

RESEARCH ARTICLE

Development of Arduino Based Intelligent Traffic Control System for Intersections in Akure, Nigeria

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ABSTRACT

Traffic congestion at urban intersections remains a major challenge, causing delays, fuel waste, economic losses, and environmental pollution. Conventional traffic control systems are limited by fixed signal timing and their inability to adapt to real-time traffic demand. This study proposes an Arduino-based Intelligent Traffic Control System (ITCS) that integrates infrared sensors with Arduino Uno microcontroller to detect actual vehicle flow and adaptively allocate right of way. Applied to the Araromi intersection, simulation results showed that the ITCS introduced two key innovations of gapping out and maxing out. Unnecessary delays on low-demand approaches during off-peak periods were eliminated, while green times were extended till maximum only when queued vehicles were detected during peak hours. These features ensured efficient traffic discharge and reduced congestion. The optimized signal cycle was 80 seconds, with the main street (east-west approaches) operating on green, red, and amber times of 40, 35, and 5 seconds, respectively, while the minor street (north approach) operated on 30, 45, and 5 seconds, respectively. The findings indicated that reducing unnecessary waiting times significantly lowers fuel consumption, emissions, and economic costs. Moreover, cost analysis revealed that the ITCS can be implemented with a low budget, making it scalable for other intersections and adaptable to developing countries. By combining affordability, adaptability, and environmentally friendly operation, the proposed ITCS offers a practical and innovative solution for improving urban traffic management.

Keywords: Intelligent Traffic Control System, Microcontroller, Arduino, Infrared Sensors, Traffic Congestion, Environmental Pollution

INTRODUCTION

Transportation is essential to human existence and sustainable growth, yet it is often faced with several difficulties, such as traffic congestion, queue spillover, delay and jams, that are critical at intersections. These challenges result in time wastage, noise pollution, higher fuel consumption, greenhouse gas emissions and economic implications [1,2]. These adverse consequences are particularly

severe in developing nations like Nigeria. Even though major efforts had been made to expand capacity and upgrade the metropolitan road networks, the persistent congestion levels in cities as a result of urbanization and increased socioeconomic growth, suggests corresponding efficient traffic control systems that transcend concrete, steel and traditional methods [3]. Therefore, addressing urban traffic challenges requires not only infrastructural expansion but also intelligent, adaptive control systems that can respond dynamically to changing traffic conditions.

Commonly, vehicle-actuated traffic signals and pretimed traffic signals are the two types of traffic signals situated at signalized intersections [4,5]. The use of pretimed traffic control systems had also augmented the problems of congestion and delay due to its rigid nature, insensitivity to real-time traffic situations and the inability to adjust to changing traffic situations during peak and off-peak hours [6,7]. These limitations underscore the necessity for intelligent traffic control systems (ITCS) that incorporate detection systems to accommodate the variability of real-time traffic conditions at intersections [8].

In Nigeria, limited attempts have been made to introduce ITCS at intersections, but research tailored to local traffic condition remain scarce. In the case of Akure, assessment of traffic situations had been largely conducted, however, only few studies have focused on developing intelligent traffic control systems to fit the traffic experiences at these intersections. Consequently, most intersections continue to operate at a low level of service, highlighting the urgent need for effective traffic control systems [5, 9-14].

Camera-based detection system has been proposed, particularly in Akure, where real-time image data were used with Python-programmed algorithms for vehicle detection and counting. This approach highlights the potential of vision-based solutions to reduce delays and congestion [15]. Also, sensor-based systems using infrared, ultrasonic and piezoelectric sensors integrated with microcontrollers have been explored for some locations in Nigeria [16-20]. These designs attempted to adjust signal timing dynamically based on vehicle density, showing promise for peak-hour management.

While these efforts demonstrate the potential of sensor-based systems, they remain unable to provide a sustainable solution across multiple unsignalized intersections. More importantly, existing studies have not adequately addressed the challenge of scalability, affordability, and adaptability to local traffic conditions differ at various intersections. Consequently, Akure and other cities currently lack effective ITCS capable of dynamically managing real-time traffic demands at intersections.

Therefore, an adaptive ITCS that flexibly allocate signals to the vehicles on a real time basis is developed for Araromi intersection, Akure, Nigeria. This proposed system is cost effective and expandable on a large scale for applications at other intersections in Akure and urban areas of developing countries with little resources. This research work seeks to provide a sustainable solution to the problem of traffic congestion, time loss, economic loss, pollution, emissions and

safety. The proposed ITCS is expected to contribute to sustainable development goals (SDG) 9.1, 11.2, and 11.6 by promoting resilient infrastructure, enhancing traffic safety through adaptive control, and reducing vehicular emissions to enhance urban air quality.

MATERIALS AND METHODS

MATERIALS

Materials for this research work include electrical components and materials that were procured locally within Akure, Nigeria.

