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Application of CDS Photoresistors: An Inexpensive Approach to Implementing Intelligent Road Traffic Signal Control in Developing Countries

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Abstract— *Considering the increase rate at which traffic congestion occur in urban cities which is associated with longer waiting time of vehicles on traffic queues, despite good road networks; it is imperative to apply state-of-the-art technologies to curb this challenge. This research applied CDS Photoresistors as an inexpensive approach to implementing an intelligent road traffic signal control in developing countries. In doing this, inexpensive and open-source materials like Arduino mega microcontroller, LEDs, and photoresistors were used in developing a prototype system. Despite the application of the inexpensive CDS Photoresistors, methods such as object-oriented system analysis and design and fuzzy logic modelling were applied in the analysis of the traffic signal control system as well as incorporation of intelligence into the prototype system. The microcontroller was used to run the fuzzy logic operations in order to make the traffic signal control have a level of intelligence that will mimic the behavior of a human traffic controller so that the system can learn traffic situations of the road at all time. Results obtained indicate that by adding intelligence to the traffic control system through the application of the CDS Photoresistor sensor (for monitoring) and fuzzy logic (for reasoning), the prototype system displayed a better performance as it senses its environment and strikes a balance in the flow of traffic for the different lanes.*

Keywords— *Arduino ATMega2560; Microcontroller; CDS Photoresistors; Fuzzy Logic; Inexpensive; Object-Oriented System Analysis.*

I. Introduction

A. Background Information

Road traffic congestion has become one of the most challenging situations encountered around the world in recent times. In 2015, it was recorded that about 1.25 million people are killed in road traffic accidents worldwide with Africa having the highest death rate and Europe the lowest [15]. In 2018, road traffic accident is considered the ninth leading cause of death across all age groups worldwide and is predicted to be the seventh by the year 2030 [16].

Despite the good road network system in urban cities, road traffic congestion is still on the increase on daily basis. This is due to the increase on the number of vehicles that apply on the roads [1]**[**2**]** and [3]. In most cases, poorly implemented road traffic monitoring and control systems greatly contribute to traffic congestions.

Inefficient road traffic monitoring and control which results to increase in congestion not only inconveniences vehicle drivers and passengers, it also increases the average waiting time of vehicles on traffic queues [5][13] thereby leading to excessive emission of greenhouse gases by road vehicles. Inconveniences experienced by drivers and passengers could also lead to fatigue and other health-threatening conditions. In some cases, drivers tend to violate traffic rules and regulations due to tiredness which usually leads to accidents and consequently deaths.

Naturally, increase in the average waiting time of vehicles on traffic queues potentially has health and economic implications. Vehicles emit more Carbon (II) Oxide (CO) as they wait longer. This is poisonous to the human health and environment. However, in health-emergency situations where it is required that a patient be taken to the hospital for immediate medical attention, long traffic queues (due to longer average waiting time) could lead to lose of life [3]**.**Vehicles burn more fuel as they wait longer on traffic queues and passengers waste their productive time which has severe economic implications in their financial wellbeing. As technology advances and the need to solve vital societal problems of this sort increases, it is imperative to utilize relevant tools and techniques in proffering solution(s) for the betterment of the entire society.

B. Research Contribution

This project proposes to adopt CDS Photoresistors for the implementation of intelligent control of road traffic signals. Intelligence in this context implies that the road traffic signal tends to emulate the behavior of a human traffic controller stationed at a junction where road lanes intersect. This is to reduce the average waiting time of vehicles on traffic queues, which has significant effect on societal economy, environment, health and wellbeing. By so doing, the challenge of road traffic congestion and its associated consequences is downtrodden to a reasonable extent.

This however was achieved by utilization of inexpensive materials such as the CDS photoresistors, ATmega2560 Arduino microcontroller, LEDs, and interconnecting jumper wires. Fuzzy logic and object – oriented systems analysis and design techniques were applied in understudying the principle of operation of a conventional road traffic signal control system. This accounted for the incorporation of intelligence, as well as quick, affordable, and easy implementation respectively.

The remainder of this research is structured as follows; Section II reviews works related to design and implementation

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of intelligent road traffic control systems, Section III presents the architectural design of the system, Section IV presents and discusses obtained results, and finally, the research is drawn to a conclusion in section V.

