Smart Traffic Controller

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***Abstract*—Traffic Light controllers are used to control vehicular traffic flow and pedestrian movements. This is to ensure orderly and safe movement of vehicles and pedestrians. But the control provided by the existing systems does not consider parameters such as dynamic traffic density at different times within the 24-hour period and pedestrian safety crossing in totality. This results in traffic congestion and pedestrian safety issues at cross-roads and junctions. In light of this, this paper proposes a controller system based on Arduino microcontroller which monitors the traffic density using Infrared sensors to control the traffic flow by automatically varying the signal transition time slices for each direction, and Passive Infrared Radiation based (PIR-based) motion detection sensors to monitor and control pedestrian waiting and crossing times. The system will later be upgraded with additional functionalities where emergency service vehicles approaching, will be detected by using ultrasound sensors and given priority to cross the intersection safely without any obstructions.**

***Index Terms*—Microcontroller, Arduino Mega, traffic light, traffic density, infrared sensor, Doppler effect, motion detector, traffic congestion.**

I. Introduction

Traffic lights are made up of three conventional coloured lights (RED, YELLOW, GREEN) and have been very useful in controlling vehicle traffic flows, railway traffic flow and pedestrian crossings for more than a century now. In each direction, the red signal prohibits traffic flow, yellow as warning signal, and green allows traffic flow.

Traffic congestion has become a global problem faced by many countries, especially, with the current high increasing human and vehicular population. This is evident in most big cities. Some engineering solutions such as multiple lanes constructions, flyovers and several others have been implemented but the problem has still not been fully solved. Increasing number of vehicles with no adequate road infrastructure to accommodate them, consequently causes traffic congestion when the demand reaches the capacity of a road.

The complexity aspect of this traffic congestion problem is as a result of several factors contributing to the situation. People live and work in different areas of the city, and this introduces parameters of the traffic congestion, dependent on the time of the day, the day of the week and in which direction most of the people are moving. Construction works can also lead to complete closure of some roads or decreasing the size of the lanes thereby constricting the smooth flow of vehicles. Weather conditions such as heavy snow and rainfall also contribute by worsening the situation because the operating speed of vehicles are reduced under these unavoidable conditions.

Traffic research has still not been able to completely predict the conditions that can suddenly cause a traffic congestion. It has been found that, some other incidents such as a car abruptly stopping or an accident can ripple through all the vehicles behind it and causes congestion.

The delay timings for the current traffic light systems have been pre-configured or hard coded and do not take into account the diverse parameters that results in building up the traffic congestion. According to statistics, the percentage split of the causes of traffic congestion, 5% is attributed to poor signal timing [1] [2]. The existing control systems require upgrade to consider the volume of traffic and the flow density, pedestrian crossing idle time in order to fix the traffic congestion problem and its economic and environmental implications. This proposal is a relatively simple, low-budget and real-time intelligent control system which seeks to be an improvement of the existing system to help fix this 5% poor signal timing part of the problem. This controller system uses Arduino microcontroller for the traffic control by monitoring the volume of traffic and the flow density through infrared sensors which will be installed at calculated distances by the road sides, and motion detection sensors to monitor and control pedestrian crossing, and then take the decision to vary the transition times and/or activate certain functions of the system accordingly, based on the inputs read from the various sensors.

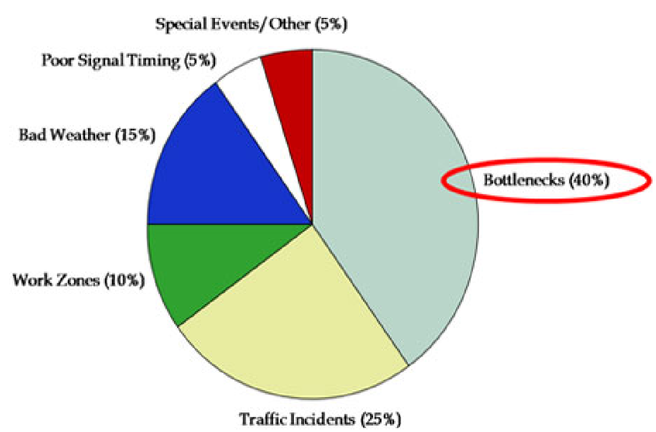

Fig. 1. Causes of traffic congestion [1].