- **Microcontroller:** Arduino Uno microcontroller features ATmega 328P microchip with digital and analogue input/output pins for intergation with other components. Arduino also provides an integrated development environment (IDE) that operates on a computer, used to write and upload computer code to the physical board. The Arduino mega board is powered via USB connection or with an external power.
- **IR (Infrared) Sensor:** The IR sensor is an electrical device that detects specific parameters of its environment by creating or recognizing radiations. It detects motion as well as measure the thermal signature of an object. An IR sensor consists of a transmitter and receiver, where the transmitter consistently sends out infrared beams for the receiver to pick up.
- **Liquid Crystal Display (LCD):** LCD is a screen that employ liquid crystal technology for visual output. The liquid crystal display shows the number of vehicles counted by the IR sensor and other information as programmed.
- **Light emitting diodes (LEDs):** LEDs produces light when electrons recombine with holes in the semiconductor, releasing energy as photons. The traffic signal indicator features three LEDs, each with with red, yellow, and green colors.
- **Other electrical components:** Other electrical compoments include resistors, capacitors, jumper wires, breadboard, Veroboard and battery. The resistors were used to limit the flow of current through components and the circuit. A capacitor holds electrical potential in the field created between its plates. Jumper wires were used to connect the various components into a circuit. The circuit is powered with an Arduino power cord and a 6V battery.
- **Modelling materials:** Strawboard, grass effect, plywood, road effect, emboss card, top bond, walkway, trees and toy cars were the materials used in modeling the intersection geometry.
- **Software and Coding:** The IDE is a computer-based application that allows creating and uploading code written in C++. It provides a code editor offering functions like colored syntax, paired braces, and automatic structuring.

SYSTEM DESIGN

The block diagram of the intelligent traffic control system is shown in Figure 1(a). Before transferring to Vero board, the circuit was connected on a breadboard in order to effectively adjust, accommodate and implement change in the connections as shown in Figure 1(b). The entire components were connected to the Arduino Uno micro controller which acts as the brain of the system. It interacts with the IR sensor through the input pins and processes the input of vehicle detection to give the output as signal through the corresponding LEDs at the output pins of that IR sensor. The entire system was powered through the power input of the Arduino, while the power is indirectly distributed to other components.

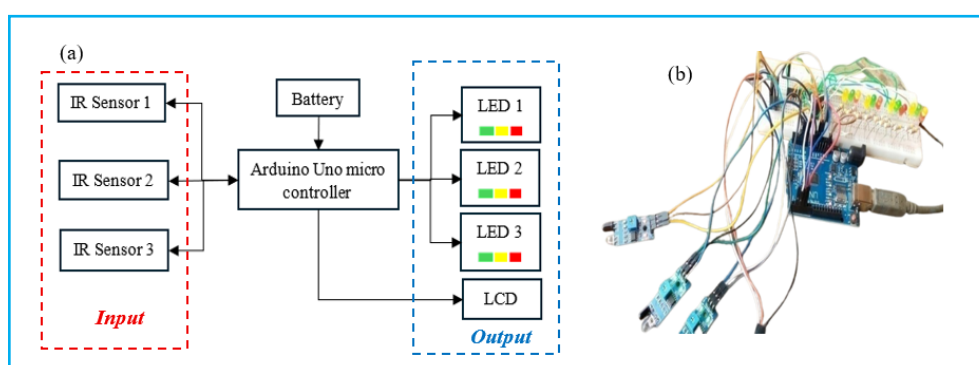


Figure 1. System design: (a) block diagram; (b) Connected circuit



Figure 2. Araromi intersection in Akure Nigeria

STUDY AREA

The intersection under consideration is a three legged at-grade intersection along the popular Oba Adesida dual carriage way, linking Cathedral area to the west and the main market to the East. Araromi intersection in Figure 2 is on latitude $7^{\circ}15'16.4''\text{N}$ and longitude $5^{\circ}11'34.9''\text{E}$. Araromi intersection had moved from being a signalized intersection to being unsignalized, due to the defective pretimed traffic control system at the spot. Due to its at-grade nature, drivers chose the right of way on their own which many times led to conflict in traffic. Also, drivers intending to go left-turning take too much time

in finding acceptable gap in the conflicting traffic, but builds up long delay time and long queue. However, in recent times, the guidance of traffic wardens at the location helped in controlling traffic but also leading to delay associated with human preference and precedence of right of way. Moreso, in the evening, traffic congestion begins to set in due to low visibility and traffic conflict overwhelming human ability.

OPERATION OF ITCS

The circuit was integrated with the developed physical model. IR sensors provide the micro controller with real time traffic data through the input pin. The Arduino Uno micro controller processes the real time data received from the sensors, by executing the program written in programming language “C++” and already uploaded to the Arduino board through the Universal Serial Bus (USB) and the IDE software. The Arduino processes this input and the information from the processed real time data is sent by the micro controller to the corresponding LEDs connected to the output pin of the microcontroller. Signal from LEDs serve as indications of right of way to the direction corresponding to the detected vehicles. Data is also displayed through the LCD connected to the output pin of the microcontroller.

SYSTEM FLOWCHART

The flowchart of the ITCS operation is presented in Figure 3. The process begins with all lanes on red to ensure safety before traffic flow is initiated. Once a vehicle is detected, the system grants right of way by switching to a green indication. During this green phase, the system continuously monitors for the presence of vehicles. If no vehicle is detected, the signal gaps out, thereby avoiding wasted green time. However, if vehicles remain present, the green indication is maintained until the maximum permissible green time is reached. At this point, the system maxes out and terminates the green phase even if vehicles are still detected, ensuring fairness across all lanes. This adaptive control mechanism enables efficient traffic flow management by balancing real-time demand responsiveness with safety and cycle time constraints.

