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Design and Implementation of Intelligent Traffic Control System using Programmable Logic Controller

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ORIGINAL RESEARCH ARTICLE

Abstract- Generally, traffic light systems are regarded as open loop control systems, that is, they are in continuous operation without any form of feedback that can help the system take a decision based on certain conditions. And so, this is specifically part of the reason why there exist high vehicular densities at roundabouts. Having considered in providing a solution to this problem, this project integrated a 4I/O Programmable Logic Controller (PLC) into the traffic light system circuitry which provided feedback based on signals received from the input sensors connected to the PLC. When these sensors get energized due to the presence of a vehicle, it sends an ON-bit signal to the PLC through the input port terminating the sensor and the PLC. This signal in turn triggers the output port mapped in the microprocessor so that it energizes the Light Emitting Diodes (LEDs). During simulation, two forms of control were used: Primary (default) and Secondary control systems. On the secondary control, the PLC receives signal from the ultrasonic sensor on road tracks A and B then allows long queued vehicles to pass while it stops vehicular movement on road track C and D and vice versa. It is identified that this method of traffic light control has helped to ensure orderliness and evenly distributed vehicular flow at case study roundabout.

Keywords- Control, Traffic, Programmable Logic Controller, Simulation

1 Introduction

The rapid development of smart cities is a major focus for scientists and engineers due to the need to improve the safety of human lives and create conveniences for the large rural to urban human flow. Highly concerning are the hazards posed to on-road commuters owing to road traffic jam. This traffic congestion generates more problems that impact negatively on humans such as time wastage, fuel burn, exhaust fume, etc. which contributes to an increased cost of living for inhabitants of the town (Schrank, Lomax, and Eisele, 2011). More so, human productivity is reduced because of the less mobility of vehicle users. Based on global traffic parameters, it is evident that traffic jam hinders vehicle users' mobility, particularly in developing communities, regardless of traffic lights being used to control the motion of these vehicles.

Over time, various road traffic management systems have either been proposed or implemented especially dating back to 1868 (Day and McNeil, 1998). Ever since technologies have made improvements in finding ways of utilizing applications that will aid road management in cities that there is no need for road traffic wardens and officers; with numerous innovations, there are now changes to the style of signs and indicators but the operational principle of the road traffic control has not changed.

The traffic signals have so far not impacted positively on our Nigerian roads because traffic jams are still obvious on our major junctions. This is specifically due to existing fixed-time traffic signals that do not align with the ever-changing traffic patterns.

Adaptive traffic control represents a clear edge over the conventional one and looks to be the next promising solution to the road congestion problem (Cai et al, 2009). Due to its importance, various researchers all over the world have been coming up with different findings that can help improve the traffic light control technology. Ghazal et al (2016), integrates an XBee wireless system for a secured communication between controllers that can activate a lengthy ON mode for the green light until all the queued vehicles have passed. The superiority of Dynamic Phase Scheduling of a road traffic system was considered by Zachariah et al (2017) over Static Phase Scheduling of road traffic system as a means of assigning lengthy phase durations to traffic-congested lanes and shorter phase durations to traffic-congested lanes in other to attain an automatic traffic light system. By utilizing a network mode learning software Mei et al (2017) developed a program that can simulate various traffic conditions and performs its control.

Road traffic load has key dependence on time, day, season, weather parameters and some situations that can't be deciphered (Kumari, 2017). Bottlenecks and delays are very likely if the parameters are not effectively considered. To achieve this, an intelligent road traffic control system is developed to consistently sense and monitor the road traffic situation and effect the controls embedded in it. This prediction ability of the smart system will create an optimal control so that vehicle users can as well become aware of roads with gridlocks well ahead of time and the system can be able to perform logical calculations to allow passage of vehicles on roads

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Section B- ELECTRICAL/ COMPUTER ENGINEERING & RELATED SCIENCES
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with the highest densities while stopping vehicular mobility on the roads with very fewer densities.