II. Review of Related Literatures

Considering the nature of this research which is focused on utilizing inexpensive and opensource materials and techniques in implementing intelligent road traffic control signals in developing countries, it is imperative to note that in an embedded system of this sort, geographical location, cost of materials and overall intelligence are of utmost importance. In this light, literatures related to road traffic signal control implementation with respect to location, cost of materials, and intelligence are reviewed.

In [1], an Intelligent Traffic Information System which is Based on Integration of IoT and Agent Technology was developed. this traffic management system was based on IoT and is cost effective, scalable, compatible, and easy to upgrade. The research was proposed to employ IoT, agent and other technologies in managing road traffic. The IoT was based on Wireless Sensor Network (WSN) which was used to realize intelligent recognition on tagged traffic objects as well as monitoring. The system gathers real-time traffic data generated by sensory units and monitors the flow of traffic using multi agent-based technique. The WSN is been utilized to acquire real-time traffic information like the road traffic condition, number of vehicles on the road, average speed of vehicles, etc. It was understood that wireless sensors consume less power, is less expensive, and can inherently process commands in a distributed fashion, which makes it appropriate for implementing the traffic system.

Although the proposed system performs road traffic monitoring to a good extent, it does not actually achieve control as traffic information is transmitted across by intelligent agents to central unit for data monitoring and analysis. Thus, it is perceived as an Information Chaining System which falls under the class of Intelligent Traffic System (ITS) known as data analysis system [2] However, the use of numerous sensors, mobile agents, intelligent agents, etc. presents a lot of security loopholes to the system which will expose the entire system to malicious attacks. This may lead to further road accidents and insecurity of both drivers and passengers.

[2] Worked on an intelligent traffic monitoring system, a comparative study of different approaches for enhancing traffic system the world over. The model proposed in this research utilises infrared proximity sensors and a centrally placed microcontroller, it also makes use of vehicular length along a length to implement intelligent traffic monitoring. The vehicular length along a length follows a simple algorithm based on the length of traffic on each lane of the road. This simply means that the length of traffic on the other lane affects the time allotted to the current lane.

Instead of using Wireless Area Networks like WiMAX as suggested in [1], proximity sensors were used to obtain the length of the traffic. Emergency vehicles such as ambulances, fire-fighting trucks, police vans, etc. were also taken into consideration. Despite that the prototype of the proposed system was not achieved, the research presented a good insight to the fundamentals of road traffic management as a comparative study was carried out to some extent. Moreover, functionalities such as monitoring of violators of traffic rules and regulations and reporting to appropriate authorities were not realised. Appropriate software engineering principles ought to be adopted in developing the computer programs that will run on the AT Mega 2560 microcontroller. Road users and others alike were not given the opportunity to study the traffic situation of the road before applying a route.

[12] Worked on embedded web technology in traffic monitoring system. In this case, embedded web server (EWS) technology in combination with the internet were used to achieve remote monitoring of traffic conditions, traffic control, and communication of traffic data. The proposed system consisted of two major components – an embedded web server, and a bus controller. The bus controller is used in designing the traffic monitoring, and each point of control corresponds to the EWS. The hardware configuration of the proposed system included an embedded ARM processor (Raspberry pi ARM 11), ZigBee, GSM, Webcam, RFID, 4panel LEDs, MAX323, stepper motor, application system components, and bus controller (IC 18452).The software configuration included an HTTP engine, TCP/IP protocol, Common Gateway Interface (CGI) script, virtual file system, configuration module, security module, application interface module, embedded operating system, embedded application, controlling module, interface driver, and embedded SQLite database. The CGI is considered the most important in the EWS as it defines the standard between the Web server and CGI script. The CGI is programmed using the C language and embedded with the HTML script. The project possesses certain strengths such as the use of SQLite which is lightweight as an embedded database, utilisation of the Internet technology, and the use of the Raspberry pi ARM 11 processor which is quite suitable for moderately working environment and supports the uClinux operating system. However, the architecture of the entire system is somewhat over bloated and cumbersome which will potentially affect the system control [9]. If the project were to be implemented, it will be poorly scalable due to the complexity of the architecture and the tight coupling characteristic the system components inherently possess. Again, adequate software engineering principles were not adopted in the construction of the software units which drive the hardware and relatively the entire system.