MEASURED PARAMETERS

- **Response time:** This is the time taken for each sensor to detect vehicles at its approach and request for service. This was measured as the time taken for the sensors to indicate double lights and change the LEDs indication to amber.
- **Green interval:** The ITCS produces three traffic light colors (green, amber, and red) known as indications from the aspects (LEDs). The green interval is the duration given to vehicles in a phase to move through the intersection. This was gotten by setting a stop watch, the moment the traffic signal changes from amber to green indication, and the stop watch was stopped immediately the traffic signal changes to red light.
- **Amber interval:** This is the yellow transition interval between the termination of a green indication and launching of a red indication on the

traffic signal. This is referred to as the clearance amber, as it helps the traffic near the stop line to clear and get ready for the next indication of green or red.

- Red interval: This is the duration of red indication to stop all conflicting traffic when an approach is given the right of way.
- Cycle length: This is time taken for a complete rotation around all the intervals (green, amber, and red) in a phase.

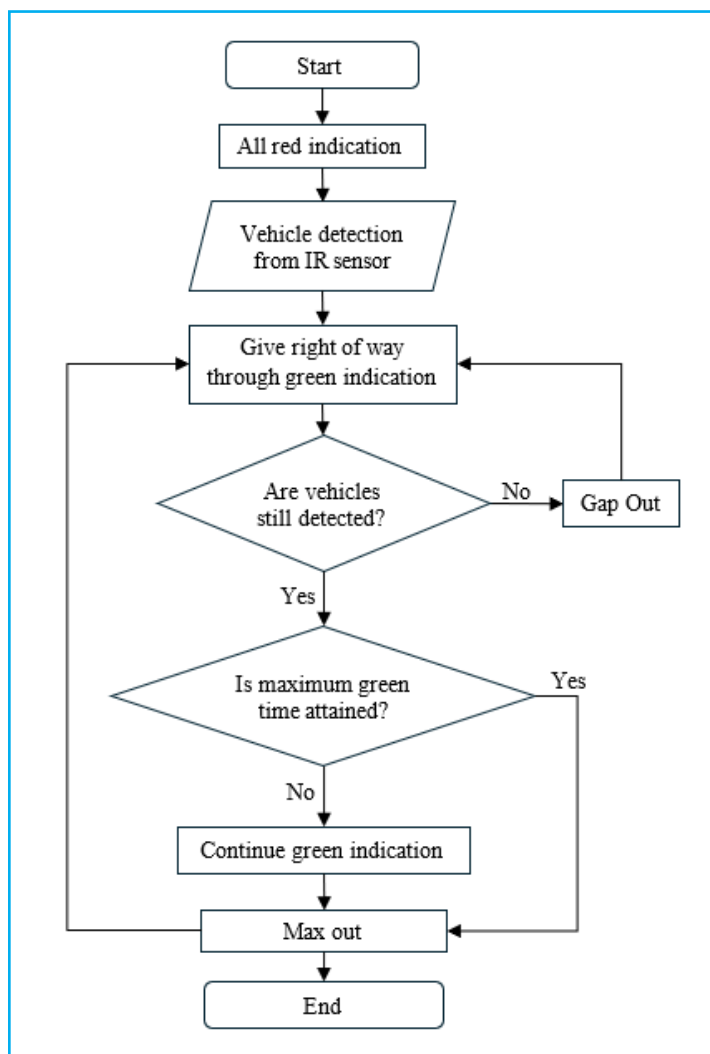


Figure 3. ITCS flow chart

RESULTS AND DISCUSSION

THE DEVELOPED INTELLIGENT TRAFFIC CONTROL SYSTEM

The developed ITCS system is presented and labelled in Figure 4. The developed system consists of three IR sensors, three signal face, Arduino, LCD, battery and toy cars for simulation. The signal face with hanging LEDs were directed to incoming vehicles for easy sighting of the traffic signals. Each traffic signal on the model is placed directly opposite the sensor they are working with in such a way that it is visible to the driver using the leg. Infrared sensors are placed at a specific distance away from the intersection to detect the motion

of vehicles. The directions of traffic movements were also delineated with pavement markings. The major street being a dual carriage way with a greater traffic volume, and larger section with higher functional class was indicated to be at the East and west of the intersection. Whereas, the minor street with the less traffic volume and smaller cross section was the North of the intersection. Accelerating and decelerating lanes provides drivers with an opportunity to speed up and slow down, respectively. The aforementioned lanes were not controlled with indicators, for they allow free merging of vehicles. The enclosed housing for Arduino uno micro controller is exposed in Figure 5. The ITCS can be powered on or off, and reset by pressing those buttons.