This work considers the application of an effective and adaptable road traffic control system at roundabouts with dual lanes. Considering the high rate of road accidents at crossroads, this option of road traffic control will be suitable and more convenient. In this work, the Programmable Logic Controller (PLC) will perform the function of secondary control and play a pivotal role in automatically controlling the traffic light. And so, the ultrasonic infrared sensor will send a signal to the PLC and relative to the embedded software program it will energize the LEDs being the output devices. The main devices that will be utilized to execute this project are Allen Bradley MicroLogix 1000 PLC as controller, decade counter 4017 and 555 timers as timing interface and LEDs to display the output.

2 Materials and Methods

2.1 Design Methodology

The design of this work is actualized by having the Programmable Logic Controller at the centre of the system. The ladder logic is embedded in the memory storage of the PLC and gets executed when it receives instructions from the input. The input section comprises sensors that are configured to send signals to the microprocessor when energized. The microprocessor will perform a mathematical operation to interpret input signals that will generate the controlled output. The system design implementation is carried out relative to the diagram depicted in Fig. 1. The block diagram in Fig. 1 determines the interconnection and operation of every module in the system. The components of the block schematic include;

- Power supply
- Sensor devices
- Programmable Logic Controller
- Timing circuit Interface
- Traffic light indicator

2.1.1 Power Supply Circuit

The mains power supply circuit is a linear power supply system that utilizes ~240VAC at the input which is then converted to different signal power levels for the various devices. When stepped down to 24VDC, it was applied to power the PLC which in turn powers all its input and output ports with the same voltage level. The sensor is powered with a 5VDC which is gotten by stepping down the 24VDC. And the timing circuit interface was driven with a 9VDC. This was achieved by including an LM7809 IC between the output section of the PLC and the circuit so that the IC steps down the 24VDC to 9-12VDC which in turn was used to power the LEDs.
The rms voltage is 24V and the peak inverse voltage will be $\sqrt{2}V_{rms} = \sqrt{2} \times 24 = 33.94V$.

Then a rectification occurs next with the use of a full wave bridge rectifier circuit to convert the current signal from A.C. to D.C. The maximum load current and the peak inverse load were highly considered when selecting the type of diode to be used. As it should be able to withstand the peak voltage of 33.94V.

The output waveform after being rectified will look like a square waveform with all ripples removed using the capacitor. The choice of the capacitor used is based on the analysis below;

$$V_{rms} = 2.4 \times \frac{I_L}{C_1} \quad (1)$$

I_L= Load Current (20mA)
C_1= Capacitor for filter
$V_{rms} = V_{peak} \; x \sqrt{2} = 33.94 \times \sqrt{2} = 47.998V$
From equation (1)
$47.998 = 2.4 \times \frac{20mA}{C_1}$
$C_1 = 1000.04uF = 1mF$ (preferred value)

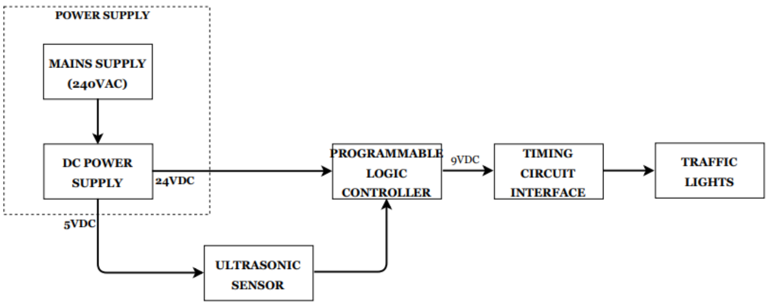

Fig. 1: Block Diagram of an Intelligent Traffic Control System Using PLC.