A research which was focused on the implementation of a priority-based secure traffic management system by the application of IoT was carried out in [3]. This research was focused on reducing the tendency of traffic congestion and the average travel time of emergency vehicles by using the type of occurred incident for establishing priorities. Also, considering that the proposed intelligent traffic system utilises wireless communication which is prone to cyber-attacks, a technique was proposed to detect and respond to the hacking of traffic signals as such attacks could be life threatening if emergency vehicles are affected. It is a sort of Emergency Vehicle to

Infrastructure (EV2I) system which is based on the priority of an emergency vehicle depending on the type of incident and the hacking of traffic signals. Specific attention was given to emergency vehicles. In this case, an approach known as Emergency Priority Code System (EPCS) was used to dynamically control traffic flows in emergency situations. The EPCS system determines the type of incident by gathering information about an accident scenario via callers and/or live-feed cameras. It then assigns a priority code to the incident based on the degree of accident. The priority code determines which of these emergency vehicles gets the maximum priority; the ambulance, fire service van, or police. On emergency situations, the EPCS defines a specific route which it considers as optimal (i.e., the shortest path to the destination), and then turns the traffic signals along the path to green. This certainly reduced the traffic congestion along the path of the emergency vehicle and consequently the average travel time. However, this is at the expense of other vehicles that are not on the path of the emergency vehicle. Also, to detect and respond to intrusion from unauthorised access, the system takes note of the normal traffic patterns and then monitors statistically when there will be a change in the flow of signal. An approach related to that used in **[**11**]** was adopted in this case. One of the major drawbacks in this system is that if the green wave is eventually distorted, the traffic situation will be worsened by synchronisation which will be difficult to correct [14]. It was not clearly stated how the EPCS traces the shortest route to the destination of the emergency vehicle. Technologies such as GPS could as well be imbibed into the system as to know the exact location of emergency vehicles to know when exactly to change the traffic light to green. Also, the control mechanism of the system was not clearly highlighted as appropriate software engineering methodologies were ignored in the research.

In **[**4**]** Wireless Sensor Networks (WSNs) which implements the IEEE 802.15.4 standard protocol IEEE 2006 and multiple fuzzy logic controllers were utilised to achieve a dynamic control system for real-time traffic monitoring. The project basically consisted of three modules; WSN which is used for real-time traffic data acquisition, phase sorting module for solving the phase execution order according to the priority assigned to each phase on the basis of the number of cars on the queue for a particular phase, and fuzzy logic controller for calculating the appropriate green time duration of the relevant phase. Four (4) fuzzy logic controllers were used in an isolated intersection. Each fuzzy controller manages both the phase and the green time of traffic lights. Phase in this sense refers to the period of time in which it is possible, for a given set of lanes, to proceed in the allowed direction. The major reason behind this work was to make use of inexpensive materials in producing a system that is flexible with simple computational solution and can be implemented on open-source components. This research exploited the advantages of WSN such as, low cost, ease of deployment and maintenance, non-invasiveness, flexibility, and scalability, as well as the prospects of parallel usage of fuzzy controllers which accounted for better performance, fault tolerance, and support for phase-specific traffic light management. The presence of cars on traffic queues is been detected by Reduced Function Devices (RFDs) which are positioned along the roadside. This is achieved by evaluating the distortion of the magnetic field of the earth. One of the major drawbacks in this research is the inability of the system to predict traffic conditions. This could have been achieved using neural network. The combination of neural network with the system will however improve the performance of the fuzzy controller as it will make its decision not to only be based on the traffic situation detected by the WSN, but also on the probability of the short-term progression of the traffic condition. By this, the phase choice would depend on the number of vehicles on the queue while the green time duration of the traffic lights would be determined based on the traffic flow prediction by the neural network [4]. Also, the system could have been made more intelligent and multifunctional by adding more sensors and actuators. In this case, the temperature and humidity of the atmosphere can be sensed in order to detect elements such as rain, snow, fog, etc. which will facilitate the realisation of more advanced Intelligent Traffic System (ITS) applications.

C. Research Gaps

Thus far, considering the related literatures reviewed, the following research gaps have been identified as regards the application of inexpensive materials in the development of intelligent road traffic signal control system;

1. None of the research was focused on under-developed or developing societies where the standard of living is very low, and finances required to implement road traffic signal control of such intelligence may not be available.
2. None of the research utilised CDS photoresistors as an inexpensive material for the implementation of intelligent road traffic signal control.
3. Attention was not actually given to the utilisation of object-oriented system analysis in combination with fuzzy logic in implementing intelligent road traffic control system.