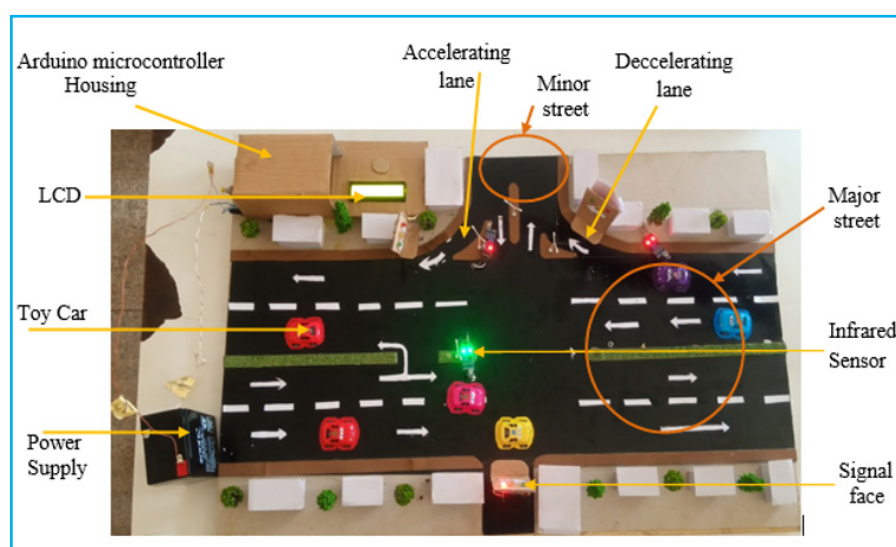


Figure 4. The Built-up model of the Intelligent Traffic Control System

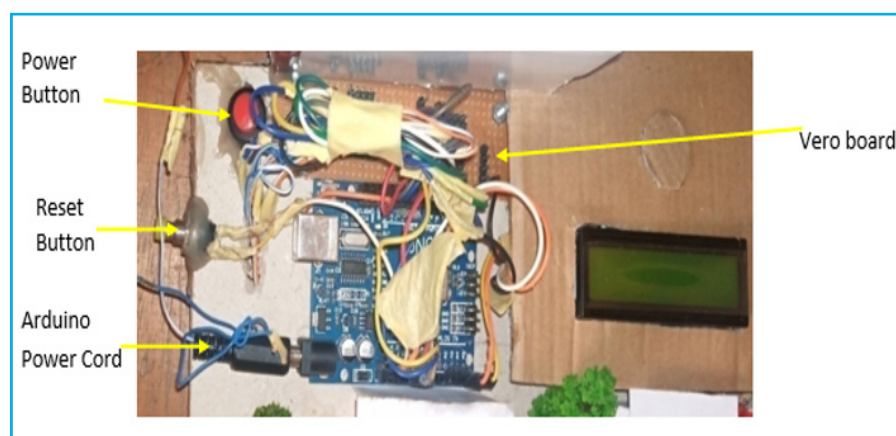


Figure 5. The interior view of the arduino housing

TRAFFIC CHANNELIZATION AT THE INTERSECTION

Figure 6 shows the separation and regulation of conflicting traffic into definite paths of movement by using ITCS to order vehicular movements on the developed model based on the intersection geometry. The path A is the eastbound through movement, B is the eastbound left turn movement, E is the westbound through movement, and H is the south bound left turn movement. Paths C and F are

U-turns, while paths D and G freely have the right of way at all times as they are not under control. Any of the opposing traffic among A, B, E and H are stopped with the red indication when any of them is given the right of way by the green indication. The brown colored block arrows are the positioning of IR sensors on the model. The LEDs are positioned in front of the A, B, E and H movements for clear visibility. Whenever, the green LED for a left turning movement is on, the other conflicting traffic gets red LED light to stop. The traffic channels are grouped into three phases, which are west approach (A, B, C), east approach (D, E, F) and north approach (H). Whenever one of these phases gets the green signal for the right of way, the other two phases get to be stopped with the red signal.

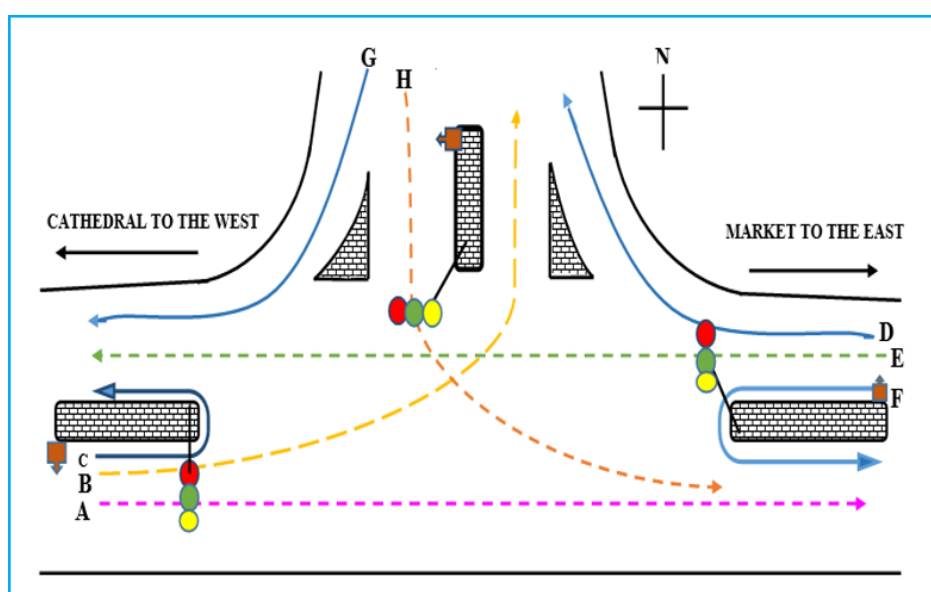


Figure 6. Channeling traffic using ITCS

PERFORMED SIMULATION ON THE DEVELOPED SYSTEM

When the power button is switched on, lights are produced by the sensors, LCD and LEDs as shown in Figure 7(a) and Figure 8. On powering up the system, all LEDs indicated “RED” by default, while the sensors produced single color light which may be red or green. These lights only indicate that the sensor is being powered, and must not be confused with the signal lights on the LEDs. The single green light in Figure 7(a) and Figure 8 was produced by the sensor, while the red light was the LEDs signal. The default indication of red lights on the LEDs on all legs indicated that the system is yet to take a decision, as no vehicle is detected yet by the sensors. On detecting vehicles as shown in Figure 7(b), the sensors put up two colors to signify detection. In this case, the sensors displayed double green colors on detecting the vehicle on the eastbound left turn movement B. On detecting this vehicle, the LED signal changed to amber as shown in Figure 7(c), and then changed to green as shown in Figure 7(d). As the right of way was given to the west approach, other conflicting traffic received a red indication.

