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Article *in* WSEAS TRANSACTIONS ON CIRCUITS AND SYSTEMS · January 2024

DOI: 10.37394/23201.2023.22.18

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Design and Construction of a Density-Controlled Traffic Light System

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Abstract: - This work introduces the application of piezoelectric sensors on the road which intersects to form a T juncture, the application of the sensor aids in regulating the control of traffic density on each side of the road. Traffic congestion as of today is caused by the improper management of time and eventually leads to traffic delays. This was undoubtedly observed during early hours when a lot of civilians head out to their workstations and during closing hours in the evenings. The increasing population and economic activities in urban areas contribute to higher vehicle ownership and usage, leading to more traffic on the roads. It is achieved from the general desire of people to achieve goals, which ultimately leads to daily overcrowding of the present transportation infrastructure. But despite attempts at solutions, everyone despises traffic congestion, and it only gets unfavorable. The objective of this project is to create a dynamic road signal that is based on density. The synchronization signals automatically change to detect intersection traffic density. The components required to build this project include the microcontroller (Arduino uno), LEDs (light emitting diodes), piezoelectric sensors, jumper wires, a 9 V battery, a switch, and an operational amplifier. The result of the work focuses on the detection of density from a sensor which will be constructed underground to operate as a counter for every vehicle that passes by as it will be powered by a battery of approximately 9 V. The sensor which is known as the piezoelectric sensor abides by the rule of piezoelectric effect, which states that the stress produced from a non-static object, or the mechanical energy produced from a moving object will produce an electric charge in response to the mechanical energy generated. The electric charge produced from the piezoelectric sensor will be transmitted to the microcontroller (Arduino Uno). Through the input stage of the signal received, the program in the microcontroller will command the light-emitting diode (LEDs) to function accordingly to the state of density detected from each side of the road. Thereby regulating the flow of traffic movement efficiently and accurately. Overall, the application of the piezoelectric sensor on the road can accurately detect the presence of a vehicle passing.

Key-Words: - Density detector, piezoelectric sensor, microcontroller, Arduino Uno, transmission, communication signal, traffic light.

Received: February 2, 2023. Revised: November 12, 2023. Accepted: December 14, 2023. Published: December 31, 2023.

1 Introduction

The issue of traffic congestion and road accidents has become a major issue to deal with in society. The conventional traffic light system reduces the productivity of individuals as well as time wastage in signaling transmission. This means of the signal gives rise to chaotic congestion which includes a high volume of vehicles, inadequate infrastructure, and the illogical distribution of the signaling system, [1]. As a result of this compilation of vehicles on the road; it leads to an increase in pollution level as vehicle engines remain powered on. In most cases, a huge volume of natural resources in the forms of petrol and diesel is consumed without any meaningful outcome and electrified-controlled vehicles struggle with the maintenance of battery health. Hence, to reduce these to a significant level as much as possible, a different scheme needs to be implemented by bringing in automation techniques sensor-based in this category of a traffic signaling system. Installation of traffic light panels at crossroads should be thought about in a strategic location where it will have a positive impact rather than cause issues. A properly set up and working traffic signal promotes orderly traffic flow and lowers the probability of potential vehicle collisions. Therefore, analyzing crash statistics, speed data, and most importantly, road conditions are necessary for the development of this project. A traffic light needs to be properly designed, situated, and routinely maintained to function, [2]. As it is today, traffic lights are installed in several lanes with fixed time delays, switching from one signal to another according to a successive cycle causing needless and undesirable congestion in one lane while the other lanes remain empty. The density-based traffic management system is suggested considering this circumstance, which frequently causes the loss of productive time, [3]. Therefore, considering how busy our roads are, especially during peak hours, there is a critical need for a more effective traffic management system. One that will ease traffic at most busy intersections, [4]. The speedy increment in the number of vehicles without a rapid extension in road network is the main reason for obstruction which is a reference to one of the major concerns in society, [5].

While it may be tough to tackle this obstruction entirely, there are still a few numerous ways to sway its future rate of increment like the quick response to traffic- blocking incidence and accidents, terminating mechanism from major roads quickly by utilizing the service of straying vehicle's run by Traffic Management Centres (TMC). This is a recommendable plan for minimizing traffic delays, building new roads in developing areas, enhancing the road system in urban areas, and implementing car-sharing services that would lessen the demand for individual vehicle ownership and consequently lower the number of automobiles on the road.