D. Research Objectives

The aim of this research is to apply CDS photoresistors as an inexpensive means of implementing intelligent road traffic signal control system in developing countries. The objectives are as follows;

1. To understand the principle of operation of conventional road traffic signals in under-developed or developing countries.
2. To develop and algorithm for intelligent road traffic signal control.
3. To apply fuzzy logic and object-oriented system analysis in the modelling of an intelligent road traffic signal control.
4. To build a prototype system for an intelligent road traffic signal control by applying software engineering principles and utilising inexpensive and off-the-shelf technologies.
5. To compare the performance of the proposed prototype system with that of the already-existing one.

III. Design Framework/Architecture

In developing the architectural framework of the prototype system, the principle of operation of a conventional road traffic control signal was observed, monitored, and studied. This is in order to understand the principle of operation of the system. For the purpose of this research, the prototype system was developed for traffic control signals situated at a road junction where four lanes.

A. Object-Oriented System Modelling

Having considered the nature of this research and the advantageous features of object-oriented programming such as data abstraction, encapsulation, scalability, code reusability, polymorphism, etc. [8][10], the developed system is modelled using appropriate object-oriented analysis and design principles and patterns **[**6**][**17]. As a result, a combination of 'Throwaway Prototype' and 'Rapid Unified Process (RUP)' [7] was adopted as the software development methodology for the project. This method includes analysing and modelling the gathered requirements using appropriate object-oriented and Unified Modelling Language (UML) tools and techniques.

Requirements Gathering and Definition:

In this section, the basis of operation of the conventional traffic control system were observed as thus;

1. The system has power supply unit(s) which provides 24/7 electricity to the traffic signal.
2. Each traffic signal has three lights with red, amber, and green coloration.
3. A traffic signal is dedicated to control one lane of the road.
4. A traffic phase of a particular lane is the time taken for the traffic signal dedicated to control the lane to show its green light, through the amber, and down to the red.
5. A traffic cycle is the duration taken for all the lanes to complete one cycle each.
6. The traffic signals mounted at a road intersection function collaboratively in a clocking synchrony. In this case, 60 seconds is allocated to the green light duration (flow duration) of each traffic lane per phase.
7. Whenever the traffic signal of a particular lane has its green light turned on (indicating flow), the red light will turn off, the other lanes will have their red lights on (indicating stop) and their green lights off.
8. For a road lane which has its green lights on, until the 60 seconds allocated to it elapses, the other lanes cannot flow. That is, their red lights will remain on and green lights off.
9. For each road lane, there is a particular distance from the road intersection away to a specific point. This is known as the traffic zone for the lane.
10. The road traffic signals have no intelligence whatsoever to detect when a lane is congested or not.

Having considered the basis of operation of the conventional traffic control, the requirements of the prototype system which is an improvement on the operation of the conventional road traffic signal were captured as follows;

1. The system will monitor and control road traffic in real-time; the system achieved this by monitoring the situation of the road in real-time. This traffic situation T_s is directly proportional to the summation of the readings of the sensors attached to each lane of the road making the intersection at the junction and inversely proportional to the green time duration G_t assigned to the lane.

$$T_s = R_1 + R_2 + R_3 \ldots + R_n \quad (1)$$

$$T_s = \frac{1}{G_t} \quad (2)$$

2. The system will achieve monitoring by capturing the situation of the road in real-time; as vehicles enter the traffic zone it is been recorded by the system.
3. The system will achieve control by accepting and processing the captured data regarding situation of the road in real-time; traffic situation T_s of a particular lane is a function of the sum total of the photoresistors readings (R) attached to the lane within the traffic zone. Therefore, in combining equations 1 and 2,

$$T_s = \frac{R_1 + R_2 + R_3 \ldots + R_n}{G_t} \quad (3)$$

4. The system will reduce average waiting time of vehicles by striking a balance between the flows of traffic in different lanes; this will depend on the traffic situation of the road. If there is equal amount of traffic in all the lanes of the road, the system will make use of a balanced clocking signal (load balancing) for the traffic control. Else, the system will control the traffic based on sensed situation of the road as per lanes with higher and lower traffic queue.
5. The system should not allow a vehicle to wait more than 10 minutes on a traffic queue.
6. The range of traffic distance covered by the traffic signal should be about 400 meters from the road junction where the signal is situated. This is the traffic zone of the road lane.
7. The network throughput of the interconnected systems should be of optimal strength in order to facilitate real-time communication and responsiveness of the entire system; this is in order to account for better quality of service. With respect to this, the communication channel between the road sensors and the traffic signal is wired to reduce data loss due to pathloss, as well as preventing intruders from attacking the network.
8. The system should protect the centralised traffic information from unauthorised access to avoid malicious damage.