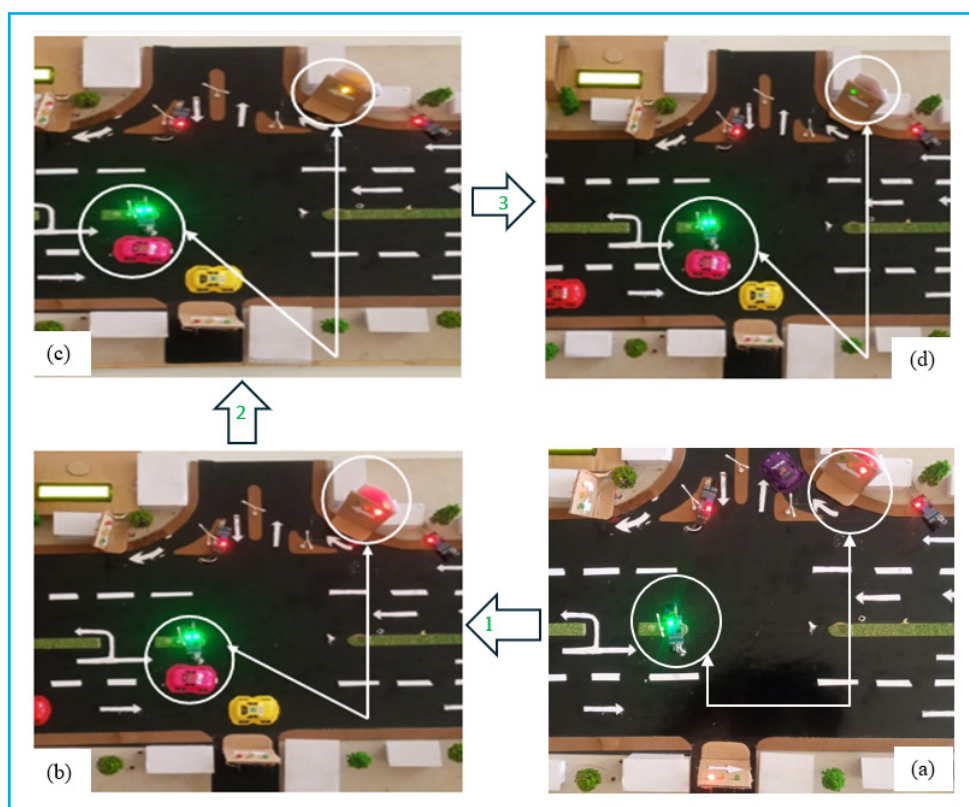


Figure 7. Physical simulation showing the changing of sensors lights and traffic lights

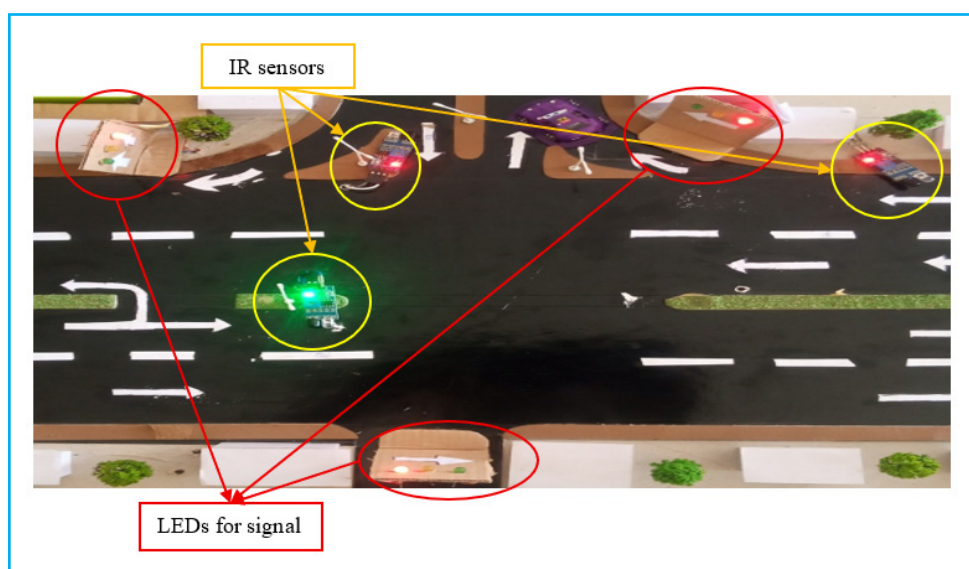


Figure 8. ITCS on powering without detected vehicles (all sensors with single light and traffic light showing all red)

SCENARIO-BASED SIMULATION RESULTS

- Scenario 1: When no vehicle is detected on one leg of the intersection as presented in Figure 9, the ITCS continues to pass vehicles on the approaches with vehicles until vehicles are detected on other legs, then it terminates the right of way for the current approach, while it discharges other legs following this same procedure as shown in Figure 7.

