Traffic Light Controller
Project Final Report

Motivation

In 2014 54% of the total global population were urban residents [1]. The prediction was a growth of nearly 2% each year until 2020 leading to more pressure on the transportation system of cities. Additionally, the high cost of accommodation in business districts lead to urban employees living far away from their place of work/education and therefore having to commute back and forth between their place of residence and their place of work. More vehicles moving need to be accommodated over a fixed number of roads and transportation infrastructure. Often, when dealing with increased traffic, the reaction is: just widen the lanes or increase the road levels. However, cities should be making their streets run smarter instead of just making them bigger or building more roads.

Figure 1 shows a typical intersection along with the traffic lights and pedestrian walk lamps and buttons. Figure 2 presents all the movements by cars and pedestrians that happen at an intersection. Both Figures indicate how complicated a smart traffic light system would be to implement. Many external factors such as the existence of several traffic lights, pedestrian lights, multiple vehicle movements and pedestrian movements play a decisive role when controlling such a system. Any error might result in congestion and the loss of time, money and effort. In addition, in a city, traffic flow through one intersection can affect other intersections increasing the complexity of the system.

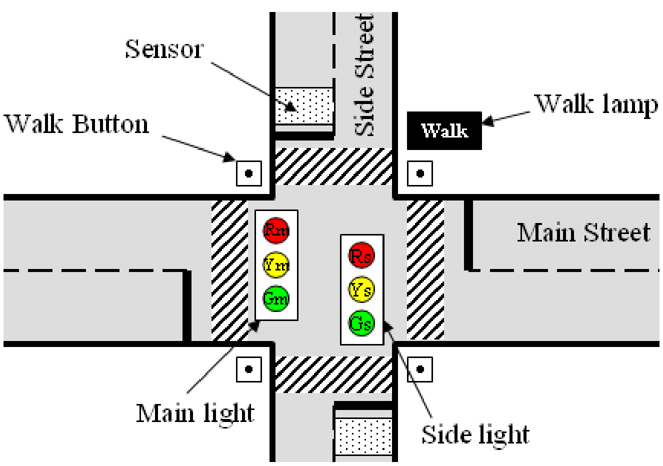

Figure 2: Diagram of intersection with corresponding lights [2]

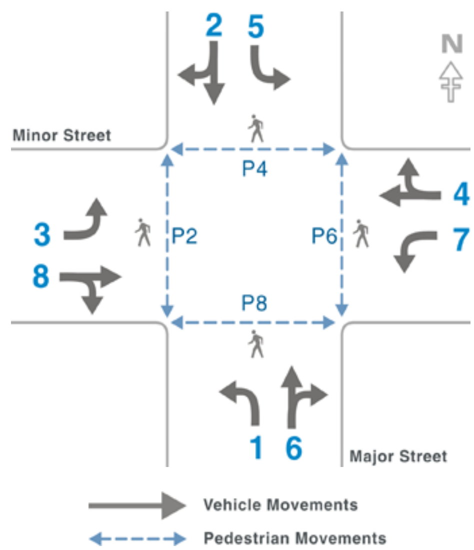

Figure 1: Typical vehicular and pedestrian movements [9]

A crucial part of making the streets smarter is utilizing traffic signals that use sensor data, communication and automated algorithms to keep traffic flowing more smoothly [3]. In other words, intersection signals should be able to adjust, in real-time, to traffic conditions resulting in minimizing both the hassle and cost of commuting as well as minimizing the carbon footprint of the transportation vehicles by making the system more fuel efficient and minimizing wear and tear resulting from excessive breaks. A smart transportation system is expected to also minimize the number of accidents which will lead to fewer fatalities, less patients in hospitals and less pressure on emergency response systems. This will in turn release funds which might be used to make the life of citizens better rather than buying more supplies for hospitals and emergency vehicles and increasing their number. The system is also expected to benefit individual commuters by lowering insurance rates (since there are less accidents happening), fuel cost and cost of lost time and arriving late to work/school.

Proposed Solution

A smart traffic light system utilizing sensor data, communication and automated algorithms was developed to keep traffic flowing more smoothly. The aim was to optimally control the duration of green for a specific traffic light at an intersection. The traffic signals should not flash the same stretch of green all the time, but should depend on the number of cars present. When traffic is heavy in one direction, the green lights should stay on longer; less traffic should mean shorter greens.

This solution is expected to eliminate inefficiencies at intersections and minimize the cost of commuting and pollution.