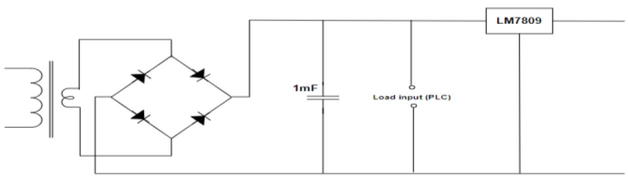

Fig. 2: Power supply circuit

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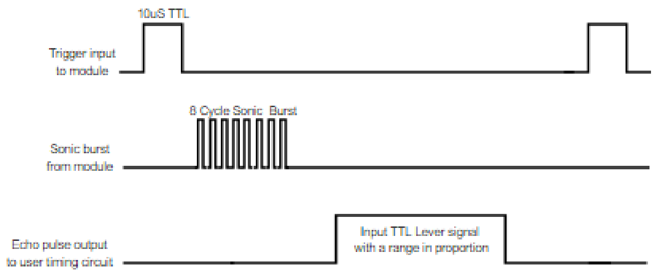

Fig. 3: Sensor Timing chart of the range finder signal

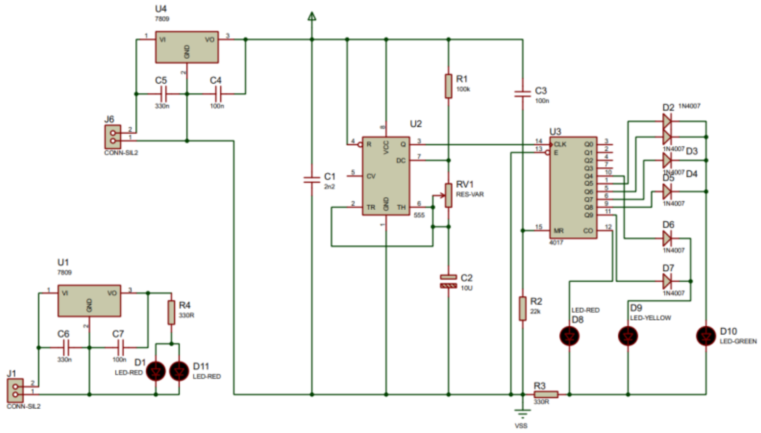

Fig. 4: Timing circuit interface with voltage regulator IC.

2.1.2 Sensor Devices

The HC-SR04 Ultrasonic sensor is used to determine input pulses for the PLC in this system operation. This sensor has a 4-pin module namely Vcc, Trig, Echo, and GND respectively. It provides a 2cm-400cm non-contact measurement function with an accurate range of 3mm (Zhmud et al, 2018). Its operation model comprises a transmitter, receiver and a control mechanism. The sensor operates with the principle of distance being relative to speed and time so that if a pulse of 10uS is applied to trigger the input. This will send an 8-cycle trigger of ultrasound frequency at 40kHz to increase its echo which is the proportion of pulse width and range.

2.1.3 Programmable Logic Controller

The choice of Allen-Bradley MicroLogix 1000 device is due to its compact size so that design complexity is reduced. More so, its built-in EEPROM memory can retain all ladder logic programs and data in a situation when the controller loses power supply and so battery back-up is eliminated. The system specifications include scan time – 10ms, preconfigured 1K data and program memory. Scan time is the time needed by a PLC to check the states of its inputs/outputs. Data memory is the capacity for data storage. Program memory is the capacity to control software. The inputs are electrically isolated from the CPU power and data bus. As it is with inputs, outputs are electrically isolated from the CPU power and the data bus. The PLC is programmed through a personal computer (Allen-Bradley, 1998).

Table 1. PLC Memory Map

File number	Type	Logical address range
0	Output image	O0:0 to O0:3
1	Input image	I0:0 to I0:3
4	Timers	T4:0 to T4:255
5	Counters	C5:0 to C5:255

2.1.4 Timing Circuit Interface

The timing interface, as shown in Fig. 4, is a combination of a power circuit, LM7809 IC that drops the power signal from the output section of the PLC from 24VDC to 9VDC to drive the circuit that will order the preset timing sequence of the three LEDs (Red → Amber → Green →Amber → Red) in a continuous state. This is achieved using the CD4017 IC, a CMOS decade counter with a five-stage Johnson counter and 10 decoded output that counts to 10 decimals and the 555 timer IC which is set in astable mode to produce pulses that depend on the timing of a resistor and a capacitor which is used on the clock input of the CD4017 IC to make the red, amber and green LEDs to glow. More so, pulses from the 555 timer IC are utilized to time glow but controlled by varying the potentiometer. The 1N4148 diodes have been used to bring stability to the signal on the LED.