Use Case Analysis

After establishing the system requirements, use cases were developed in order to further analyse complex requirements and are detailed below as follows;

TABLE 1.0: Use Case For Initiating Default Control Of The Traffic Signal.

Use case number:	#1
Use case name:	Initiate Default Control
Priority:	High
Primary actor:	Traffic signal and photoresistor
Brief Description:	This describes how the system initiates the default signal control.
Dependent on:	Road situation.

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Precondition:	System is functioning properly, appropriate sensors are positioned at appropriate points, and there is no interference in communication between the subsystems.
Trigger:	System is turned on and running. Photoresistors are all sensing.
Main Flow	
1.1. System checks the sum photoresistor readings for each lane. 1.1.1. If the sum of photoresistor readings for each lane are equal or almost equal, i. Assign 60 seconds each to each of the traffic signal attached to each lane per traffic phase. ii. Initiate the traffic cycle. iii. Continue with step II 1.1.2. If the sum of photoresistor readings for each lane are not equal, i. Exit default control state.	
Post condition:	Default control state initiated.
Special requirements:	Functional traffic signal, photoresistors, cable communication channel.

TABLE 2.0: Use Case For Monitoring The Road Traffic Situation.

Use case number:	#2
Use case name:	Monitor Road Situation
Priority:	High
Primary actor:	Traffic signal, photoresistors, & vehicles
Brief Description:	This describes how the system monitors the situation of the road.
Dependent on:	Photoresistor readings and traffic light signals.
Precondition:	System is functioning properly, and running at its default control state.
Trigger:	Vehicles entering the traffic zone.
Main Flow	
1.1. If the sum of photoresistor readings for each lane are not equal, i. Exit the default control state. ii. Compare the photoresistors readings for lanes 1, 2, 3, & 4. iii. If lane 1 readings > lane 2, 3, 4, a. Calculate the difference between the highest lane reading and the lowest. b. Multiply the difference by 2. c. Add the result to the default duration allocated to the lane 1 (i.e. 60 + result). d. Allocate result in c to the flow duration (green time) of lane 1. e. Subtract result in c from the total traffic cycle duration which is (60 * 4) = 240 seconds. Therefore 240 – result in c. f. Divide the result in e equally by three and allocate equally to each of the remaining three lanes (2, 3, 4). g. Repeat steps a – f after the elapse of traffic phase of lane 1. h. Repeating until photoresistor readings for each lane are equal or almost equal. i. If step h gives a true result, 1. Initiate default control.	
Post condition:	Road situation has been monitored.
Special requirements:	Functional traffic signal, photoresistors, cable communication channel.

By taking a critical observation of use case #2 which is focused on monitoring the road situation, it was ascertained that the control of traffic signal and reduction in the wait time of vehicles on the traffic zones were achieved. However, the reduction in wait time was achieved by virtue of comparing the summative photoresistor readings of each of the road lanes and taking appropriate actions as outlined in the main flow of use case #2. Therefore, the interrelation between the use cases is depicted in the use diagram in figure 1.0 below.