II. System Design

The first prototype design of this system focuses on a cross-road intersection as shown by Fig. 3 (the controller circuit diagram), but will consider only one vertical and one horizontal directions for simplicity sake in order to facilitate the integration and testing of the system's design architecture, hardware and software. This can be extended to the full four-directional multi-lane intersection, just as the objective of the project research, after successful integration and testing.

The two routes (vertical, V and horizontal, H) at the intersection, each has one traffic light. Three pairs of active infrared sensors (transmitters and receivers) will be installed on both sides of the road V and H respectively in "break beam configuration mode". The "vertical traffic light" (Vs) controls traffic flow from road V to the other two routes. Likewise, "horizontal traffic light" (Hs) also controls the traffic flow from road H to the other two routes (Fig. 2).

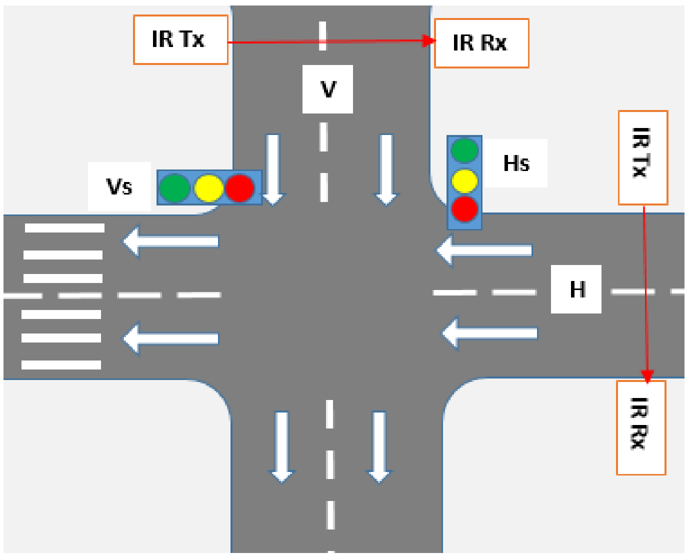

Fig. 2. A cross-road intersection.

The infrared (IR) transmitter and receiver pairs are installed at each side of the road such that the radiation beam transmitted by each transmitter constantly falls directly on the corresponding receiver (break beam configuration) [3]. Input from the first IR sensor on each road, in the direction to the intersection, is used to update a corresponding counter value ("vehicle counter"). When a vehicle traverses the road between the transmitter and the receiver, the IR radiation beam is interrupted and the IR receiver sends a signal to the controller unit and the "vehicle counter" is incremented. This data is continuously collected from sensors on the respective roads and used by the system algorithm to automatically adjust the green signal transition time at real time. Four modes of operation or transitions are proposed for this implementation; "Normal", "Congestion", "Pedestrian" and "Sleep" modes. The counter readings and their frequencies of updates form the basis for deciding which mode to switch to and the transition times slots that should be used at each point in time under a given traffic situation.

The transition mode selections and the transition time adjustments are all done at real time in accordance with the current traffic situation at a given moment. On the controller unit, colour-coded indicator lights will be used to indicate which transition mode is in operation (BLUE = Normal, RED = Congestion, YELLOW = Sleep).

A. Normal Mode

Under normal traffic condition, the "Normal" transition mode is activated and all roads will have equal transition time slots. Inputs from the IR sensors will continuously be read to update the "vehicle counters". So long as none of the counters exceeds a predefined normal threshold value, the system will continue operating in this mode. The maximum threshold values are predefined possible allowable maximum values within a specified period of time. When the counter value falls below the minimum normal threshold value, the system switches to "Sleep" mode and when it exceeds the maximum it switches to operate in "Congestion" mode.

