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Intelligent Traffic Management System Utilizing Fuzzy Logic-Based Dynamic Time Allocation Technology

N. K. C. Nwaogwugwu[1]; I. E. Achumba[2]; C. K. Agubor[3]; O. C. Nosiri[4]; J. T. Wosu[5]
[1, 2,3,4,5]Department of Electrical and Electronic Engineering, Federal University of Technology, Owerri, Imo State, Nigeria

Abstract—*Considering the increased rate at which traffic congestion occur in urban cities which is associated with longer waiting time of vehicles on traffic queues resulting in loss of fuel, time and productivity, as well as fatigue and other health-threatening conditions; it is imperative to apply innovative, fully functional and affordable technologies to curb this challenge. Unfortunately, state-of-the-art traffic management systems are not able to solve this problem as they do not employ intelligent traffic control techniques at road junctions. This research developed an intelligent road traffic management system using Fuzzy logic-based Dynamic Time Allocation Technology (DTAT). In doing this, a sensor network for the detection of vehicular presence and movement was designed using motion sensors and IP cameras. Furthermore, a camera system for capturing vehicle plate number of offending drivers, as well as traffic offence SMS gateway for communicating with offenders and appropriate authorities was developed. Fuzzy Logic techniques as well as load balancing and remote procedural call (RPC) were applied in implementing the fundamental operations of the system. Results obtained indicate that the frequency at which traffic flows at a particular lane of the road within a period of time is a function of the number of vehicles that enter and leave the traffic zone at that point.*

Keywords—*Road traffic, Fuzzy logic, Load balancer, RPC, UML and Dynamic Time Allocation Technology.*

I. Introduction

Traffic congestion is a global phenomenon. A good number of major cities in the world experience heavy vehicular traffic. For example, according to [1], many cities in Nigeria are faced with series of traffic congestions. Extreme traffic congestion is a problem in some Nigerian cities, with large city drivers clogging the streets at speeds of three to five kilometers per hour. Congestions of very large magnitude, often referred to as hold-ups or go-slow, are commonplace during the morning and evening rush hours and on most working days. Similarly, the highways surrounding Hong Kong Island, which are approximately 2,100 kilometers long, are used by more than 762 thousand vehicles. As a result, travel times across the nation have increased [2].

Lack of investment in public transportation infrastructure, and the prevalence of private automobile ownership are all factors that contribute to traffic congestion, according to [2]. A number of additional factors contribute to this problem, including inadequate road planning, small roadways, increasing economic activity, fast urbanization, and rising population density.

Loss of time, energy, fuel, and low productivity are just a few of the challenges encountered as a result of road traffic congestion. Fatigued drivers are more likely to break the law on the road, which can cause serious accidents and even fatalities. There may be health and economic consequences if the average time cars spend waiting in traffic jams increases [3] [4]. The longer vehicles wait, the more carbon dioxide (CO) they emit. Both people and the environment are at risk from this. Additionally, because of the greater average waiting time, excessive traffic waits could cause patients to lose their lives in health-emergency circumstances requiring quick medical attention [3].

It is vital to enhance traffic control systems urgently in order to address these issues [5]. Unfortunately, most existing traffic management systems are static, pre-programmed light systems that fail to adequately account for real-world traffic factors including the number of vehicles and pedestrians, as well as delays and waiting times for road users. Interestingly, Intelligent Traffic Control systems have come to the rescue.

The need of intelligent real-time traffic management systems for contemporary urban traffic control systems that strive for road network optimization was demonstrated in [6] [7]. Intelligent traffic systems and services were described in [2] as the integration of transportation infrastructure, vehicles, and users with information and communications technology.

Thus, the primary aim of this work is to develop an intelligent traffic management system utilizing fuzzy logic-based dynamic time allocation technology.

The rest of the paper is structured as follows: section II is the literature review; section III presents materials and method; section IV describes the system implementation; while sections V and VI present the results and conclusion respectfully.