System Architecture

The proof of concept system block diagram is presented in Figure 3. The traffic lights are LEDs and the car counting sensor is an ultrasonic sensor. Both blocks are connected to an Arduino Uno using physical wires. The Arduino is the traffic light controller which receives the collected sensor data and manages the traffic lights by switching between green, yellow and red. The Arduino computes the number of cars in the street of the intersection it is monitoring based on the distances measured by the ultrasonic sensor and the timing between those measurements. The Arduino then sends the number of cars every minute (this time was chosen based on little study, additional experiments should be conducted to determine the optimal frequency at which to send the number of cars to the local server) to the local server which is a laptop. This communication is done using the Arduino's serial port. The local server exchanges the number of cars received with the cloud server in order to train and update the machine learning algorithm to better predict the changes in timings of the traffic light. This communication is done using Wi-Fi. More specifically, the cloud server uses a logarithmic equation that takes the data received (number of cars) as input then determines the seconds of green needed for a smooth traffic flow. This calculated time of green is then compared to the current actual time the green light is on (this data is saved is a database on the cloud server). The server then comes up with a decision: if the current actual green time is less that the calculated time the decision is to increase the green time, else the decision is to decrease the green time. This decision is sent back to the local server and then forwarded to the controller which adjusts the green time accordingly.

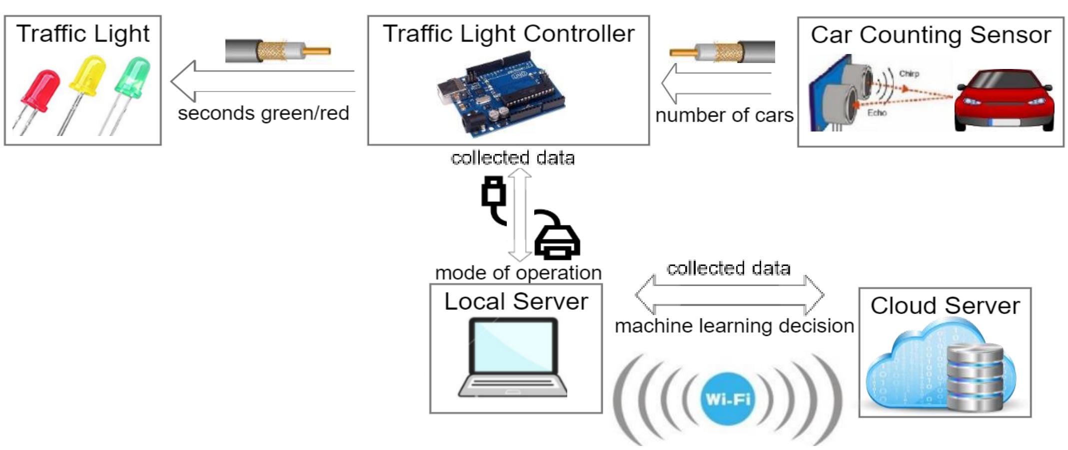

Figure 3: Functional Blocks

This architecture is a general design, some of the blocks, like the local or cloud servers can be removed in the future depending on the requirements of the client.

Car Counting Sensor

To be able to detect a passing car, two set of experiments were conducted assuming the presence of only one lane. In the first experiment, only one car passed the sensor and the range of distances when a car passes by was extracted. While in the second experiment, 34 cars passed back to back in order to extract the minimum time elapsed between two consecutive cars. The rule is that if the sensor reading is within an acceptable range of distances over an acceptable period of time, then a car is detected and hence the counter is incremented. The circuit setup for these experiments is presented in figure 4, all the additional components (other than the ultrasonic sensor) were used for experimental purposes and will not be present in the actual project circuit.

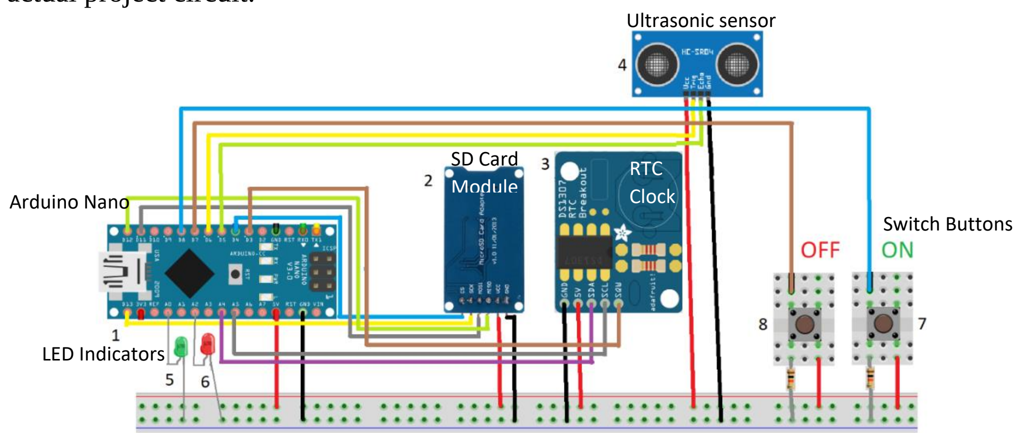

Figure 4: Car Counting Experiment's Circuit Setup

Experiment 1

This experiment had only one car passing in front of the ultrasonic sensor at different speeds and the distances measured by the sensor over time were recorded and then plotted to obtain figure 5.

