS_YELLOW`.
2. `SN_RED`, `SN_PRIMARY_GREEN`, `SN_EXTENDED_GREEN`, `SN_YELLOW`.
3. `EW_RED`, `EW_PRIMARY_GREEN`, `EW_EXTENDED_GREEN`, `EW_YELLOW`.
4. `WE_RED`, `WE_PRIMARY_GREEN`, `WE_EXTENDED_GREEN`, `WE_YELLOW`.

3.2 Transitions

Transitions are triggered by:

1. **Sensor Inputs:** Vehicles detected (`S1 = 1`) or congestion (`S5 = 1`).
2. **Timer Expiry:** States transition when their timers expire.
3. **Idle Lane Skipping:** If no vehicles are detected (`S1 = 0`), the FSM skips to the next lane in sequence.

4 FSM Table

Current State	Condition (Input)	Next State	**Output**	**Timer Extension**
ALL_RED	NS_S5 = 1	NS_EXTENDED_GREEN	NS Green; Others Red	Yes
ALL_RED	NS_S1 = 1	NS_PRIMARY_GREEN	NS Green; Others Red	No
ALL_RED	SN_S5 = 1	SN_EXTENDED_GREEN	SN Green; Others Red	Yes
ALL_RED	SN_S1 = 1	SN_PRIMARY_GREEN	SN Green; Others Red	No
ALL_RED	EW_S5 = 1	EW_EXTENDED_GREEN	EW Green; Others Red	Yes
ALL_RED	EW_S1 = 1	EW_PRIMARY_GREEN	EW Green; Others Red	No
ALL_RED	WE_S5 = 1	WE_EXTENDED_GREEN	WE Green; Others Red	Yes
ALL_RED	WE_S1 = 1	WE_PRIMARY_GREEN	WE Green; Others Red	No
ALL_RED	No Input	ALL_RED	All Red	No
NS_PRIMARY_GREEN	Timer not expired	NS_PRIMARY_GREEN	NS Green; Others Red	No
NS_PRIMARY_GREEN	NS_S5 = 1	NS_EXTENDED_GREEN	NS Green; Others Red	Yes
NS_PRIMARY_GREEN	Timer expired & NS_S5 = 0	NS_YELLOW	NS Yellow; Others Red	No
NS_EXTENDED_GREEN	Timer not expired	NS_EXTENDED_GREEN	NS Green; Others Red	Yes
NS_EXTENDED_GREEN	Timer expired	NS_YELLOW	NS Yellow; Others Red	No
NS_YELLOW	Timer not expired	NS_YELLOW	NS Yellow; Others Red	No
NS_YELLOW	Timer expired	SN_RED	All Red	No
SN_PRIMARY_GREEN	Timer not expired	SN_PRIMARY_GREEN	SN Green; Others Red	No
SN_PRIMARY_GREEN	SN_S5 = 1	SN_EXTENDED_GREEN	SN Green; Others Red	Yes
SN_PRIMARY_GREEN	Timer expired & SN_S5 = 0	SN_YELLOW	SN Yellow; Others Red	No
SN_EXTENDED_GREEN	Timer not expired	SN_EXTENDED_GREEN	SN Green; Others Red	Yes
SN_EXTENDED_GREEN	Timer expired	SN_YELLOW	SN Yellow; Others Red	No
SN_YELLOW	Timer not expired	SN_YELLOW	SN Yellow; Others Red	No
SN_YELLOW	Timer expired	EW_RED	All Red	No

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Current State	Condition (Input)	Next State	**Output**	**Timer Extension**
EW_PRIMARY_GREEN	Timer not expired	EW_PRIMARY_GREEN	EW Green; Others Red	No
EW_PRIMARY_GREEN	EW_S5 = 1	EW_EXTENDED_GREEN	EW Green; Others Red	Yes
EW_PRIMARY_GREEN	Timer expired & EW_S5 = 0	EW_YELLOW	EW Yellow; Others Red	No
EW_EXTENDED_GREEN	Timer not expired	EW_EXTENDED_GREEN	EW Green; Others Red	Yes
EW_EXTENDED_GREEN	Timer expired	EW_YELLOW	EW Yellow; Others Red	No
EW_YELLOW	Timer not expired	EW_YELLOW	EW Yellow; Others Red	No
EW_YELLOW	Timer expired	WE_RED	All Red	No
WE_PRIMARY_GREEN	Timer not expired	WE_PRIMARY_GREEN	WE Green; Others Red	No
WE_PRIMARY_GREEN	WE_S5 = 1	WE_EXTENDED_GREEN	WE Green; Others Red	Yes
WE_PRIMARY_GREEN	Timer expired & WE_S5 = 0	WE_YELLOW	WE Yellow; Others Red	No
WE_EXTENDED_GREEN	Timer not expired	WE_EXTENDED_GREEN	WE Green; Others Red	Yes
WE_EXTENDED_GREEN	Timer expired	WE_YELLOW	WE Yellow; Others Red	No
WE_YELLOW	Timer not expired	WE_YELLOW	WE Yellow; Others Red	No
WE_YELLOW	Timer expired	NS_RED	All Red	No