II. Literature Review

Graph theory and formal approaches were utilized in [8] to suggest an intelligent traffic monitoring system. The suggested model is an intelligent traffic guidance and monitoring system that uses a city's roads, objects, and traffic lights as its nodes. The system's operations include determining the least time and distance shortest route, locating a certain region inside the city, and determining the least crowded and safest routes to the destination. Using Vienna Development Method-Specification Language (VDM-SL), the graph-based model may be simply converted into a formal model.

In their work on vehicular ad hoc networks (VANETs), [9] laid out a standard protocol that would allow for communications between vehicles, and between vehicles and roads, which would be great for preventing accidents and collisions. Methods for the simultaneous transmission of warning signals via vehicle-to-infrastructure and vehicle-to-vehicle communications using different multi-hop routings were outlined. The multi-channel (MC) strategy, which is based on two non-overlaps for vehicle-to-vehicle (V2V) and vehicle-to-road (V2R) or road-to-vehicle (R2V) communications, was used to address approaches to improvement of communication dependability through low latency. Findings from both the theoretical and practical scenarios show that the two systems work well together, and that the R2V communication protocols, which share a common node with the V2V and V2R protocols, greatly enhance message transmission in low-latency environments, making them perfect for use in future road safety systems.

For the intricate road networks in Hong Kong, [10] suggested a PC-based traffic monitoring system that doesn't need any infrastructure. Also, the system can identify the make, model, and license plate of most cars driven in Hong Kong. In order to help with traffic policy decisions, the authors analyzed data on road usage and provided their conclusions.

An approach to controlling traffic lights was suggested in [11] using distributed cooperative backpressure. The urban traffic network was represented as a smart agent-controlled queuing network. In this model, the agents at each intersection communicate with each other to share information about the length of the queue and the selected activating light phase of nearby intersections. The agents then use this data to determine the activating light phase for each time slot based on local traffic conditions. In comparison to the initial backpressure-based and fixed-time traffic control approaches, the suggested cooperative backpressure-based approach to traffic light management achieved superior performance, according to the simulation findings.

In order to improve the quality of life in a smart city, [12] concentrated on an ontology-based context-aware framework that provides services like smart traffic monitoring and smart surveillance. These services utilize IoT technology. In order to identify dangers, traffic conditions, and other similar events using useful context information, an IoT network integrates the operations of closed-circuit television (CCTV) cameras with a variety of sensors to execute real-time calculation. Multimedia Web Ontology Language (MOWL) was used to semantically interpret and address the inherent uncertainties in multimedia observations pertaining to the system.

As an essential part of a smart city, the short-term traffic flow forecast problem using real-world traffic data was the subject of [13]. Their innovative ensemble model (EM) combines models from convolutional neural networks (CNNs), deep autoencoders (DAEs), and long short-term memory (LSTMs). According to their findings, the suggested ensemble model outperforms the competition in terms of prediction accuracy (around 97.50% accuracy) and resilience in the face of traffic flows with large volatility.

To improve the overall network efficiency, [14] created a system for online agent-based signal coordination that relies on communication across several intersection control agents. Furthermore, the preliminary coordination method that pre-adjusts the intersection offsets was created using demand data from the past. The suggested method was tested on a tailored traffic simulation platform using MATLAB and VISSIM, and its performance was assessed through comparison and sensitivity analysis. In comparison to rule-based multi-agent signal control methods, the suggested approach successfully avoids network oversaturation, which in turn improves average vehicle speed and decreases average travel delay.