The purpose of this project is to control traffic by monitoring the number of vehicles that are available at a particular session of the road and sending a signal to go, stop, or ready.

2 Methodology

The idea behind this project is to make real-time decisions about traffic control using data from embedded sensors in the road, optimize traffic flow using artificial intelligence algorithms, and monitor traffic patterns to spot areas of congestion that may need extra attention. A piezoelectric sensor is used in this case. The fundamental operations of a piezoelectric sensor-based traffic control system combine sensing, data processing, and traffic control. This system consists of different stages to accomplish proper work and they include the following as shown in Figure 1:

i. Power supply phase: This phase gives the procedures for the workout for the entire power supply this system will require.

ii. Arduino phase: This phase introduces coding with the Arduino using the C++ programming language.

iii. Full connection phase: This is the final phase which involves assembling, testing, and connecting every required module to the Arduino as well as soldering all the components.

Fig. 1: Block Diagram of density-based traffic light system

2.1 Power Supply

This project was powered using a 9V, DC power supply. This is enough to power the Arduino and all other components attached to it. The Arduino Uno can be powered between 7 V to 12 V. It is recommended that the power provided to the Arduino not be less than 7 V or greater than 12 V unless the board cannot power the other components, and if it exceeds twelve volts, the board may burn due to overheating. The microcontroller and other components on the board are powered by the Arduino using a 5 V inbuilt voltage regulator. A switch is used with the battery to provide on/off control of devices, disconnecting the battery from a circuit to prevent it from draining while not in use, and regulation of the power supply to a circuit.

2.2 Arduino Phase

The Arduino platform is widely used for creating electronic projects and developing new concepts. It is built around a microcontroller board that can be programmed to operate a variety of devices, including lights, motors, and sensors. Numerous industries, including robotics, the Internet of Things (IOT), home automation, and educational projects, use Arduino. There are different types of Arduinos, these include; Arduino uno, Arduino mega, Arduino nano, etc. The Arduino Uno along with other components was used in the design and construction of this project. The Arduino uno analyzes data from these components as shown in Figure 2 and used in previous literatures, [6], [7].

Another component used in this phase is the piezoelectric sensor as revealed in Figure 3.

Fig. 2: Arduino Uno

2.3 Piezoelectric Sensor

The piezoelectric sensors were deployed to count vehicles before changing a traffic light's signal. It serves as the input to the Arduino Uno. The sensor detects a vehicle that passes over it through an electric charge, it then sends a signal to the traffic light through the Arduino Uno. This device was designed in such a way that when the number of vehicles spotted increases up to three the traffic light is turned to green to allow the vehicles to pass through a certain point, [8]. The traffic light controller receives a signal when a little electric charge is detected. Multiple piezoelectric sensors can be strategically placed along the road to detect the first vehicle before triggering a traffic light's signal change. The counter begins when the first sensor detects a vehicle and sends a signal to the controller, [9]. However, the first sensor to detect a vehicle passing will trigger the sensor to activate the traffic light. Once the traffic light turns green, a timer will be allocated to the road. The purpose of the timer is to stop interruptions while other sensors detect vehicles from other roads. While the first road with a green signal at the traffic light, the initial condition given to the three roads in the junction will be applied to the other sides of the junction with a red signal in the traffic light.

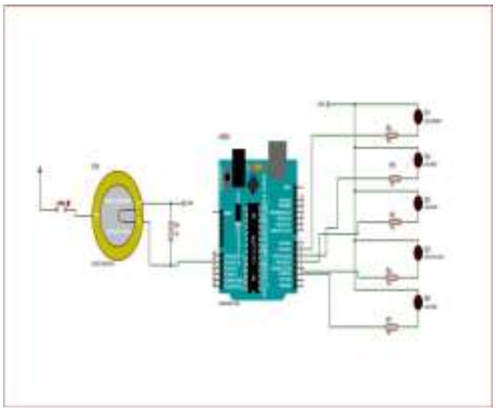

Fig. 3: Input circuit diagram of the piezoelectric sensors

2.4 Formulation for Analysis

When an object is pressed, there is a small force exerted and it is distributed over that particular area where the force field is present, this results in higher pressure detection. In contrast, pressure is reduced when the force is distributed over a broader area. When the force exerted on a solid does not remain constant but instead varies or changes over time, we speak about non-static pressure. Vibrations, collisions, and other forms of dynamic loading on the material can all contribute to this phenomenon, [10]. While calculating the density of a moving, it is necessary to determine the relationship of density, speed, and number of vehicles.