B. Congestion Mode

In a situation of higher traffic flow density, the system switches to the "Congestion" mode and the green transition time slot for the road with the highest flow is increased at real time to allow more vehicles from that direction to cross the intersection in order to avoid congestion.This mode is activated when any of the "vehicle counter" values exceed the normal threshold value.

C. Pedestrian Mode

The "Pedestrian" mode will only be activated only when when there is a pedestrian waiting to cross. The system will use a Passive Infrared Radiation based (PIR-based) motion detector [4] [5] [6] to detect the presence of a pedestrian. Because this project seeks to solve the fixed or hard-coded transition time problem, when there is no pedestrian waiting, this mode will be deactivated and the pedestrian red signal will always be on to allow more time for vehicles to cross. Once a pedestrian is detected waiting, this mode will be enabled and the system will thus consider the pedestrian signal transition in its decision process.

This mode will also include some safety mechanisms to completely ensure pedestrian safety when crossing the road.This will ensure that once a pedestrian is still crossing, even if the allowed crossing time has elapsed, no vehicle will be permitted to move in that direction until the pedestrian has completely crossed. This will also be implemented by installing PIR-based motion detectors at the crossing, whose field of view will be set to monitor the middle of the road. Once a pedestrian is detected crossing, the transition time of the red signal for the vehicles to that direction, will be extended by the system logic.

A piezo buzzer will also be used at the same time to signal to the pedestrian of how much crossing time is remained. When the crossing time is about to elapse, the buzzer or beeper will initially beep relatively long at one second interval for 15 seconds and then finally, short beeps, 0.5 second intervals for 5 seconds.

At the crossing, a push button will be installed at each side of the road to be used to interrupt the normal operation of the system to reduce the waiting time of the pedestrian. This function is recommended to be used by old people or physically challenged people who cannot stand for a relatively long time.

D. Sleep Mode

Under the condition where vehicles rarely pass the intersection (especially late in the night) and does not make sense to hold vehicles at the intersection, “Sleep” mode is activated and green transitions will be disabled and only the yellow signals will be blinking and drivers would be required to use their discretion and the conventional driving rules to cross the intersection. This transition mode is activated only when all ”vehicle counter” values are below a predefined minimum value within a specified period of time.

III. Components

The electronic circuit design of this intelligent controller composes of the following components;

- Arduino Mega 2560 micro-controller
- IR sensors
- Breadboard
- 220 ohm resistors
- Red, yellow and green LED’s
- Jumper wires
- Piezo buzzer
- Push Buttons Switches
- PIR-based motion detector

A. Arduino Mega 2560

This microcontroller board is based on ATmega2560. It has 54 digital input/output pins , whereas 15 supports PWM (Pulse Width Modulation), and 16 analog input pins, 4 UARTs (hardware serial ports) which can be used to connect many other devices, power jack, 16 MHz crystal oscillator, USB port, ICSP header, and a reset button. It is a high Performance, low power AVR 8-bit microcontroller and has 4kb (4096 bytes) of EEPROM (non-volatile memory).The board can operate on an external supply of 6 to 20 volts. The microcontroller can be powered through a USB connection or with an external power supply. The power source is automatically selected [7].

B. IR Sensors

Infrared sensors are electronic devices used to detect objects and to also differentiate between objects based on their features. IR sensors emits or receives the infrared radiations of frequency ranging from 430THz – 300GHz. The transmitter has LED which emits infrared radiation while the IR receiver or detector is a photo-diode which is sensitive to infrared light of the same frequency as the radiation emitted by the transmitter. When the radiation emitted by the LED of the transmitter hits the photo-diode of the receiver, the output voltage of the receiver changes in accordance with the intensity of the IR light [3] [8].