A Dynamic and Intelligent Traffic Light Control System (DITLCS) which takes real-time traffic information as the input and dynamically adjusts the traffic light duration was proposed in [15]. The suggested DITLCS operates in three modes: Fair Mode (FM), Priority Mode (PM), and Emergency Mode (EM). All vehicles are given equal priority in Fair Mode (FM), vehicles of different categories are given varied levels of priority in Priority Mode (PM), and emergency vehicles are given the highest priority in Emergency Mode (EM). In addition, they suggested a deep reinforcement learning model to cycle through the three phases of traffic lights (red, green, and yellow), and they used a fuzzy inference system to choose one of three modes (FM, PM, or EM) based on the data collected about the traffic. On various performance measures, the simulation results showed the efficiency of DITLCS in comparison to other cutting-edge methods.

For an isolated intersection, [16] suggested an adaptive approach to controlling the traffic lights that takes into account variables like waiting time and traffic volume. Using this approach, the shortest queue was given priority. Experimental results demonstrate that in comparison to a fixed-time control algorithm, the suggested approach significantly reduces vehicles' waiting times.

In order to address the difficulty of managing mixed-traffic situations, a novel Traffic Light Control System (TLCS) called PALM was suggested in [17]. PALM modifies the timing of the traffic lights based on the traffic flow at each intersection and nearby ones. Additionally, it enhances the CAV platoons' performance by optimizing the signal timing and phases. According to the simulation results, the technique reduced average waiting time by 75.34% and 33.02% compared to the static and actuated TLCS, respectively.

The issue of traffic jams at junctions was addressed by [18]. They created a traffic simulator that accurately mimics real-life traffic conditions by simulating a variety of scenarios. Their argument was that the best way to make the most of our current infrastructure is to implement adaptive real-time traffic optimization, which allows the traffic control system to change, adapt, and learn from its surroundings. Additionally, they proposed a policy gradient algorithm–based vision-based deep reinforcement learning method for configuring policies for traffic light control. Findings from early experiments show that this innovative approach to traffic light policy configuration is very efficient.

A framework for managing and controlling traffic lights in an IoT environment by applying techniques such as Vehicle-to-vehicle (V2V), Vehicle-to-infrastructure (V2I), Vehicle-to-everything (V2X), the Internet of things (IoT), and artificial intelligence (AI) was proposed in [19]. Also covered in detail was the dynamic scheduling of traffic signals using real-time data collected from embedded sensors in both roads and vehicles. In addition, the authors used mathematical approaches in conjunction with a Neuro-Fuzzy traffic control system to make a smart judgment according to the current traffic patterns.

III. Materials And Method

This paper tends to utilize inexpensive and off-the-shelve components in developing the proposed solution. object-oriented systems modelling and dynamic time allocation techniques were adopted as development methodology.

A. Materials

i. Proteus 8 – a simulation software tool developed by Labcenter Electronics. It is used for simulating the operations of the system.
ii. Arduino Uno Microcontroller – an open-source electronic development board that has the capability of accommodating sensors and actuators, as well as executing Embedded-C code which drives operations of the system.
iii. Arduino IDE – a software development tool used for writing programs that run on the Arduino board.
iv. Torch LDR – light-dependent resistors that represent the number of vehicles on each lane.
v. Traffic Lights – comprising of red, yellow, and green light emitting diodes (LEDs), it is used to represent road traffic signals at each lane of the road.
vi. 7SEG-MPX2-CA-BLUE – digital liquid crystal display (LCD) counter timer mounted alongside each traffic light. It is used for the dynamic display of the traffic flow and wait time of each road lane.
vii. ESP8266 Wi-Fi Module – for transmission of captured traffic signal to MySQL database

B. Methods

In this work, a composite methodology has been adopted. It involves:
i. Object-Oriented System analysis and design utilizing Unified Model Language (UML) tools.
ii. Fuzzy logic-based Dynamic Time Allocation development techniques.

This composite method begins with understanding the operational functionalities of the DTAT-based smart traffic control system. Then it applies unified modelling language (UML) techniques in designing the entities, attributes, operations, and relationships that drive the operational flow of the solution. Finally, program models are written in C language.