This relationship is expressed as:

$$q = k \times v \tag{1}$$

where (q) is density, v is speed and k is the constant, [10].

Equation 2, 3, 4, and 5 shows a few illustrations:

$$V = g \times d \tag{2}$$

V = voltage, g = piezoelectric coefficient, and d = deformation or strains.

To determine the number of cars passing by a sensor per time:

$$N = \frac{Q}{V} \tag{3}$$

N = number of vehicles that pass through the sensor per time, Q = pace at which traffic moves.

The area's traffic density equation becomes:

$$\rho = \frac{N}{A} \tag{4}$$

where ρ = density, N = number of cars, and A = area of the sensor.
The equation for determining a traffic light system's cycle time:

$$T = \frac{(2 \times D)}{V} \quad (5)$$

Where V is the average speed of the cars, D is the duration of the green light phase, and T is the cycle time of the traffic light system.

2.5 Working Principle

The main function of the piezoelectric sensor is applicable as a counter for vehicles passing by before getting to a traffic juncture. The traffic light controller receives a signal when a little electric charge is detected. Multiple piezoelectric sensors can be strategically placed along the road to detect the first vehicle before triggering a traffic light's signal change. The counter begins when the first sensor detects a vehicle and sends a signal to the controller. The total number of cars spotted climbs from one to three when following vehicles pass over the other sensors. However, the first sensor to detect a vehicle passing will trigger the sensor to activate the traffic light. Once the traffic light turns green, a timer will be allocated to the road. The purpose of the timer is to stop interruptions while other sensors detect vehicles from other roads. While the first road with a green signal in the traffic light, the initial condition given to the three roads in the juncture will be applied to the other sides of the juncture with a red signal in the traffic light.

Therefore, creating an ordered list like an array in a program. The red light will not be assigned with any timer since it depends on the sensor to activate a traffic light fixed to a particular road. While the green light and yellow light will be given a specific time of five (5) seconds respectively for both. For instance, sensor A in road A detects a vehicle passing by and activates the traffic light to turn green, other roads (B and C) remain stopped and a particular amount of time will be assigned to road A which was given the green light. While the time counts down for road A, the condition of both the first sensor to detect a vehicle together with the first sensor to count at least 3 vehicles will be applied on sensors (B and C). Whichever sensor meets up with the condition stated will be able to activate the green light, while the other will continue to activate in an ordered list with sensor A. These conditions will continue to remain under the loop except if the traffic light system is powered down. In all, improving traffic flow and lessening congestion at junctions can be achieved by deploying piezoelectric sensors to count vehicles before changing a traffic light's signal. Figure 4 shows an illustration of the connections of the piezoelectric sensor.

Aside from coupling the electronic components for the project, there are steps in building the proposed model to collaborate with the electronics. Firstly, all the materials required to build and design the layout of the traffic light system were assembled, they included the modelling board, glues, white and black cardboard, straws, and modelled items such as toy cars, people, streetlights, and grasslands. After, the modeling board was carefully measured and shaped into the desired size and figure that would perfectly suit the layout of the proposed model. The black cardboard was also shaped to the same size as the modeling board which will represent the road while the white cardboard will be used to draft out the layout of the road marks. The length of the road is divided into four (4) centimeters on each side, while the lane is measured approximately one (1) centimeter, given a total of nine (9) centimeters for road demarcation. Other parts on the modeling board include the grassland and buildings.

The installation of the piezoelectric sensor will be fixed in three car lengths before the traffic light, given the distance for the sensor to send a signal to the microcontroller which commands the traffic light to change signal at any time. The height of the modeling board is two (2) centimeters, which provides sufficient space for the microcontroller to be arranged inside the model. There are also a few pillars supporting the stands of the model that prevent damage to the microcontroller when an external force is applied at the top to test the piezoelectric sensor. The placement of the sensor will be directly beneath the black cardboard (road), to capture the threshold value easily without applying too much pressure on the sensor. Figure 5 below shows the step-by-step progress of the construction of the layout.