2.1.5 Traffic Light Indicator

In this design project, the conventional display for a road traffic light is utilized. This is achieved by implementing three light-emitting diodes (LEDs) of 'Green', 'Amber' and 'Red'. The LEDs were connected to the diodes in a reverse position so that the LEDs conduct in a forward-

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biased condition and the diodes conduct in the reverse biased condition of the LED thereby limiting the reverse voltage to one diode drop ~0.7v then a resistor in series placed with the combination of LEDs will reduce the current. While the potentiometer controls the time deviations between each LED through the 555 IC. From the developed logical program embedded in the microcontroller of the PLC, the four tracks of the road traffic light will function in an open-loop state. But performs a secondary control when there is dense traffic.

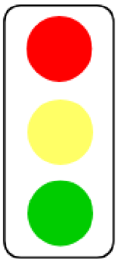

Fig. 5: Traffic light indicator

2.2 Closed-Loop Control Model

The developed closed-loop model is used to describe the feedback control mechanism in which the control action is dependent on the controlled output so that such output is compared with the reference input and a differential signal is produced (Saeed, 2013). This produced differential signal is put in the controller to remove the error and provide the output response as the desired signal.

The ultra-sonic IR sensor monitors the passage of vehicles so as to detect vehicles that have stopped for a length of time. When this happens, it measures and compares the acquired signal with the input reference. The differential signal is then used to energize the controller which then provides the controlled signal as the output based on what the final control element can deliver. Since the block diagram indicated is a linear system with input x(t) and output y(t), we can define the output/input relationship with a differential equation in nth order as

$$m_a \frac{d^a}{dt^a} y(t) + \cdots + m_1 \frac{d}{dt} y(t) + m_0 y(t) = n_b \frac{d^b}{dt^b} x(t) + \cdots + n_1 \frac{d}{dt} x(t) + n_0 x(t) \quad (2)$$

If m and n are constants, we can find the Laplace Transform of the above equation as thus;

$$m_a S^a Y(s) + \cdots + m_1 SY(s) + m_0 Y(s) = n_b S^b X(s) + \cdots + n_1 SX(s) + n_0 X(s) \quad (3)$$

$$(m_a S^a + \cdots + m_1 S + m_0)Y(s) = (n_b S^b + \cdots + n_1 S + n_0)X(s)$$

The transfer function for the closed loop system becomes;

$$G(s) = \frac{Y(s)}{X(s)} \quad (4)$$

and

$$\frac{Y(s)}{X(s)} = \frac{n_b S^b + \cdots + n_1 S + n_0}{m_a S^a + \cdots + m_1 S + m_0} \quad (5)$$

$$G(s) = \frac{Y(s)}{X(s)} = \frac{n_b S^b + \cdots + n_1 S + n_0}{m_a S^a + \cdots + m_1 S + m_0}$$

2.3 Circuit Construction and Testing

The entire system circuit was design in two steps. Firstly, based on specification the components were put together on bread board and then simulated for the required output. This circuit was further produced on a Printed Circuit Board (PCB) for efficiency. Secondly, the second step is interfacing the Programmable Logic Controller (PLC) and the personal computer.

2.3.1 Road Tracks

The standard four-way road network has been chosen for this work to satisfy the efficacy of the design project implementation. The terminal of this road network is a roundabout which represents a typical road system faced with jams and queues. The model developed for the road access is based on two control measures – open-loop control is under a normal condition where the lights a triggered to allow or stop access using a preset time while the closed-loop control energizes the system based on a monitored condition.

