An Automatic Traffic Light Control System using Microcontroller and Fuzzy Logic Algorithm

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Abstract: The road traffic congestion is the big problem for urban areas in the big city. The traffic management and optimization are important factors to help provide better life quality to people. The advanced technology in the present, such as a microcontroller and image processing, can help to analyze real-time traffic conditions and identify changes in the traffic flow. In this paper, the traffic control system will be proposed with a microcontroller using the Raspberry Pi and an algorithm based on the Fuzzy Logic Algorithm in order to design the automatic traffic light control system. This system will be installed at the intersection to help reduce the delay which occurs during the traffic light changing to optimize the traffic flow.

Keywords—**Traffic Light, Transportation, Road, Fuzzy Logic, Microcontroller**

1. Introduction

Nowadays, the road is the main option for the travel and transportation in big cities. With the increment of population, growing number of vehicles, higher demand of the road usage lead to the traffic congestion problem. Roads are considered as a limited resource that should be allocated properly. Traffic congestion has caused many critical problems. For a traveler, the traffic congestion means waste of time, miss opportunities, etc.

In several cities, the countdown timer is used to control a traffic light at intersections, but the countdown timer value is manually calculated and set by the estimation of a human, and sometimes the value is not reasonable with the current traffic condition. Many researchers have proposed the development of traffic controller, which focused on an algorithm to decrease the delay that will occur at the intersection. In this paper, we will propose the automatic traffic light control system based on the microcontroller and the fuzzy logic algorithm to solve the road traffic congestion problems and improve the efficiency of the traffic light control system.

The designed system is composed of a microcontroller module using the Raspberry Pi (for identifying the real-time traffic condition and send data to a centralized control system for processing) and rule-based algorithms based on the Fuzzy Logic Algorithm to act as a decision-making unit, which use the traffic condition of each traffic flow and decide which traffic flow should be given the green signal.

The remaining parts of this paper include related works, existing traffic control mechanism, brief explanation of Fuzzy Logic Algorithm, system framework and algorithm design, the simulation method and results, result comparison with other research papers in this field. Finally, conclusions and future work are discussed in the last part of the paper.

2. Related Work

Many research papers in related fields have focused on the traffic condition analysis and finding the best solution to solve the traffic congestion problem. In order to enhance the performance of the traffic efficiency, several researchers have developed intelligent algorithms intending to schedule the traffic light timing and minimizes the delay of traveling vehicles at road intersections. In this section, we will briefly explain some of that paper, sorted by the year of publication.

2. 1 IDUTC: An Intelligent Decision-making system for Urban Traffic-Control [1]

The IDUTC is a self-adjusting traffic light control system. The sensors are placed on the road to sense the different parameters of the traffic conditions. The sensors are the actual input of the model, which collect the data of the traffic conditions. After surrounding environmental conditions, the sensors send crisp data inputs to the artificial neural network. The ANN model collects all data from the systems and process it through the hidden layers and gives the desired output. The output of ANN model is assigned fuzzy labels indicates the degree to which each crisp value is a member of a domain. Then the fuzzy expert system fires the rules based on these fuzzy values. The defuzzification unit converts the computed decisions into crisp values that are used to control the environment through the controllers installed at the traffic lights. After running the simulation on the traffic light, past data are being collected along with the present data from the sensors. The cycle goes on repeating and tries to change the traffic light timings condition.

2. 2 Urban Traffic Control Based on Learning Agents [2]

This research proposes the design of a traffic light controller based on intelligent agents that control the shifting of the traffic signal stages at the intersection, in order to learn adaptive control policies by using machine learning algorithms. The algorithm is based on the attribution of rewards according to the results of actions selected by the agents. This approach lets agents learn their own adaptive behavior, agents receive reward signal in response to taking action in their environment. The paper focuses on a single adaptive agent traffic light controller which has a certain perception of their local environment, they can indicate the number of vehicles that are present near the intersection. Intelligent agents can act independently in their environment and able to collaborate with other controller agents. Their task is to optimize the traffic flow by learning a control policy that chooses when to change signal stages according to their local perception of the environment, which is a measure of the quantity of vehicles waiting at the intersection.