5 State and Transition Explanations

5.1 North-South States

1. NS_RED:
   - Default state for North-South direction.
   - If NS_S5 = 1, transition to NS_EXTENDED_GREEN to handle congestion.
   - If NS_S1 = 1 and NS_S5 = 0, transition to NS_PRIMARY_GREEN.
   - If no input, remain in NS_RED or proceed to SN_RED.
2. NS_PRIMARY_GREEN:
   - Activates green light for NS.
   - If the timer has not expired, remain in NS_PRIMARY_GREEN.
   - If NS_S5 = 1, transition to NS_EXTENDED_GREEN for extended green duration.
   - If the timer expires and NS_S5 = 0, transition to NS_YELLOW.

3. NS_EXTENDED_GREEN:
    - Extends green light for NS due to congestion.
    - Remain in this state while the extended timer is running.
    - Transition to NS_YELLOW when the extended timer expires.
4. NS_YELLOW:
    - Activates yellow light for NS.
    - Remain in this state while the yellow timer is running.
    - Transition to SN_RED when the yellow timer expires.

5.2 South-North States

1. SN_RED:
    - Default state for South-North direction.
    - If SN_S5 = 1, transition to SN_EXTENDED_GREEN to handle congestion.
    - If SN_S1 = 1 and SN_S5 = 0, transition to SN_PRIMARY_GREEN.
    - If no input, remain in SN_RED or proceed to EW_RED.
2. SN_PRIMARY_GREEN:
    - Activates green light for SN.
    - If the timer has not expired, remain in SN_PRIMARY_GREEN.
    - If SN_S5 = 1, transition to SN_EXTENDED_GREEN.
    - If the timer expires and SN_S5 = 0, transition to SN_YELLOW.
3. SN_EXTENDED_GREEN:
    - Extends green light for SN due to congestion.
    - Remain in this state while the extended timer is running.
    - Transition to SN_YELLOW when the extended timer expires.
4. SN_YELLOW:
    - Activates yellow light for SN.
    - Remain in this state while the yellow timer is running.
    - Transition to EW_RED when the yellow timer expires.

5.3 East-West States

1. `EW_RED`:
    - Default state for East-West direction.
    - If `EW_S5 = 1`, transition to `EW_EXTENDED_GREEN` to handle congestion.
    - If `EW_S1 = 1` and `EW_S5 = 0`, transition to `EW_PRIMARY_GREEN`.
    - If no input, remain in `EW_RED` or proceed to `WE_RED`.
2. `EW_PRIMARY_GREEN`:
    - Activates green light for EW.
    - If the timer has not expired, remain in `EW_PRIMARY_GREEN`.
    - If `EW_S5 = 1`, transition to `EW_EXTENDED_GREEN`.
    - If the timer expires and `EW_S5 = 0`, transition to `EW_YELLOW`.
3. `EW_EXTENDED_GREEN`:
    - Extends green light for EW due to congestion.
    - Remain in this state while the extended timer is running.
    - Transition to `EW_YELLOW` when the extended timer expires.
4. `EW_YELLOW`:
    - Activates yellow light for EW.
    - Remain in this state while the yellow timer is running.
    - Transition to `WE_RED` when the yellow timer expires.

5.4 West-East States

1. `WE_RED`:
    - Default state for West-East direction.
    - If `WE_S5 = 1`, transition to `WE_EXTENDED_GREEN` to handle congestion.
    - If `WE_S1 = 1` and `WE_S5 = 0`, transition to `WE_PRIMARY_GREEN`.
    - If no input, remain in `WE_RED` or proceed to `NS_RED`.
2. `WE_PRIMARY_GREEN`:
    - Activates green light for WE.
    - If the timer has not expired, remain in `WE_PRIMARY_GREEN`.
    - If `WE_S5 = 1`, transition to `WE_EXTENDED_GREEN`.
    - If the timer expires and `WE_S5 = 0`, transition to `WE_YELLOW`.
3. `WE_EXTENDED_GREEN`:
    - Extends green light for WE due to congestion.

- Remain in this state while the extended timer is running.
- Transition to `WE_YELLOW` when the extended timer expires.

4. `WE_YELLOW`:
    - Activates yellow light for WE.
    - Remain in this state while the yellow timer is running.
    - Transition to `NS_RED` when the yellow timer expires, completing the cycle.

6 Conclusion

This comprehensive FSM design ensures safe, adaptive, and efficient traffic light management for a four-way intersection by dynamically adjusting to real-time traffic conditions. All possible states and transitions have been detailed to provide a clear understanding of the system's operation.