2.3.2 Ultrasonic Sensor on Road Layout

An ultrasonic sensor has been utilized to give feedback to the input section of the PLC at the instance when vehicular density is increased or vehicular flow is lengthy and stalled. The ultra-sonic sensor is placed by the side of the median strip 50m far from the roundabout. This is to enable effective monitoring and give sufficient dead time. The sensors will be placed facing the side of vehicles for proper transmission and reception of signals.

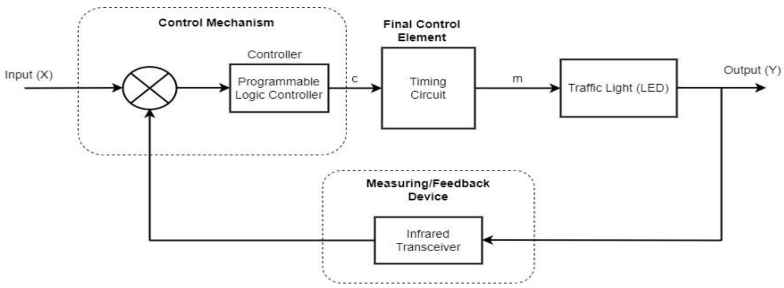

Fig. 6: Closed Loop Control Model

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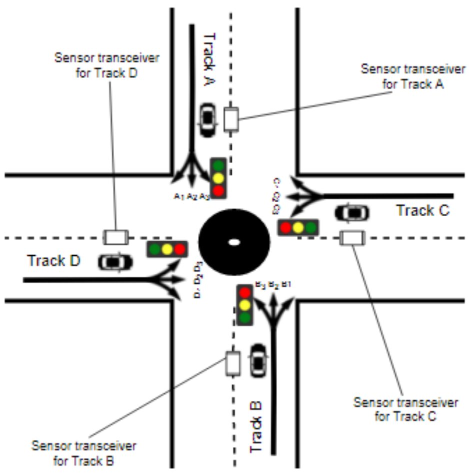

Fig. 7: Road layout with points implementation of ultrasonic sensor.

2.4 PLC Memory Operation

The flowchart depicts the internal operation of the system. When the device is initialized, the RAM and other aspects of the microprocessor come on and become obvious on the indicator lights. The input ports are scanned to read the terminated ultrasonic infrared sensor devices which are then stored in a specific memory destination. The variables' values are then taken to be utilized and the results are returned to the memory (Chen, 2005).

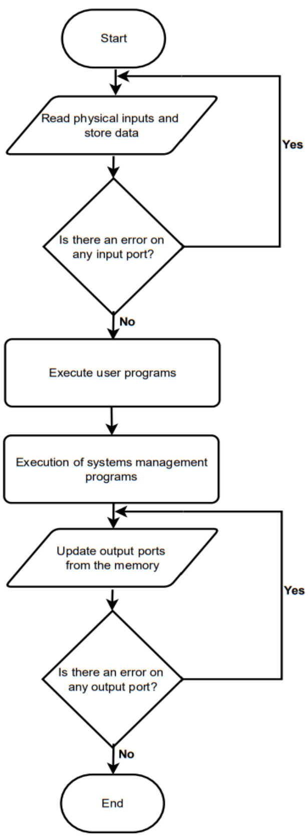

Fig. 8: Flow chart of PLC memory operation.

The memory is diagnosed so that the device is void of all forms of error. The output ports interfacing with the timing circuit is thereby updated with the stored data from the system memory.

2.5 Principles

The conventional road traffic light system works relative to the principle of an open-loop system. The open-loop system which is also the primary control operates to time and is not capable of self-control which means it can't derive the desired output relative to a feedback function. The secondary control parameter has been designed to run on the primary control so depending on the signal from the feedback system, it overrides the open-loop control and has the closed-loop control actuated for only one cycle of output. This will continue while allowing other tracks to continue in their normal states.