2. 3 An Agent Approach for Intelligent Traffic Light Control [3]

This system consists of agents and their environment, such as cars, road networks, traffic, and traffic light. Each agent controls all traffic lights at a road junction by an observe-think-act cycle. The agent repeatedly observes the current traffic condition at the junction to collect the traffic information near each intersection, then uses this information to reason with condition-action traffic-control rules to control all traffic lights, and determine how the agent should act in each traffic condition in order to efficiently manage and optimize the traffic flows. To work with a wide road network, agents will perform their individual works while collaborate with others in order to solve complicated traffic problems.

2. 4 A Dynamic and Automatic Traffic Light Control System for Solving the Road Congestion Problem [4]

The traffic light control expert system composed of a radio frequency identification reader (RFID), an active RFID tag, a personal digital assistant (PDA), a wireless network, a database, a knowledge base and backend server. In this expert system, the RFID reader detects a RF-ACTIVE code from the active tag pasted on the car. When the data is received, the reader will save all information in the PDA. The PDA connects to the backend server and store them into the database in the server. The server uses the received data to calculate maximum flow, interarrival time and average car speed. These data would be used as the input parameters of the traffic light control simulation model in the server. After getting the simulation results, the system is able to give alternatives depend on traffic situations and the red light or green light duration is being set via a traffic light control interface for solving the traffic congestion problems. All rules are used in the IF-THEN format. The system is using the forward chaining approach, starting from a basic idea and then tries to draw conclusions. The simulation model running in this system gives three optimal alternatives. The system uses these alternatives as the collected data to choose the best and the most solution for that particular traffic congestion situation.

2. 5 An Intelligent Traffic Controller Based on Fuzzy Logic [5]

This research paper proposes an intelligent traffic controller utilizing the fuzzy logic technology and image processing technique for real-time image acquisition. There are two traffic signals set in a T-junction. Inputs regarding the number of vehicles at each participating signal are obtained through vision sensors. The number of detected vehicles is sent to the controller. The system processes inexact data and produce a unique output for each scenario. The fuzzy membership function relationships have been defined in the form of ‘if-else’ statements in the fuzzy inference system. There are 30 rules defined which include all possible scenarios for each traffic signal. The fuzzy logic is used to calculate the extension of signal operation time provides longer green light intervals for routes with a greater amount of traffic.

2. 6 An Intelligent Traffic Light Scheduling Algorithm Through VANETs [6]

This paper introduces an Intelligent Traffic Light Controlling (ITLC) algorithm aims to decrease the waiting delay time and increase the throughput. This algorithm utilizes the vehicular ad-hoc technology to gather the real-time traffic characteristics of each surrounding traffic flow. The largest density first schedule is implemented to set the phases of each traffic light cycle. The area around the signalized road intersection where vehicles are ready to cross the intersection as ‘ready area’, which is guaranteed fair sharing of the intersection. The ready area is defined around the signalized road intersection to determine the maximum allowable time for each phase. The maximum allowable time should not exceed the maximum green time. The actual time set for each phase depends on the location of the farthest vehicle in each process of the traffic flow.

3. Existing Traffic Light Control Mechanism

Traffic lights have been utilized to schedule and control the traffic flows at each intersection using light cycle schedules. They allow all traffic flows to share the road intersection safely. The queuing delay at each intersection decreases the traffic flow efficiency all over the road network.

The existing traffic light control mechanism in urban areas of Thailand, such as Bangkok, there is a station for traffic police at each intersection in order to manually control the traffic light stage switching for each road of the intersection.