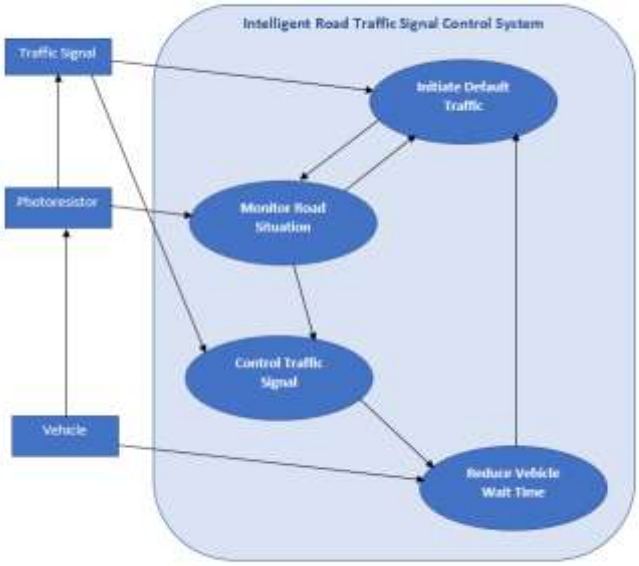

Figure 1.0: Use case diagram of the system

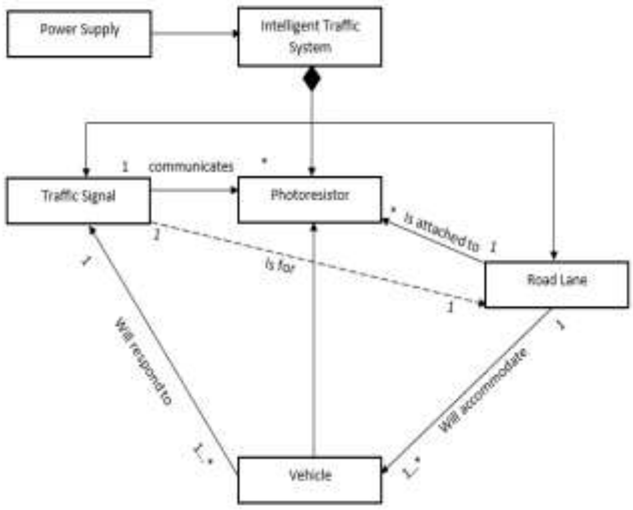

Figure 2.0: Conceptual Class Diagram of the System.

From the conceptual class diagram which depicts the block diagram of the system, the entire system is powered by a power supply. The intelligent traffic system is composed of traffic signal, photoresistors, and road lanes. One traffic signal is attached to one and only road lane. Also, one traffic signal communicates with many photoresistor and these many resistors are attached to one and only one road lane. A road lane can accommodate one or many vehicles and one traffic signal controls one or many vehicles.

B. Fuzzy System Model

In order to incorporate intelligence into the system, fuzzy logic was applied. This facilitated the tendency of the traffic signal control to learn and understand different traffic situations without been explicitly programmed. In this case, the fuzzy sets were identified, the decision matrix developed, and the system modelled.

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TABLE 3.0: Fuzzy Membership Functions

PARAMETER		POSSIBLE RESULT
OUTPUT	Traffic Situation (T_s)	Heavily Congested; Congested; Loosely Congested; Free
INPUT 1	Light intensity (A)	Low; Slightly low; Not low
INPUT 3	Green light duration (B)	Longer duration; Long duration; Default duration; Short duration

From the table above, the membership functions (MFs) one output (T_s), and two inputs being the light intensity (A) of the photoresistor and the green time duration of the traffic signal (C). Therefore, the possible results of the parameters include,

T_s = {Heavily congested, Congested, Loosely Congested, or Free}

A = {Very High, High, Low, Slightly Low, or Not Low}

B = {Longer, Long, Default, or Short}

To reduce the average waiting time of vehicles on traffic queues, the system attempts to strike a balance in the traffic situation of the road lanes at an intersection. Therefore, the decision matrix of the system is represented as thus;

TABLE 4.0: Fuzzy Decision Matrix

	Precondition	Inference		Consequence
P1	If light intensity is LOW and average wait time of vehicle is LONGER	Traffic situation is HEAVILY CONGESTED	**Q1**	Set green time to LONGER DURATION
P2	If light intensity is SLIGHTLY LOW and vehicle wait time is LONG	Traffic situation is CONGESTED	**Q2**	Set green time duration to LONG DURATION
P3	If light intensity is NOT LOW and vehicle wait time is MEDIUM	Traffic situation is LOOSELY CONGESTED	**Q3**	Set green time duration to DEFAULT DURATION
P4	If light intensity is NOT LOW and vehicle wait time is ZERO	Traffic situation is FREE	**Q4**	Set green time duration to DEFAULT DURATION
P5	If light intensity is LOW and vehicle wait time is MEDIUM	Traffic situation is LOOSELY CONGESTED	**Q3**	Set green time duration to DEFAULT
P7	If light intensity is SLIGHTLY LOW and vehicle wait time is ZERO	Traffic situation is FREE	**Q4**	Set green time duration to DEFAULT

It is based on this that the behaviour of the CDS photoresistors which perform the fuzzification process by capturing the physical quantity in real-time was programmed in the Arduino ATmega2560 microcontroller. The microcontroller however performs the function of defuzzification and utilises the output results for the optimal control of traffic signal in each traffic phase and cycle.