2.6 Program Testing

The signal going through the output ports with the following addresses O:0/0, O:0/1, O:0/2 and O:0/3 controls the road traffic light indicator on each road track. While some of the input ports as well are terminated with the ultrasonic infrared sensor on each road track with port addresses I:0/0, I:0/1, I:0/2 and I:0/3 respectively. Output ports O:0/0 and O:0/1 will be controlled by the input port I:0/1 and the output ports O:0/2 and O:0/3 will be controlled by the input port O:0/2. The control program will be highly influenced with the aid of timer bits. The input switches with addresses I:0/1 and I:0/2 represents the sensors for each port for the opposite road tracks.

The road tracks are labelled A1, A2, A3 for track A; B1, B2, B3 for track B; C1, C2, C3 for track C and D1, D2, and D3 for track D are utilized to signify the number of directions each track leads. For tracks A and B, their sensor switches are aligned with the I:0/1 address and tracks C and D are aligned with the I:0/2 address.

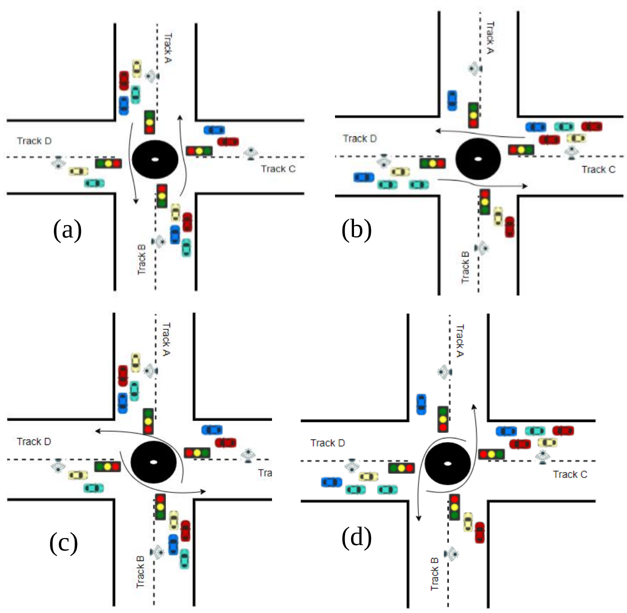

Fig. 9: Sensor position and four road track configurations.

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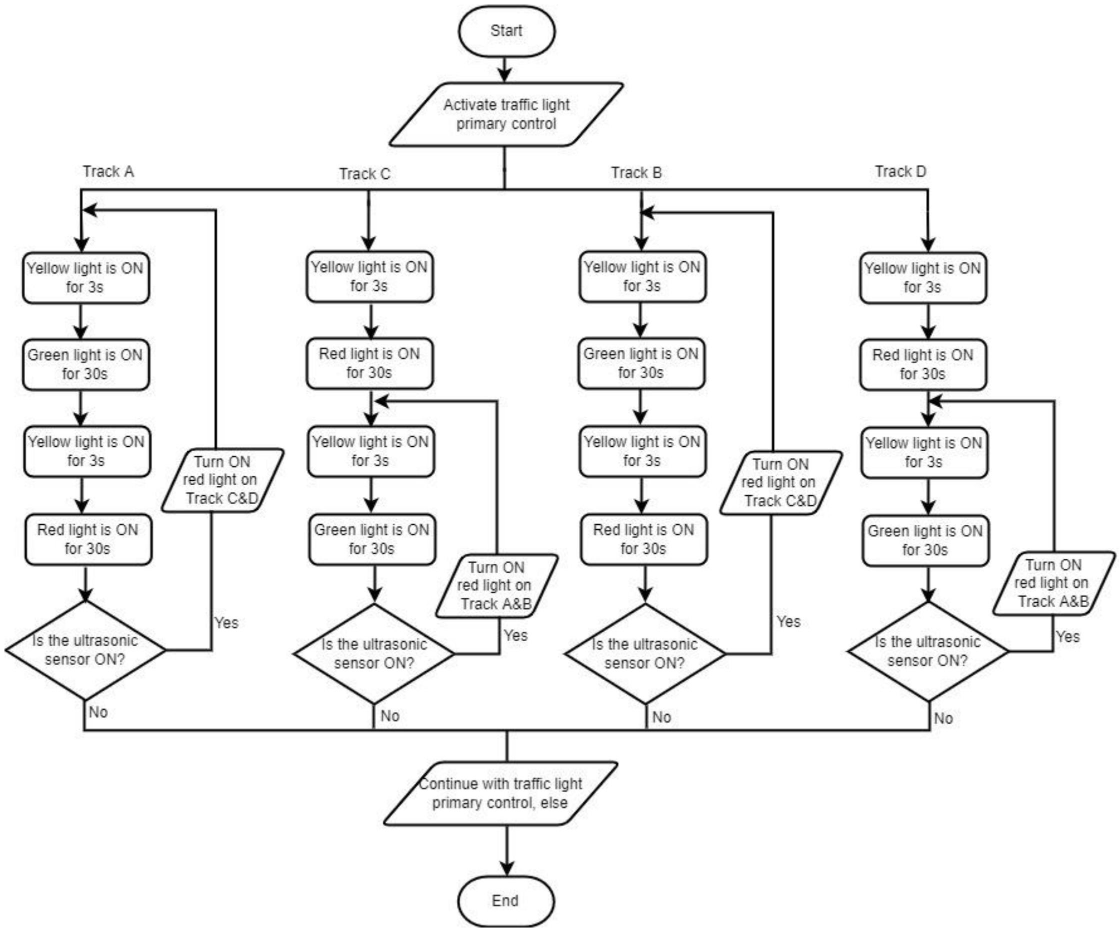