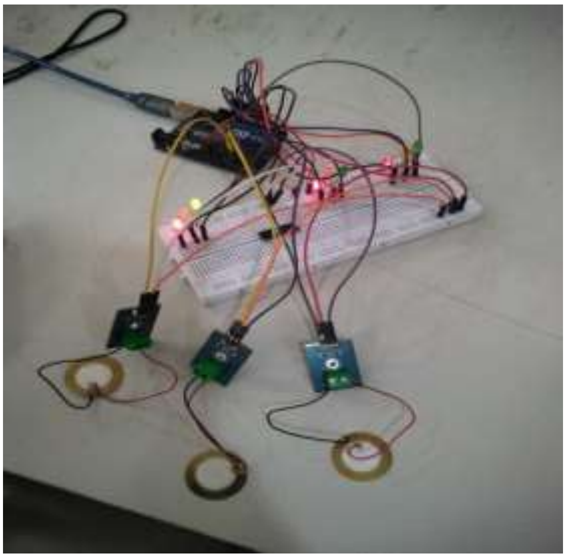

Fig. 4: Connection of the piezoelectric sensor

Fig. 5: Final phase of the layout

3 Results and Discussion

The Arduino integrated development environment (IDE) has a user-friendly interface that makes it easy to start writing and uploading code right away. The Arduino Integrated Development Environment (IDE) links up with the Arduino hardware for program uploading and exchange. The integrated development environment (IDE) is compatible with several operating systems. It uses a C and C++ language to program the Arduino hardware as shown in Figure 6.

The results obtained from the piezoelectric sensor which is used as a counter to detect movements of the vehicle and traffic control are analysed. In the previous chapter, it was discussed that the initial state of the traffic system is on red signal (stop). The first sensor to detect a vehicle passing will trigger a signal into the microcontroller which eventually changes the red signal to a green signal, the signal will be allocated with a particular amount of time assigned to it from the command in the microcontroller. However, while the time allocated is activated, it will disrupt any interruption from other roads. After the green signal timeout, the yellow light will be activated for a short period to readjust the traffic light to the initial condition. Then once the red light is turned on, the same condition will be applied to the next sensor that initially detected a vehicle or more and generate a continuous loop for all the sensors. It is necessary to note that the red light will not be assigned with any timer since it depends on the sensor assigned to change the signal (light).

Fig. 6: Arduino integrated development environment, [11].

Figure 7 displays the declaration of the outputs which are the LEDs and the inputs (sensors). A specific timer for the green light and yellow light with 5 seconds respectively on both commands the traffic light to allow vehicles pass for a total of 10 seconds. As discussed earlier, the red light won't be declared at any time due to its dependence on the piezoelectric sensor. An array is also declared to permit an ordered flow of the traffic system respectively to their density rate. Figure 5 shows the exact pin declaration of each LEDs and sensor connected to the proto board. Due to the specific type of program applied (OOP, object-oriented program), the declaration of the layout is different. The private and public sector of the class is displayed in the figure as well. The set-up stage in Figure 5 defines the input at which the microcontroller receives and its command which is shown as the output. The input layout defines the declaration of all the sensors fixed in the road which counts the vehicles passing.

3.1 Density Management Test

The system of this project is guided through the operation of arrays which is initialized in Figure 7. An array is a data structure that enables you to store numerous values of the same type in a single variable. It is similar as having a group of objects organized into a box, each with a unique position or index. The array in Figure 8 describes how each of the sensors placed on the road is arranged in order. It consists of three (3) different slots for the three sensors that are placed on the road. The array consists of binary figures such as zeros (0's) within, and it is initialized with one (1). This states that the sensor has detected a vehicle passing by and once this step is initialized, the electric signal generated from the pressure detected by the piezoelectric will be transmitted to the microcontroller to instruct the traffic light to change the signal. However, in this process, while the first sensor to detect a vehicle has activated the traffic light, the remaining slots in the array which is the second and third will be free for the next sensor which detects a vehicle while the first sensor is on green signal count down. This process is repeated in a loop.