C. Prototype System Implementation

Although inexpensive and open-source microcontroller was utilised in developing the prototype system, the operations of this microchip which drives the performance of the entire system are modelled and implemented as software.

Different lanes of the road are embedded with light sensors which detect the intensity of sunlight as shown in Plate 2 below. Figure 3.0 below presents the schematic diagram of the hardware components.

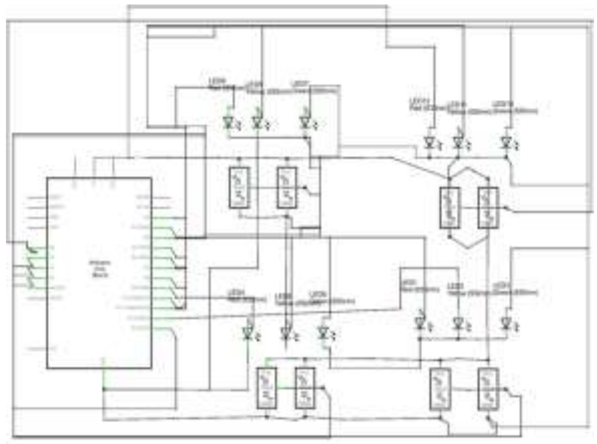

Figure 3.0: System Hardware Schematic Diagram

The system schematic diagram in figure 3.10 above shows the connection between various components that made up the system. Each lane has three different lights which are red, yellow and green. The lights of the system are controlled by time that is being monitored by the microcontroller which enables the system to give priority to a specific lane for a period of time depending on the sensor readings. The lights are connected from digital pin two through 13 on the microcontroller board. The terminals connected to the board are the positive terminals, while the negative terminals are connected together to form a uniform negative line before being connected to the GND (negative) terminal of the board.

The sensors have three terminals; positive, negative and signal. The positive is connected to the 5v terminal on the microcontroller; this is because the sensor works with 5 volts as its input power supply for proper operations. The negative is connected to the GND terminal of the microcontroller board, while the signal lines are connected to the analogue input lines on the board. The schematic diagram is the skeletal structure of the overall hardware build-up of the system; it is the structure based upon which connections are made.

Plate 1 below shows the pictorial view of the interconnection of the sensors, the microcontroller, and the LEDs.

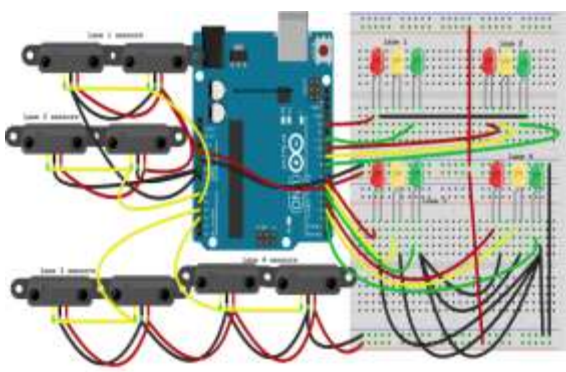

Plate 1: System Circuit Connection.

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Plate 2: System Prototype – Front View

Plate 3: System Prototype – Rear View

IV. RESULTS AND DISCUSSIONS

Considering that the traffic situation Ts is affected by certain factors such as the readings of the photoresistors and the flow duration of each phase, these factors are considered the key parameter indices (KPIs) for test-running the prototype system. However, this conforms with equation (3) which describes the traffic situation.

The developed prototype system was tested against the conventional traffic control signal which is based on the clocking technique earlier mentioned. By so doing, a dummy firmware program was initially developed to emulate the behaviour of the old traffic control system as described in the requirements gathering and definition (see Section III). This traffic control system was subjected to a condition where an initial flow duration of 60 seconds was assigned to each of the lane for one complete traffic cycle. It is important to recall that a traffic cycle consists of two traffic phases. i.e., two lanes flowing in opposite directions in each traffic phase. The average wait time of vehicles was then monitored for the cycle. This same condition was maintained for the firmware program that runs the prototype system. In this case, an initial flow duration of 60 seconds was also assigned to each of the lane and the photoresistor readings altered. The photoresistor readings were altered by placing pieces of woods (representing vehicles) along the path that make up the traffic zone. Higher priorities were given to lanes with higher readings as stipulated in the computer program.