C. PIR Motion Detector

Passive infrared sensors (PIR sensors) detect the radiation emitted by objects in their field of view. They are usually used in PIR-based motion detectors. PIR sensor only detect movement of objects in general, but do provide information on the object. PIR sensor devices operate solely by detecting the radiant heat emitted or reflected by objects. It has been found out that all objects with a body temperature above absolute zero (-273.15 degree Celsius or 0K) emit heat energy in the form of electromagnetic radiation. A PIR-based motion detector is used to sense movement objects within its range and has a wide range of applications such as in automatic doors, lighting and intruder alarm system. In a differential mode, a PIR sensor detects movement within its range; a pair of complementary pulses are processed at the output of the sensor. And to implement this output for a practical purpose, the differential signal is rectified using a bridge rectifier and fed to a relay driver circuit. The contacts of this relay close and open in response to the signals from the PIR, thereby activating the attached load across its contacts and acknowledging the presence or detection of a foreign object within an area [4] [5] [6].

IV. Algorithm

1) Start in Normal mode
2) Read IR sensors inputs and increment ”vehicleCounters”
3) If any vehicleCounter is greater than Normal threshold value, switch to “Congestion mode”
4) ELSE IF vehicleCounter value is less than Normal threshold value, switch to “Sleep mode”
5) ELSE operate in Normal mode
6) Read motion sensor input
7) Is pedestrian waiting (if YES, enable pedestrian mode and begin counting up waiting time)
8) IF pedestrian waiting AND pedestrian button is pressed, reduce waiting threshold time
9) Is waiting time above threshold (IF YES, switch on red signal to stop vehicles in pedestrian direction)
10) Switch pedestrian green signal and begin counting down pedestrian crossing time
11) If pedestrian crossing time is zero, switch pedestrian red signal and read “safety-crossing motion sensors” inputs
12) Is pedestrian still crossing (IF YES, extend vehicle red transition time in pedestrian direction ELSE, switch vehicle green signal)
13) Read pedestrian waiting motion sensors inputs
14) Is pedestrian waiting (If YES maintain pedestrian mode ELSE, disable pedestrian mode)
15) Repeat(loop)

V. Future Enhancement

As part of this proposal, the smart controller is intended to evolve for functionality and performance enhancement. In future design, other transition modes, functionalities or features will be added to enhance the system.