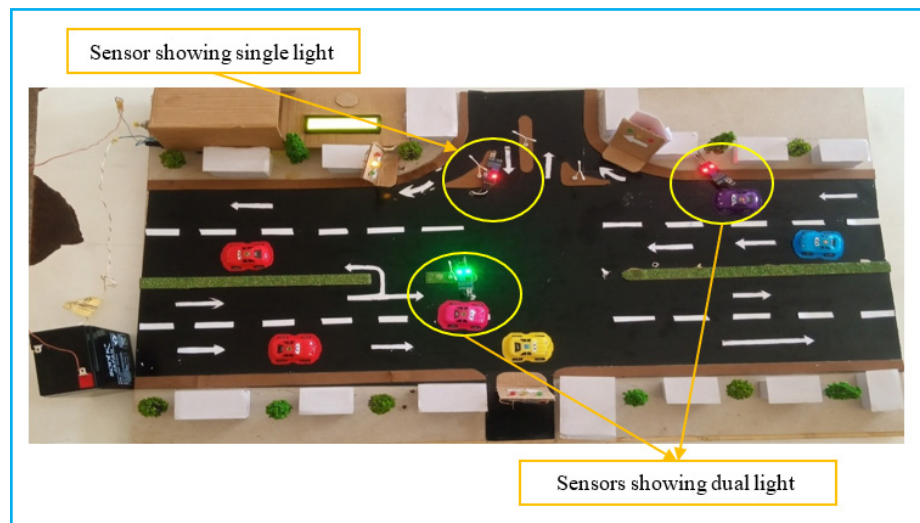


Figure 9. Two sensors detecting vehicles (only two sensors showing dual light)

- Scenario 2: In the case of peak hours where the three sensors are continuously detecting vehicles from all legs as shown in Figure 10, the ITCS discharges each approach and max out at its maximum allowed green time for each leg in order to serve others. This is because the micro controller recognizes that the green light should be switched to another phase due to queued traffic on other legs waiting to be discharged, as a result of the real-time traffic data received from the sensors which indicated the presence of vehicles.

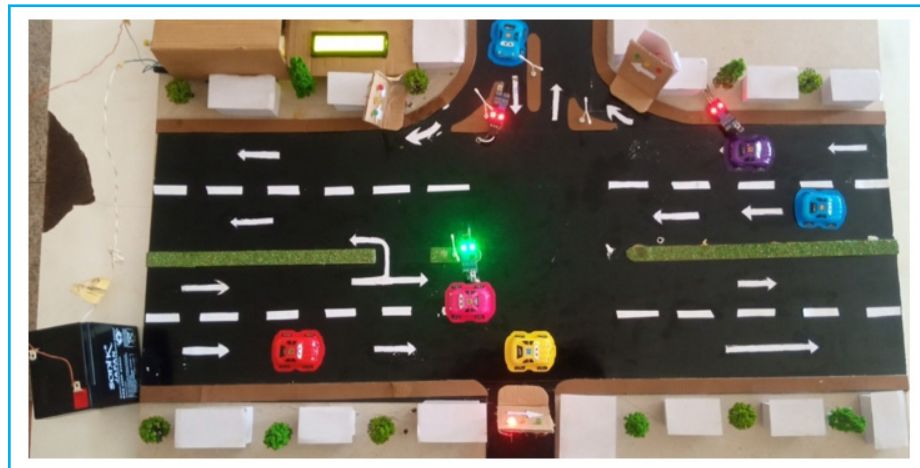


Figure 10. All sensors detecting vehicles (all sensors showing dual light)

- Scenario 3: In the case of off-peak hours where the sensors detect few vehicles on some legs, the ITCS discharge each legs and gaps out to terminates green time early due to a lack of continuous traffic demand. The microcontroller knows that the green light needs to be changed to a different phase because there are no more vehicles in the present phase to justify the continuous green time, since vehicles are not detected by the sensors on this particular approach.

Conclusively, if the sensor on a particular approach keeps sensing vehicles and the sensors on other approaches do not, the micro controller will keep giving the right of way to the approach with vehicles until the other sensors senses vehicle, it then maxes out. This is very effective and efficient during off peak hours where there is little or no vehicles at a particular road leg (Figure 9), so the ITCS gives priority to the road leg with detected vehicles. Also, the ITCS is effective and efficient during peak hours by giving the right of way to all the approaches with queued vehicles through maxing out on each leg after attaining the maximum green times.

In comparison with existing literature, the features of gapping out and maxing out on lanes that this work presents, outperforms the processing algorithm used in [16-20], as the possibilities of longer green times at dense lanes are eliminated to serve other lanes with detected vehicles. Also, this system detects vehicles in darkness, which is an improvement over the computer vision used in [15] that may have impaired vision at night. Therefore, this ITCS reduces the unnecessary waiting time of vehicles at signalized intersection during off-peak and peak hours. By the virtue of connecting the main market and the central business district, fuel consumption, pollutions, emissions and economic loses can also be reduced.