Fig. 10: Flowchart for the PLC based traffic light control.

3 Results and Discussion

When the device is energized from the start, the states of the sensors and the input ports where they are terminated are used to update the output ports on the PLC as it relates to the downloaded logic program stored in the memory section of the microprocessor. Then the system commences its default traffic operation by taking turns based on a preset time. This will continue until the level of any sensor switches to a high state and at once the road traffic lights on the road track with its sensor having a high state turns green and stays so until its preset duration has elapsed while the other road tracks stay low and eventually returns to normal state.

The design setup developed in this paper demonstrates the implementation of a programmable Logic Controller (PLC) on a road traffic system. This design combines the functionality of an input or feedback system (Ultra-sonic IR sensor), the process or controller (PLC) and the output system (indicator lights). The input detects the vehicular flow and density measures it with its set point parameter and takes a decision whether to adjust if there is a deviation or to maintain the continuous flow of signal that aligns with the setpoint for the desired output. Once there is a deviation from the setpoint i.e., the input sensor has now detected traffic congestion, the PLC processes the new input signal in its microprocessor and turns the colour of the congested lanes to green while the other less congested lanes will keep the red lights on until a set time has elapsed. This process has been programmed to continue as long as the lane remains congested.

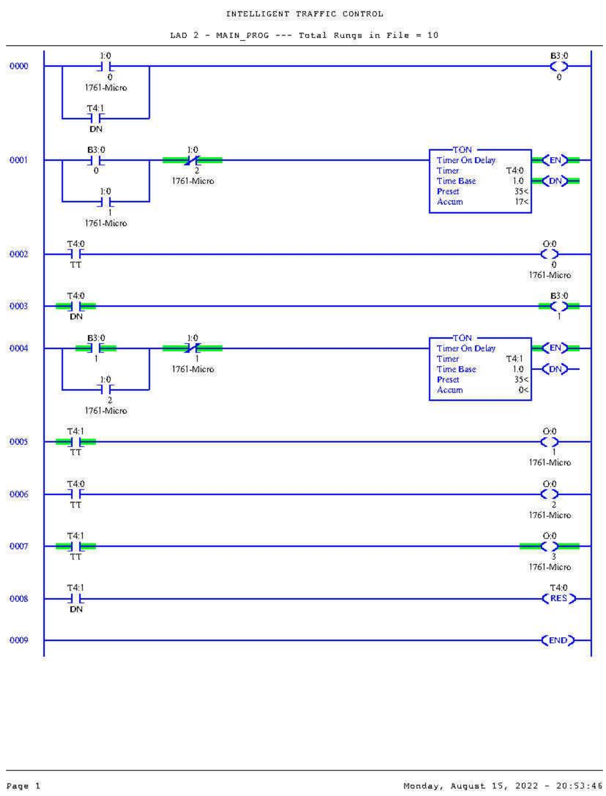

Fig. 11: Software ladder logic program on RSLogix micro

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4 CONCLUSION

This project work tried to contribute to the numerous evolving research work on an automated traffic light to reduce road traffic on busy roundabouts. More so, this project work has successfully offered an alternative way of effectively controlling traffic at roundabouts using a 4-I/O Programmable Logic Controller (PLC) and an Ultrasonic IR sensor. The timing circuit has helped to reduce the number of I/O ports that could be used by the system thereby reducing cost and increasing efficiency. The software specifically has made the programming of the system robust so that the design can be flexible and adaptable to any kind of roundabout. Further improvement of this project design can be done seamlessly with the addition of cameras and artificial intelligence for monitoring, detection, and capturing of vehicle detail analysis.