The simplest way to control the switching between the stage of traffic light is ‘fixed-timed controllers’ based on ‘time-of-the-day’ that use various patterns repeated in cycles every day, for example, on the rush hours, the traffic flow to office areas will be very bad, countdown time value for the road heading to that area will be longer than usual. The problem of this method occurs when the traffic condition is unstable or unpredictable by many reasons like accidents, weather condition, etc. Another way is ‘traffic-response controllers’, a controller that makes dynamical adjustments of cycle time and stage split.

There are two significant metrics that be used to evaluate the performance of a traffic light control system, delay and throughput. The delay is defined by amount of additional time a vehicle takes to complete its journey because of traffic lights. The throughput is the number of vehicles that cross the intersection in a specified amount of time. The general optimization goal is to decrease the delay and increase the throughput, that means the less the average delay at each road intersection is and the higher the throughput of the road intersection is, the more efficient the scheduling algorithm becomes.

4. Fuzzy Logic Algorithm

The Fuzzy Logic is an approach to computing based on ‘degrees of truth’. It is using 0 and 1 as true or false, but also includes the various stages of truth in between, for example, ‘0.5 degrees of truth’. The Fuzzy Logic is always used in artificial computer neural network and expert systems.

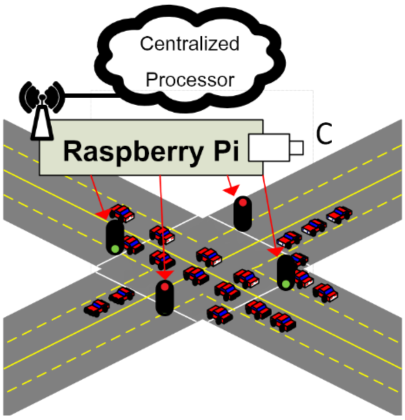

Figure 1. Device Installation

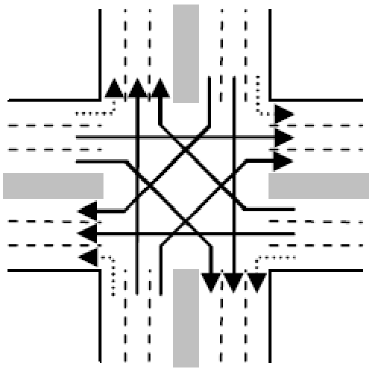

Figure 2. 6-lane Road 4-way Intersection

5. Microcontroller Device

In this system, the microcontroller device is designed to install at intersections, to detect the real-time traffic condition via the image processing method and send raw data to the centralize processor. The device is composed of the Raspberry Pi, which is a small-sized single-board computer, camera module to capture the traffic condition image, and send data via built-in network interface. Figure 1 shows the example of this device.

6. Automatic Traffic Light Control System

In this paper, we will consider only the 6-lane road with 4-way intersection, the intersection and traffic flow direction is shown as the figure below.

We can calculate the number of traffic lights required for this intersection from this equation.

$$L = \sum_{i=1}^{n} [(n-1) - D_i], \mathrm{n} \geq 3$$

When n is the number of roads met at an intersection,
D_i is the number of through lanes at the intersection from each road i

Then the number of traffic lights required for an intersection in the figure 2 is (3-1) + (3-1) + (3-1) + (3-1) = 8. Each traffic light controls each traffic flow of the intersection as shown in figure 3.