The principle of the piezoelectric effect in certain cases such as controlling traffic density is very essential. It involves applying pressure on the sensors, where the unit of pressure detected also known as the mechanical energy or stress will be converted to electrical signals which trigger the microcontroller to instruct the light emitting diode to change respectively to the perception of density control applied on the roads. The operation of the piezoelectric sensor is very efficient and responsive to the control of traffic density. Its accuracy toward the measure of traffic density during this prototype test guarantees that the installation of these sensors on the road will be able to reduce traffic density most cost-effectively through its mode of operation. However, this prototype is limited to a single-lane road. However the implementation of two or more sensors to work together on a particular road is no different. The Figures displayed above describe the entire process of this project. Through the use of an array, the data from all of the sensors may be neatly compiled and stored in one place. Because of this, sensor data is much easier to manage and manipulate.


```
#define yellow 20
#define green 10
#define red 10
#define sensor_1 A0
#define sensor_2 A1
#define sensor_3 A3

#define sensor_one 10
#define sensor_two 20
#define sensor_three 30

#define delay_time_1 5
#define delay_time_2 10

long int timer = 0;
long int previous_timer = 0;

int order[3]={0,0,0};


class trafficlight
{
  private:
    int red_pin ,green_pin ,yellow_pin ;
  public:

    trafficlight(int green_pin ,int red_pin ,int yellow_pin);
    void stop();
    void get_ready();
    void go();
    void off();

};
 trafficlight trafficlight_1(7 , 5 ,6);
 trafficlight trafficlight_2(10, 8 ,9);
 trafficlight trafficlight_3(13 , 11 ,12);
```

Fig. 7: Pin declaration

```
}
void strobe(trafficlight &traffic)
{     timer = millis();
      while(true)
      {
        if((millis() - timer) < delay_time_1)
        {
          traffic.go();


        }
      else if((millis() - timer) >= delay_time_1 && (millis() - timer ) <= delay_time_2)
      {
        traffic.get_ready();
      }
      else
      {
        traffic.stop();
        break;
      }
  }


}
```

```
while(true)
{
  if(order[0] == sensor::sensor_one)
  {
    strobe(trafficlight_1);
  }
  else if(order[0] == sensor::sensor_two)
  {
    strobe(trafficlight_2);
  }
  else if(order[0] == sensor::sensor_three)
  {
     strobe(trafficlight_3);
  }
  order[0]= order[1];
  order[1]= order[2];
  order[2]= 0;
  if(order[0] == 0)
  {
      break;
  }


}
```

Fig. 8: Array initialization

4 Conclusion

In conclusion, using piezoelectric sensors in a T-junction traffic light system has a lot of benefits in terms of efficiency, safety, and the environment. In accordance with the principle of the piezoelectric effect, the piezoelectric sensors produce an electric charge when exposed to mechanical stress or pressure. This effect is caused by the arrangement of crystals and ceramics within the sensor. The depth of a piezoelectric sensor determines its sensitivity to variations in pressure or force at different depths. There are several applications of piezoelectric sensors which can be applied in various situations. As a high-voltage power source in electric cigarette lighters and gas grills, the piezoelectric effect is likely the most widespread application.

The results obtained from the piezoelectric sensor which is used as a counter to detect movements of the vehicle and traffic control are analysed. The electric charge produced by the piezoelectric sensor was transmitted to the microcontroller (Arduino Uno). Through the input stage of the signal received, the program in the microcontroller commands the light-emitting diode (LEDs) to function according to the state of density detected from each side of the road. Thereby regulating the flow of traffic movement efficiently and accurately. Overall, the application of the piezoelectric sensor on the road can accurately detect the presence of a vehicle passing. For efficiency and traffic flow optimization, the installation of the piezoelectric sensors changes the way traffic is managed at the T-junction to improve proficiency and traffic flow.

Acknowledgments:
The authors acknowledge the Covenant University, Ota, Nigeria for full sponsorship of this research.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Akinwumi Sayo carried out the simulation and responsible for preparation of the work for publication from the original research group.
- Okeke Jeff has implemented the Algorithm and executed the research analysis
- Ayanbisi Oluwasegun and Arijaje Theophilus has organized and executed the experiments of the work.
- Ogunwale Emmanuel, Oladapo Olutade and Araka Ifeanyi were responsible for the Construction.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

The authors acknowledge the Covenant University, Ota, Nigeria for full sponsorship of this research.

Conflict of Interest

The authors have no conflicts of interest to declare.