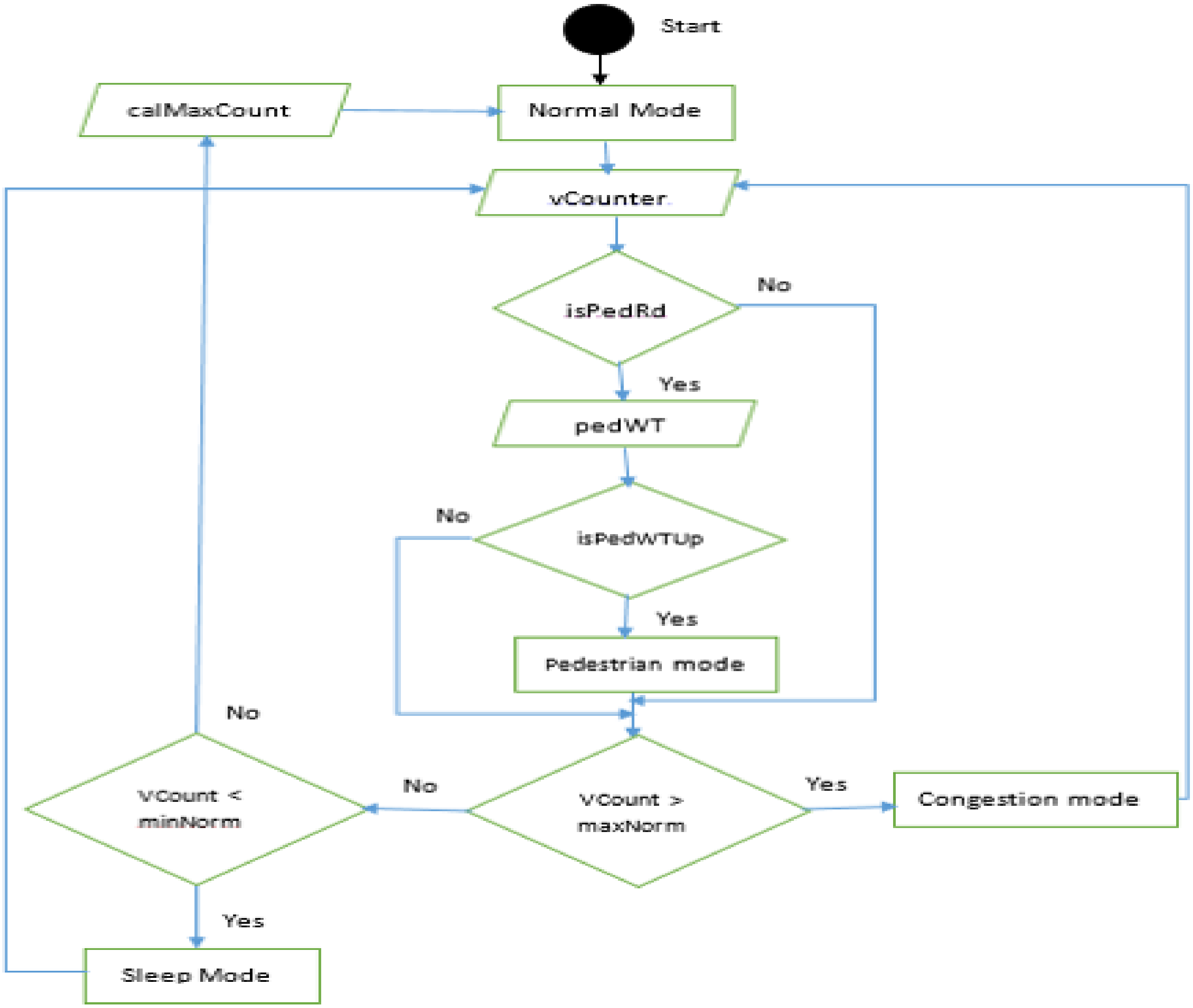

Fig. 3. Flow chart.

A. Emergency and Post-emergency Modes

"Emergency" and "Post Emergency" transition modes will be added as an upgraded version of the system. This mode will be activated only when emergency service vehicles approach the intersection. Ultrasound sensors [9] will be used to pick the sound frequency of the sirens and compare with a dataset of sound frequencies stored in the database. The Doppler Effect phenomenon will be used for the activation of the "Emergency" mode as the vehicle approaches based on the progressive increase of the pitch and deactivation of the "Emergency" mode and subsequent activation of the "post-emergency" mode when the siren fades out as the vehicle leaves the intersection [10]. When the "Emergency" mode is activated, other signals will turn red to stop all vehicles, including all pedestrian signals, except for vehicles in the direction from which the emergency vehicle is coming, will get green light. A LCD display will be used to show the current active transition mode instead of colour-coded indicator lights.

Because during the emergency mode all vehicles from all other routes will get the red signal and will be prohibited from moving, it's likely that queues will be formed from other directions. "Post-Emergency" transition mode is thus activated immediately after every emergency. In this mode, the system will check which road has the longest queue and then give it the green signal first by checking which IR radiation beams are completely blocked. And their positions on the road will determine the length of the queue. In this "Post Emergency" mode, decisions will be based on the lengths of queues for predefined time after which this mode will be deactivated.

B. Doppler Effect

Doppler effect is the change in frequency of a wave (sound) due to the relative change in position or movement between