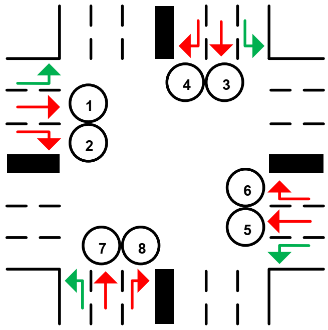

Figure 3. Traffic Lights for an Intersection

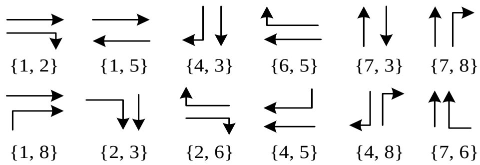

Figure 4. Possible Green Signal Patterns

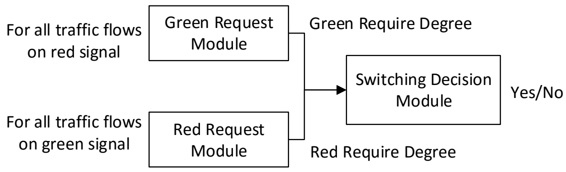

Figure 5. Diagram of the Controller

There are 12 green signal patterns that could be possible at this intersection, {1, 2}, {1, 5}, {4, 3}, {6, 5}, {7, 3}, {7, 8} are workable, but the set of {1, 8}, {2, 3}, {2, 6}, {4, 5}, {4, 8}, {6, 7} should not be considered due to the safety reason.

The fuzzy system composed of modules as shown in figure 5.

6. 1 Green Request Module

The Green Request module identifies the traffic condition of all traffic flows which is currently on the red signal. Input values for this module are the number of waiting vehicles (Q_r) and the time duration that this flow stays on red signal (T_r). This module uses input data that sent from the microcontroller device to apply with fuzzy rules to find the output 'Green Require Degree'. For example, if the number of waiting vehicles on a traffic flow is large and the time duration on red signal is long, the Green Require degree will be very high. The rules for this module is shown in figure 6.

6. 2 Red Request Module

This module observes the traffic flows which is currently on the green signal. Input values are the number of remaining vehicles (Q_g) and the time duration that this flow stays on green signal (T_g). The input data will be apply with fuzzy rules to find the output 'Red Require Degree'. If the number of remaining vehicles is zero and the time duration on green signal is long, then the Red Require degree will be very high. The rules for this module is shown in figure 7.

if WaitingVehicles is zero and RedTime is short then GreenRequireDegree is very low
if WaitingVehicles is zero and RedTime is medium then GreenRequireDegree is very low
if WaitingVehicles is zero and RedTime is long then GreenRequireDegree is low
if WaitingVehicles is small and RedTime is short then GreenRequireDegree is very low
if WaitingVehicles is small and RedTime is medium then GreenRequireDegree is low
if WaitingVehicles is small and RedTime is long then GreenRequireDegree is medium
if WaitingVehicles is medium and RedTime is short then GreenRequireDegree is low
if WaitingVehicles is medium and RedTime is medium then GreenRequireDegree is medium
if WaitingVehicles is medium and RedTime is long then GreenRequireDegree is high
if WaitingVehicles is large and RedTime is short then GreenRequireDegree is medium
if WaitingVehicles is large and RedTime is medium then GreenRequireDegree is high
if WaitingVehicles is large and RedTime is long then GreenRequireDegree is very high

Figure 6. Fuzzy Rules for the Green Request Module

if RemainingVehicles is zero and GreenTime is short then RedRequireDegree is high
if RemainingVehicles is zero and GreenTime is medium then RedRequireDegree is very high
if RemainingVehicles is zero and GreenTime is long then RedRequireDegree is very high
if RemainingVehicles is small and GreenTime is short then RedRequireDegree is medium
if RemainingVehicles is small and GreenTime is medium then RedRequireDegree is high
if RemainingVehicles is small and GreenTime is long then RedRequireDegree is very high
if RemainingVehicles is medium and GreenTime is short then RedRequireDegree is low
if RemainingVehicles is medium and GreenTime is medium then RedRequireDegree is medium
if RemainingVehicles is medium and GreenTime is long then RedRequireDegree is high
if RemainingVehicles is large and GreenTime is short then RedRequireDegree is very low
if RemainingVehicles is large and GreenTime is medium then RedRequireDegree is low
if RemainingVehicles is large and GreenTime is long then RedRequireDegree is medium