MEASURED PARAMETERS

Response time: Results from the measurement of the infrared sensors responsive time presented in Figure 11 showed that the infrared sensor was highly responsive. Practically, it took almost immediately for the sensors to send the real time traffic data to the micro controller, which was an average of 11 centiseconds.

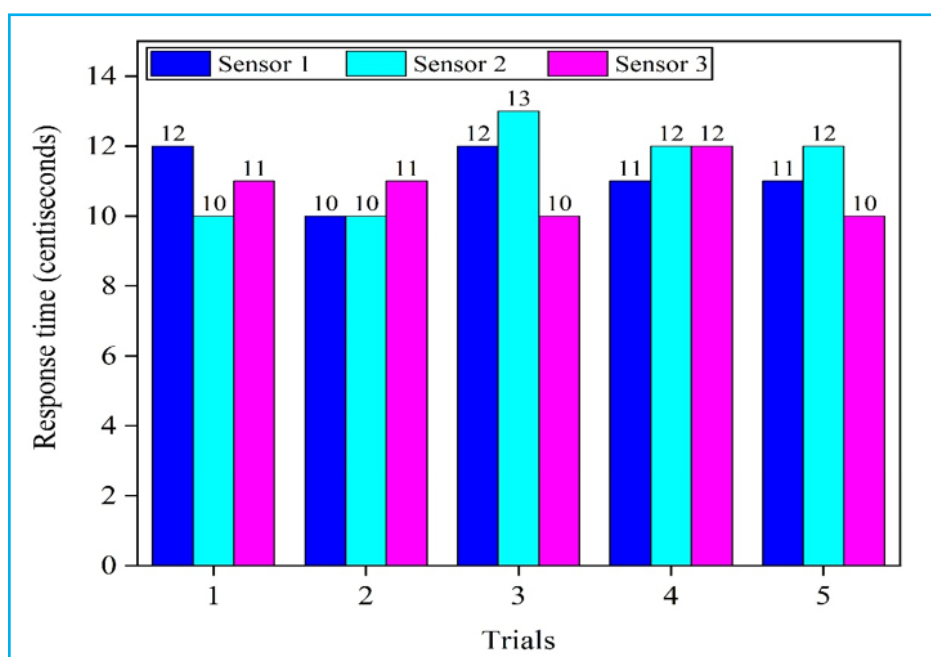


Figure 11. Sensor response time

Intervals and cycle length: Signal timing design showing the indications interval and cycle length are presented in Figure 12. The main street approaches (east and west) had maximum 40 s green time for traffic clearance. The green time could be shorter when the ITCS gaps out due to undetected vehicle on the present approach. The red interval was 35 s, which is the minimum stopping time when conflicting traffic were being discharged. The red timing could be more when the ITCS decides to discharge more than one phase. For the minor street, the north approach was 30 s for maximum green interval which could either max out due to detected vehicles on other approaches, or gaps out when vehicles are no longer detected on the present approach. The red interval was 45 s, which is the minimum stopping time when conflicting traffic were being discharged. The minimum red timing in a phase could be interrupted when traffic is no longer on other approaches, but vehicles are on the particular approach. Moreover, amber interval was constantly 5 s across all phases. Moreover, the cycle length for each phase was 80 s.

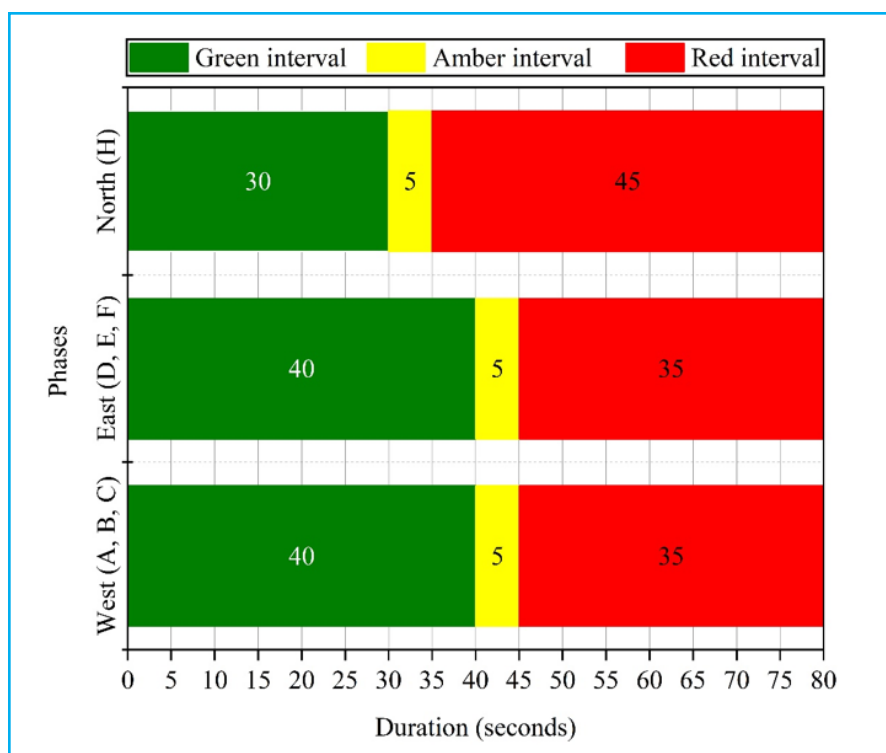


Figure 12. Intervals and cycle length

COST ANALYSIS

The cost research showed that electrical hardware that constitutes the circuit, accounted for the largest portion of costs (Figure 13). The Arduino Uno remain a moderately priced microcontroller, yet providing substantial functionality. The low cost of IR sensors, LCD modules, and locally available modelling materials contributed to the system's financial accessibility and effectiveness. Overall, this ITCS was made cost-effective by using reasonably priced electrical components and locally accessible materials to produce an efficient, low-budget intelligent traffic management model for an approximate total cost of \$193 USD.