The Requirements of the Proposed Solution

i. *The system will monitor and control road traffic in real-time*: this is the major functionality of the system.
ii. *The system will achieve monitoring by capturing the situation of the road in real-time:* the traffic situation of the road shall be captured by;
   a. Registering every vehicle within the distance range of the traffic queue,
   b. Recording the number of vehicles within the distance range of the traffic queue,
   c. Recording the average waiting time of vehicles on the traffic queue within the distance range at a particular phase of the traffic signal.
   d. Recording the rate at which vehicles enter and leave the traffic zone (i.e., distance between the road junction where the traffic signal is positioned, and the supposed point where the traffic stops at a particular phase of the traffic signal.
   e. Unregistering vehicles that exit the traffic queue.
iii. *The system will achieve control by accepting and processing captured data regarding the situation of the road:* the road traffic situation is primarily determined by the average waiting time of vehicles on traffic queues which is determined by the number of vehicles in the traffic zone and the rate at which they enter and leave the zone.
The traffic is high if the number of vehicles in the traffic queue is high; the average awaiting time of vehicles on the traffic zone is high; and the average frequency at which vehicles enter and leave the traffic zone is low.
Thus, the road traffic situation, T_s is expressed in equation 3.1 as;

$$T_s = \frac{N_v + T_{avg} + F_{avg}}{T_{ph}} \quad (3.1)$$

Where;
N_v = Number of vehicles in the traffic queue (traffic zone),
T_{avg} = average waiting time of vehicles in the traffic zone,
T_{ph} = traffic phase, and
F_{avg} = average frequency at which vehicles enter and leave the traffic zone at a particular phase of the traffic signal.
The average frequency at which vehicles enter and leave the traffic zone at a particular phase of the traffic signal, F_{avg} is determined using equation 3.2;

$$F_{avg} = \frac{1}{T_{avg}} \quad (3.2)$$

T_{avg} is defined as time taken for the respective vehicles in traffic zone to exit the zone divided by the number of vehicles that left.

Mathematically,

$$T_{avg} = \frac{(t_{ex} - t_{en})_1 + (t_{ex} - t_{en})_2 + \cdots (t_{ex} - t_{en})_n}{n} \quad (3.3)$$

Where;
t_{en} = time of entrance of each vehicle,
t_{ex} = time of exit of each vehicle, and
n = number of cars that leave the traffic zone at a particular phase.

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Traffic Phase, T_{ph}: at this point, it is important to mention that a traffic phase, T_{ph} in this context refers to the cycle of time in which the traffic signal turns from green light through amber to red for a particular lane. Thus, it is the duration of time in which a particular lane is allowed to flow before being stopped by the red light.

Mathematically,

$$T_{ph} = t_g + t_a \quad (3.4)$$

Where;

t_g = time that the green light of a particular lane is turned on,
t_a = time that the amber light of a particular lane is turned on.

iv. *The system shall store traffic data in a central database where certain users will have access to certain information:* these traffic data include the following;
   a. The real-time traffic situation of the road; which describes whether there is high or low congestion at a particular point in time,
   b. Records of vehicles that have violated traffic rules with the time, date, location, and a snapshot of the event.

v. *The system will register every vehicle within a specific range of distance which is assumed to be the traffic queue:* each car that enters the traffic zone (say 400 meters from the traffic signal) will be registered by the system in order to ascertain the number of vehicles and their average waiting time on a traffic queue within a specific period of time.

vi. *The system will unregister every car that exits the traffic queue distance range:* each car that leaves the traffic queue (traffic zone) shall be unregistered by the system in order to create room for new cars to be registered and to ascertain the traffic situation T_s.

vii. *The system will reduce average waiting time of vehicles by striking a balance between the flow of traffic in different lanes:* this will depend on the traffic situation of the road. The system will use a balanced clocking signal (load balancing) for traffic management if all lanes of the road have the same amount of traffic. Else, the system will control the traffic based on sensed situation of the road as per lanes with higher and lower traffic queue.

viii. *The system will capture and report defaulters of traffic rules to appropriate authorities:* details of vehicles that violate traffic rules shall be captured and stored to a central database where it shall be accessible by appropriate authorities

Architecture of the proposed system

The architecture of the proposed intelligent traffic management system utilizing Fuzzy logic-based Dynamic Time Allocation Technology is depicted in Figure 1.