Figure 7. Fuzzy Rules for the Red Request Module

6. 3 Switching Decision Module

The Switching Decision module applies the Green Require Degree and the Red Require Degree to the fuzzy rules. The output is the decision to switch the traffic signal to the pattern that has a highest Green Require Degree value. For example, if the Green Require degree of a traffic flow is very high and the Red Require Degree value of the green-signaled traffic flow is very high, the green signal will be switched to the flow that has the highest Green Require Degree value. The rules for this module is shown in figure 8.

if GreenRequireDegree is very low and RedRequireDegree is very low then Switching is no
if GreenRequireDegree is very low and RedRequireDegree is low then Switching is no
if GreenRequireDegree is very low and RedRequireDegree is medium then Switching is no
if GreenRequireDegree is very low and RedRequireDegree is high then Switching is no
if GreenRequireDegree is very low and RedRequireDegree is very high then Switching is no
if GreenRequireDegree is low and RedRequireDegree is very low then Switching is no
if GreenRequireDegree is low and RedRequireDegree is low then Switching is no
if GreenRequireDegree is low and RedRequireDegree is medium then Switching is no
if GreenRequireDegree is low and RedRequireDegree is high then Switching is no
if GreenRequireDegree is low and RedRequireDegree is very high then Switching is yes
if GreenRequireDegree is medium and RedRequireDegree is very low then Switching is no
if GreenRequireDegree is medium and RedRequireDegree is low then Switching is no
if GreenRequireDegree is medium and RedRequireDegree is medium then Switching is no
if GreenRequireDegree is medium and RedRequireDegree is high then Switching is yes
if GreenRequireDegree is medium and RedRequireDegree is very high then Switching is yes
if GreenRequireDegree is high and RedRequireDegree is very low then Switching is no
if GreenRequireDegree is high and RedRequireDegree is low then Switching is no
if GreenRequireDegree is high and RedRequireDegree is medium then Switching is yes
if GreenRequireDegree is high and RedRequireDegree is high then Switching is yes
if GreenRequireDegree is high and RedRequireDegree is very high then Switching is yes
if GreenRequireDegree is very high and RedRequireDegree is very low then Switching is no
if GreenRequireDegree is very high and RedRequireDegree is low then Switching is yes
if GreenRequireDegree is very high and RedRequireDegree is medium then Switching is yes
if GreenRequireDegree is very high and RedRequireDegree is high then Switching is yes
if GreenRequireDegree is very high and RedRequireDegree is very high then Switching is yes

Figure 8. Fuzzy Rules for the Switching Decision Module

7. Simulation

We have set up the simulation using MATLAB in order to simulate the algorithm. In this simulation, we have made assumptions as following.

- The intersection is 4-way intersection.
- We have fixed the simulation time to 1 minute to find the throughput of 2 simulation environments (an Automatic Traffic Light Control System and fixed-time controllers).
- To find the decreased delay time, we have separated the simulation into 3 units based on the number of vehicles in the simulation environment, and the vehicle arrival rate of each traffic flow is a random value (which is controlled by the arrival rate coefficient).

8. Results

We show the simulation results as the average percentage of increased throughput (the total number of vehicles that cross the intersection in a specified amount of time) and the decreased delay time. We will show the result using the designed system compared with the existing traffic controlling system mechanism (fixed-timed controllers). The results are shown as below.

- The throughput per 1 minute have increased 15 – 18 %
- 100 vehicles: average delay decreased by 20 %
- 250 vehicles: average delay decreased by 17 %
- 500 vehicles: average delay decreased by 14%.

9. Conclusion

The system and algorithm that have been presented in this paper is used to collect information of the real-time traffic condition to analyze and classify. An algorithm based on the Fuzzy Logic is used to make a decision to switch the traffic light signal to each traffic flow in order to decrease the delay time. By the simulations, the results have shown that the control system can help to optimize the performance of the traffic management by increase the traffic throughput up to 18 %, and can decrease the delay time up to about 20%. This research should be extended further by concentrating on the method to collaborate the system between intersections in order to optimize the globally traffic flow.

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