Hence, the conventional road traffic signal has no sense of intelligence. Therefore, the wait duration of the blocks on the traffic zone remained equal to the duration in which the opposite lanes were made to flow, in this case, 60 seconds. After experimenting for two traffic cycles for the both systems, data with respect to wait duration, flow duration, and average traffic conditions of the conventional and prototype systems were sampled.

TABLE 5.0: Relationship between Flow Duration, Wait Time, And Photoresistor Readings For Tph1.

Lane	i (Ω)	W_{tavg} (s)	Lane priority	g_t (s)
L1	0.0	40.0	2	10.0
L1'	500.0	30.0	3	20.0
L2	0.0	40.0	2	10.0
L2'	0.0	40.0	1	10.0

TABLE 6.0: Relationship between Flow Duration, Wait Time, And Photoresistor Readings For Tph2.

Lane	i (v)	W_{tavg} (s)	Lane priority	g_t (s)
L1	0.6	40.0	1	10.0
L1'	0.3	40.0	1	10.0
L2	0.1	40.0	2	10.0
L2'	650.0	30.0	3	20.0

TABLE 7.0: Relationship between Flow Duration, Wait Time, And Photoresistor Readings For Tph3.

Lane	i (v)	W_{tavg} (s)	Lane priority	g_t (s)
L1	480.0	30.0	3	20.0
L1'	0.1	40.0	1	10.0
L2	0.5	40.0	1	10.0
L2'	0.3	40.0	1	10.0

TABLE 8.0: Relationship between Flow Duration, Wait Time, And Photoresistor Readings For Tph4.

Lane	i	W_{tavg}	Lane priority	g_t
L1	0.1	40.0	2	10.0
L1'	0.2	40.0	2	10.0
L2	850.0	30.0	4	20.0
L2'	0.1	40.0	1	10.0

Results in tables 5.0 – 8.0 above show that for a specific phase cycle. It could be observed that as a specific set of lanes is made to flow, the priority for those set of lanes reduces, thereby reducing the congestion, and consequently the average waiting duration of vehicles. By comparing the relationship between the average vehicle wait time for different lanes at different traffic phases, the graph for even distribution of traffic condition is obtained and shown in figure 4.0.

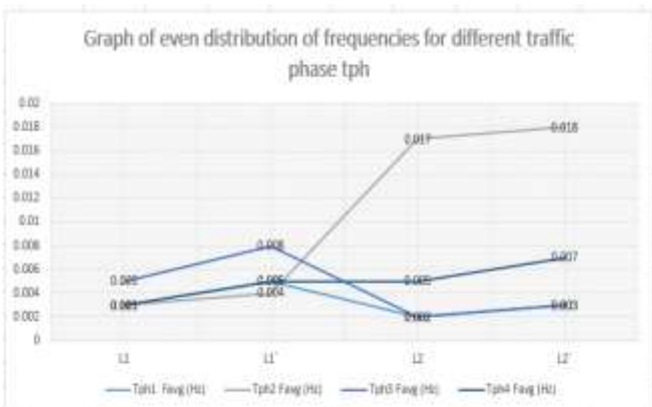

Figure 4.0: Even distribution of traffic condition for different traffic phases.

From the diagram, it is observed that though there was a sharp increase in the frequency of the third lane L2 at the second phase of tph2, it could be seen that there was a relative drop in the frequency in the next phase. This is relative to other lanes. Hence, if the results are extrapolated, the average wait time for the various lanes will all converge at a point, forming a straight line. This clearly indicates that vehicles in the lanes will all be moving at the same flow rate and waiting time, thereby maintaining a state of equilibrium in the traffic situation of the road.

V. CONCLUSION

In conclusion, the CDS Photoresistor has been applied in the development of an intelligent road traffic signal control system in this research. As an inexpensive material, the CDS Photoresistor – developed traffic signal control has shown to have a better performance than the conventional system which is based on static allocation of flow duration (as well as wait duration) to traffic lanes for each traffic phase. In the developed prototype system, even traffic condition was achieved across the road lanes for a particular traffic cycle or set of cycles. This is attributed to the incorporation of sensing mechanisms into the system as well as the adoption of fuzzy logic technique in the analysis and programming of the prototype system which as a matter of consequence, facilitated artificial intelligence in the system. Considering the inexpensive nature of materials used, and the ease of development by virtue of applying object-oriented system analysis, the developed prototype system is ideal for use in countries that are underdeveloped or developing.

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