From Figure 1, it could be seen that inductive sensor array and Passive Infra-Red PIR sensor array are used concurrently to increase vehicular sensing capability. In order to do Dynamic Time Allocation Technology, fuzzy logic is used to act upon the data coming from the sensor. After following all the fuzzy logic procedures, green time and red time – which is the output of the fuzzy logic system is optimized for each road in the junction.

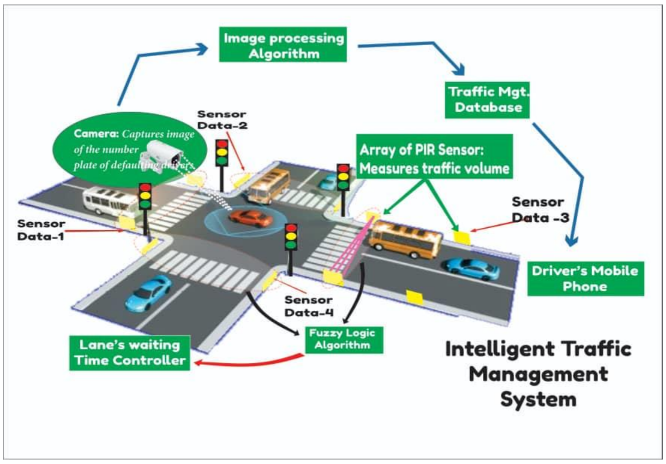

Figure 1: An Architecture of the proposed system

A sensor activates the camera to record the car license plate number when a driver beats the traffic signal. To do this, image recognition algorithm will come to play. The image from the camera will serve as input to the algorithm. First, the image will be localized for the license plate. Character segmentation will be done on the image in other to extract the characters on the license plate. The segmented characters will go through a character recognition procedure to generate a text output of the characters of the license plate.

With the license plate so gotten, it will be used as the primary key to search for the vehicle owner's phone number from the official database. The database will output the phone number and address of the vehicle owner.

The SMS gateway will then be utilized to send a message to the vehicle owner, telling him of his offence and the fine to be paid due to his offence.

Modelling the Inference Rules for the Fuzzy Controller

In modelling the inference rules for the fuzzy controller which drives the logical flow of execution of operations of the system, it is worthy of note that the three stages of fuzzy logic implementation which involves fuzzification, defuzzification, and inference rules are all implemented by traffic controller system respectively by the sensors, actuators, and program. In this case, the fuzzification process which involves the transformation of *crisp input*s to fuzzy inputs utilizes the following parameters – *wait time, go time, and vehicles on the lane.*

The fuzzy controller's inference rules are comparable to the way a human traffic controller thinks. With respect to the traffic control system, the following flow of execution occurs:

1. Allocate equal time to each lane of the road,
2. Approve go time for a specific lane and set light to green,
3. Start wait time count for other lanes,
4. Decrease go time for the approved lane,
5. Sense the amount of vehicles on the approved lane and wait time, relative to other lanes,
   a. If go time != 0 and vehicles very high,

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i. Maintain the green signal for lane.
ii. Keep other lanes to on wait with red light.
iii. Still count down the go time.

b. If go time != 0 and vehicles high,
   i. Repeat steps 5a(i) to 5a(iii).
c. If go time != 0 and vehicles normal,
   i. Check lane with highest wait time and highest vehicle.
   ii. Allocate go time to the lane and set light to green.
   iii. Repeat steps 3 – 5c(iii).
d. If go time == 0 and vehicles normal,
   i. Repeat steps 5c(i) – iii.
e. If go time == 0 and vehicles high,
   i. Increase the go time by 10% of the initially allocated go time,
   ii. Maintain the green signal,
   iii. Countdown the go time.
f. If go time == 0 and vehicles very high,
   i. Repeat steps 5e(i)–iii.