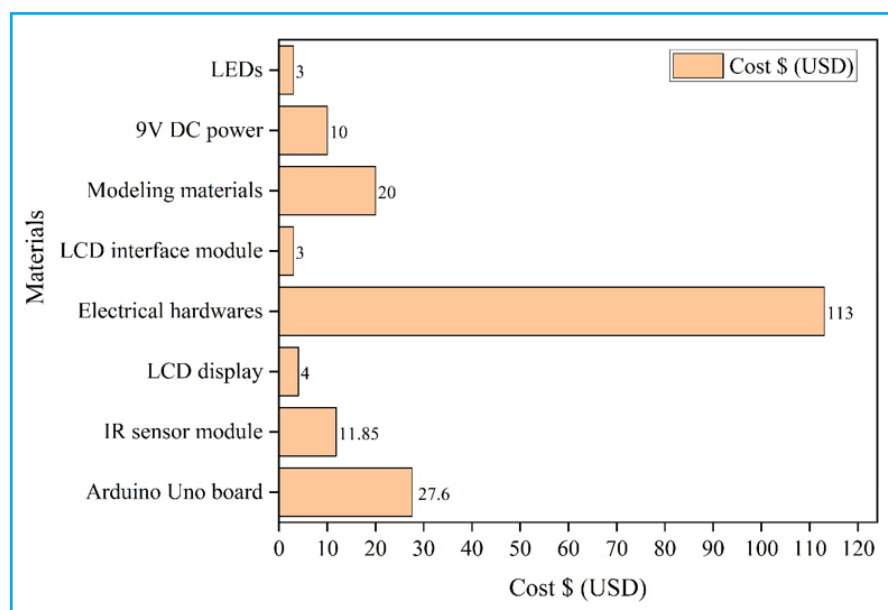


Figure 13. Cost analysis

CONCLUSION

The developed Arduino-based Intelligent Traffic Control System (ITCS) demonstrated effectiveness and efficiency through physical simulation of the model. The proposed ITCS demonstrated advancement over conventional methods of controlling traffic at intersections and could revolutionize urban mobility by enhancing efficiency, reducing environmental impacts, and improving overall traffic safety.

Key findings

1. Arduino micro controller intelligently allocated right of way to vehicles after successfully receiving real-time traffic data from the IR sensors. IR sensors were very responsive in detecting and responding to changes in real time traffic by sending signals to the micro controller within 11 centiseconds.
2. From the simulation, the ITCS demonstrated effectively by eliminating unnecessary delay during off-peak hours by gapping out on approaches with less or no detected traffic. This feature addressed a major weakness of conventional traffic control systems, which often allocate green time to empty approaches.
3. The ITCS also showed efficiency during peak hours by distributing right of way to all the approaches with queued vehicles by maxing out on each leg after attaining the maximum green times. This was to ensure fairness of traffic discharge on all approaches during peak and off-peak hours.
4. The proposed system demonstrates the ability to detect vehicles under both daylight and nighttime conditions, and, when combined with the gapping-out and maxing-out features, it showcases significant improvements over the algorithms employed in previous studies.

5. The main street approaches (east and west) of the Araromi intersection had 40 seconds green interval and 35 seconds red interval, while the minor street (north approach) had a 30 seconds green interval and a 45 seconds interval. All phases included a 5 seconds amber interval and 80 seconds cycle length.
6. The elimination of unnecessary waiting times at the Araromi intersection through the adoption of ITCS could significantly reduce fuel consumption, pollution, emissions, and economic losses, as the intersection connects the main market to the central business district.
7. From the cost analysis, the proposed ITCS cost approximately \$193 USD. This represents a low-budget system that could be scaled to other intersections and adapted for use in developing countries
8. The IR sensors used in this work were unable to differentiate between vehicles and other objects. To address the limitation of false detection, future studies should consider integrating more advanced sensing technologies capable of identifying specific vehicular parameters, thereby enhancing detection accuracy and system reliability. Furthermore, extending the current prototype into large-scale field testing and real-world deployment is recommended to evaluate performance under diverse traffic and environmental conditions.

LIST OF ABBREVIATIONS

ITCS	Intelligent Traffic Control Systems
IR	Infrared
LEDs	Light-emitting diodes
IDE	Integrated Development Environment
LCD	Liquid Crystal Display
USB	Universal Serial Bus

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Reuben Ayodeji Bolaji: writing-original draft, writing- reviewing and editing, methodology, investigation, formal analysis, visualization. **Olumuyiwa Samson Aderinola:** conceptualization, project administration, supervision,

writing- reviewing and editing. **Moses Ariyo Oladipo:** data curation, writing-original draft preparation. **Temitope Elizabeth Oguntelure:** investigation, formal analysis, writing- original draft preparation. **Oluwagbenga Abanire:** investigation, formal analysis, writing- original draft preparation. **Joshua Imoleayo Bolaji:** methodology, software.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

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