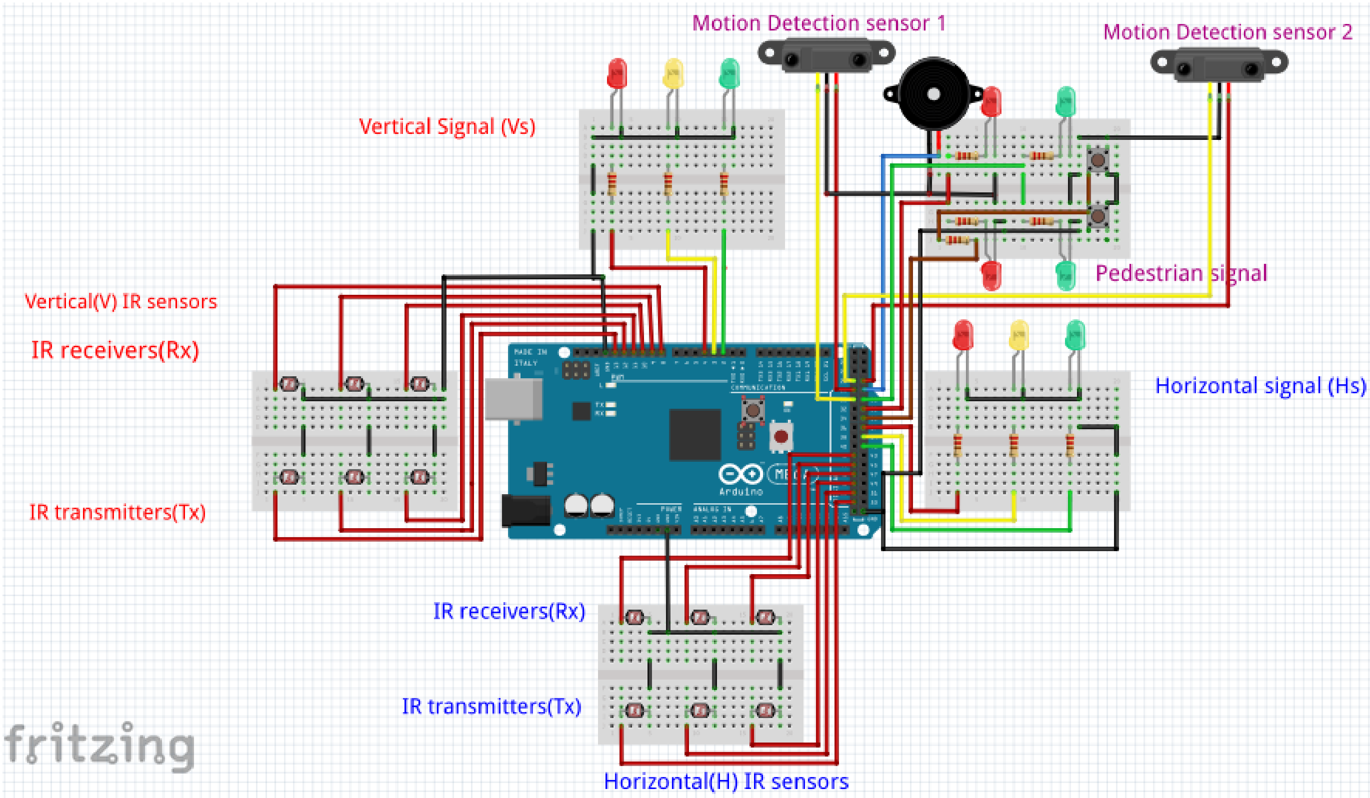

Fig. 4. The controller circuit diagram.

the observer and the source of the wave (sound). A typical example of this phenomenon is the change in the pitch of the engine sound of a car or a siren of an ambulance service vehicle as it approaches and leaves the observer. The pitch progressively increases when it is approaching and decreases progressively as it recedes and eventually fades out completely. While approaching the observer, each successive wave takes slightly less time to reach the observer than the previous wave. This reduces the arrival time of the waves hence an increase in frequency. However, if the source of waves is moving away from the observer, each successive wave takes slightly more time to reach the observer than the previous wave because each wave is emitted from a point which is farther away from the observer. This increases the arrival time of the waves and hence, a decrease in frequency [10] [11].

VI. Conclusion

This research proposal discussed the design of a smart traffic controller system which constantly monitors the traffic flow density at an intersection and automatically activate the appropriate transition mode that best handles the traffic situation to avoid a congestion by adjusting the green signal transition time based on the flow density. It was aimed at solving the fixed-time or hard-coded signal transition times in the existing traffic light controllers which do not consider the various variables. It also included some pedestrian safety crossing features and also proposed a future upgraded version with “Emergency” transition mode for emergency service vehicles which will use ultrasound sensors base Doppler Effect phenomenon for activation and deactivation.

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