From the steps highlighted above, it can be seen that it is based on the priority given to a specific lane that determines whether traffic flows (green light) or not (red light).

IV. System Implementation

Considering minimal environmental impact and accuracy, this work deployed both inductive sensor array and PIR sensors for vehicular detection. These sensors are capable of detecting when a vehicle is present, not moving, and when a vehicle is moving. These sensors produce output voltages that have a relationship with the time domain. The voltages from these sensors are fed into a processing system that extracts the necessary information. Figure 2 shows a block diagram representation of the vehicular sensing system.

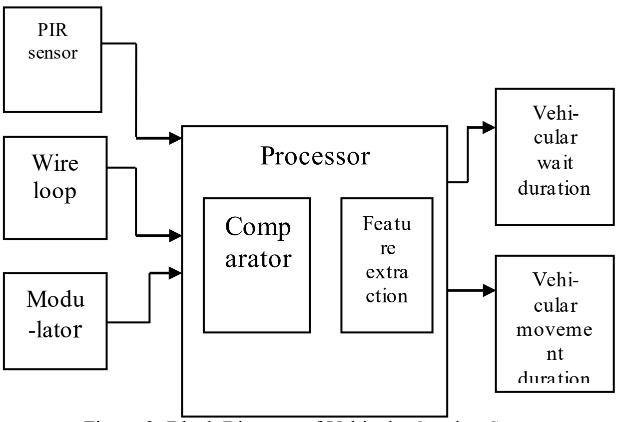

Figure 2: Block Diagram of Vehicular Sensing System

The proposed solution was implemented in Proteus simulation environment. In so doing, some of the materials outlined in section 3.0.1 which include – Arduino Uno, Torch LDR, Traffic Lights, 7SEG-MPX2-CA-BLUE, and ESP8266 Wi-Fi module were used in Proteus to simulate the traffic control system.

Nevertheless, the Embedded-C program which drives the operational functionalities of the microcontroller and consequently the entire system, was programmed using the Arduino IDE. The developed program was then converted into a hexadecimal file format and uploaded into the memory of the Arduino Uno microcontroller in the Proteus simulation environment. Traffic information gathered are the transmitted via the Wi-Fi module and sent to MySQL database for analysis.

An overview of the simulation setup is presented in figure 3.

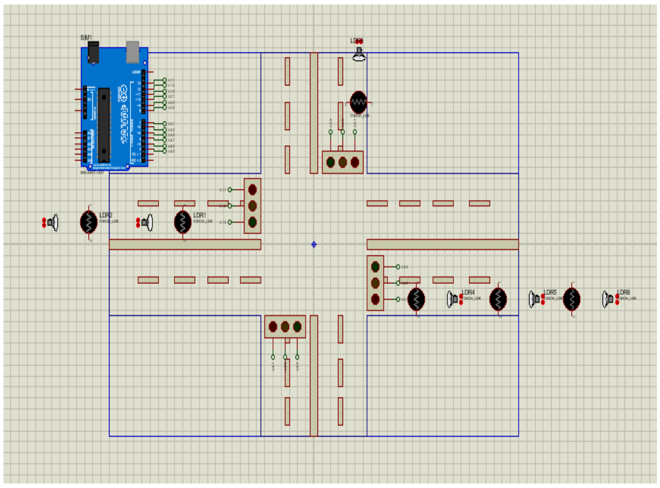
Figure 3: Simulation Setup of the Proposed System

V. Results and Discussion

A. Results

The number of vehicles, wait time, and go time for the respective road lanes were considered the KPIs upon which the performance of the proposed system was based. Data pertaining the KPIs were captured and sampled every four hours. The tables below show the samples of the results obtained in twelve hours.