REFERENCES

Allen-Bradley (2015). MicroLogix 1000 Programmable Controllers *User Manual* (Bulletin 1761 Controllers), (pp. 1-12, 6-3 – 6-11). Retrieved September 20, 2021, from https://literature.rockwellautomation.com/idc/groups/literature/documents/um/1761-um003_-en-p.pdf

Babangida Zachariah, Peter Ayuba and Luhityit Damuut (2017), Optimization of Traffic Light Control System of an Intersection using Fuzzy Inference System, *Science World Journal*, vol. 12, No. 4, pp. 27-33.

Bilal Ghazal, Khaled ElKhatib, Khaled Chahine and Mohamad Kherfan (2016), *Smart Traffic Light Control System:* Vol. 3. (pp. 161-166). International Conference on Electrical, Electronics, Computer Engineering and Their Applications.

Cai Chen, Hengst Bernard, Ye Getian, Huang Enyang, Wang Yang. Aydos Carlos and Geers Gleen (2009). *On the performance of adaptive traffic signal control* (pp. 37-43). Proceedings of the Second International Workshop on Computational Transportation Science. Seattle: ACM SIGSPATIAL International Workshop on Computational Transportation Science.

Chen Mi (2005), *"Design and Implementation of a Networked Control System* (pp. 16-23). Unpublished master's thesis submitted to the Graduate School of Technology, Eastern Illinois University Charleston, Illinois.

Day Lance and McNeil Ian (1998) *Biographical dictionary of the history of technology*, Milton Park, Oxfordshire: Routledge Taylor & Francis.

Kumari Smita and Kumari Seema (2017) Traffic Control System using PLC. *International Journal of Engineering and computing*, vol. 7, No. 4, pp. 9978-9981.

Lin Mei, Zhang Lijian and Wang Lingling (2017), *Intelligent Traffic Light Based on PLC Control*. Vol. 94, pp. 4. IOP Conference Series: Earth and Environmental Science. Binzhou Polytechnic: IOP Publishing.

Saeed Hassan (2013) *Automatic Control Systems (with MatLab Programs)* (pp. 1-3). New Delhi, Delhi 110002, India S. K. Kataria Sons publishers. Seventh Revised Edition.

Schrank David, Lomax Tim and Eisele Bill (2011). *TTI's 2011 Urban Mobility Report*, Report no. 2. Texas Transport Institute, The Texas A&M University, University Transportation Center for Mobility.

Zhmud Vadim, Kondratiev N., Kuznetsov K., and Trubin V., (2018) *Application of Ultrasonic Sensor for Measuring Distances in Robotics* IOP Conf. Series: Journal of Physics: Conf. Series 1015 (2018) 032189, Novosibirsk State Technical University

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