The microcontroller that runs the fuzzy logic program was fed input signals from four signal generators. The microcontroller then processes the input signals and produces outputs. Each input signal represents the traffic density of each lane. Consequently, the four lanes of the road that forms the intersection are represented by the four input signals. Priority issued (from a scale of 1 – 10) to each lane (input signal) is based on the level of signal for the lane in relation to other lanes. It is based on the lane priority that the flow duration and wait duration is assigned to each lane relative to other lanes. Therefore the traffic situation Ts is a function of the level of input signal, flow duration, and wait duration of each lane of the road. Tables 1 and 2 show the test results for the four input signals

B. Discussion

In the process of preparing the captured data for analysis, calculated fields were generated for each of the KPI which represented the mean of each data for a single occurrence, with the number of vehicles (NV) rounded up to the nearest whole number.

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TABLE 1: Relationship Between Lane Priority, Flow Duration, and Wait Duration for the First Traffic Phase $T_{ph1.}$

Lane	Traffic Density	Lane priority	Flow duration (s)	Wait duration (s)
1.	150	7.50	100	215
2.	200	10.00	120	195
3.	87	4.35	55	260
4.	48	2.40	40	275

TABLE 2: Relationship Between Lane Priority, Flow Duration, and Wait Duration for the Second Traffic Phase $T_{ph2.}$

Lane	Traffic Density	Lane priority	Flow duration (s)	Wait duration (s)
1.	72	4.50	60	180
2.	33	2.00	20	220
3.	180	10.00	120	120
4.	55	3.40	40	200

From tables 1 and 2, it could be seen that there is even allocation of go time of traffic signal based on the number of vehicle on each road lane at a given instant. The number of cars and their wait time are the only factors affecting the traffic flow in a certain lane. Figure 4 is simply a graphical representation of the interrelationship between road lanes and traffic flow with respect to the number of vehicles, wait time, and go time.

VI. CONCLUSION

Fuzzy logic has been applied in the development of an intelligent traffic management system. This has resulted to the development of a system that evenly distributes priorities to different lanes of a road making a traffic intersection, which is achieved by monitoring the traffic situation of the road using inexpensive and off-the-shelf technologies. The evenly distributed priorities resulted to optimal control of road traffic situation due to similar frequency at which traffic flows in different lanes within a period of time. Parameters such as the average waiting time of vehicles on traffic queues, number of vehicles on traffic queues, the frequency at which the traffic flows, and the duration of green light signal for each traffic phase were considered the key factors for determining the road traffic situation of a particular lane.

Moreover techniques such as load balancing and RPC were applied to work in synchrony with the AI technique adopted. This facilitated ideal distribution of lane priorities and optimum interchange of information among the processes running on different microcontrollers coordinating the activities of the various lanes. Both the load balancer and RPC run on the server side, i.e. the lane traffic signal microcontrollers.

Object-oriented system modelling technique was applied for the analysis and design of the software programs as well as the entire system. By adopting object-oriented system modelling, the major entities that make up the system; their respective attributes, operations, and interrelationships were identified and clearly outlined by using Unified Modelling Language (UML) tools and patterns. This inherently expatiated data abstraction, encapsulation of implementation details, high cohesion, loose coupling, parallel programming of functions, and ease of maintainability; features that fostered the security and performance of the system. RUP was adopted by building, testing, and fixing the components of the system at regular intervals.

The prototype system was simulated using Proteus 8.6, a Computer Aided Development suite. The simulation circuit was designed, and the code for priority checking of the lanes was configured in the Proteus 8.6 environment. With the use of the signal generators, the behaviour of the various sensors was emulated and the output was gotten from the microcontroller board using an oscilloscope. It is based on this that different lane signals were varied at different traffic phase in order to ascertain the even distribution of traffic flow.

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