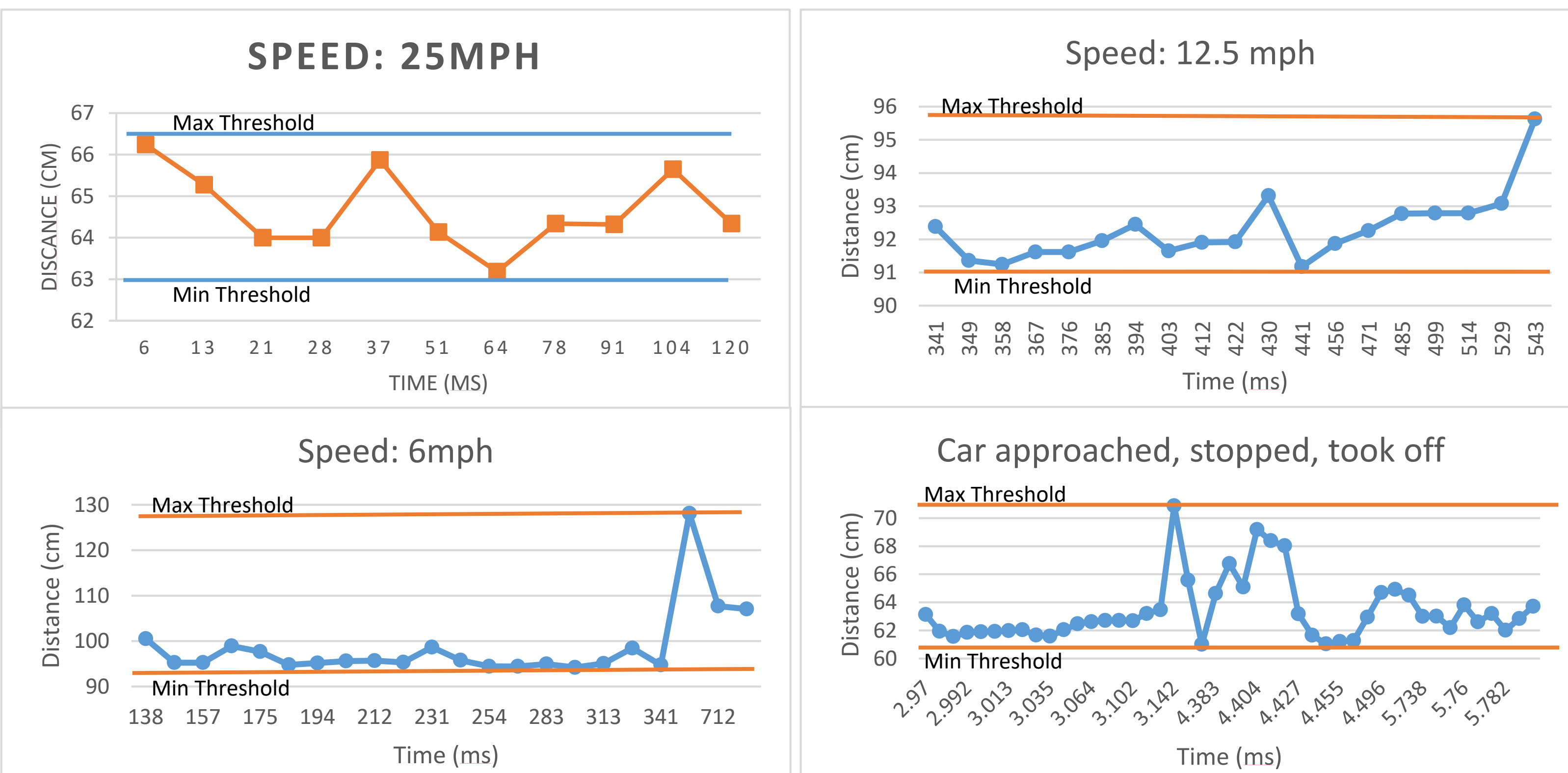

Figure 5: One Car Passing at Different Speeds

The distance values detected are not constant, however, they lie within a certain range and minimum and maximum thresholds were then extracted. If the sensor reads a value within that distance range, a car is passing by, hence a car is detected.

Experiment 2

Next, a total of 34 cars passed the car counting sensor and for each car, several distance values were recorded by the ultrasonic sensor. The plot in figure 6 was generated by plotting, for each car the distances recorded by the sensor over time (milliseconds). Each car's distance values are labeled with a specific color in order to be able to identify the different cars. As shown in the upper graph, 22 out of the 34 cars entered the street back to back and hence, a second graph was plotted to have a clearer view of the data.

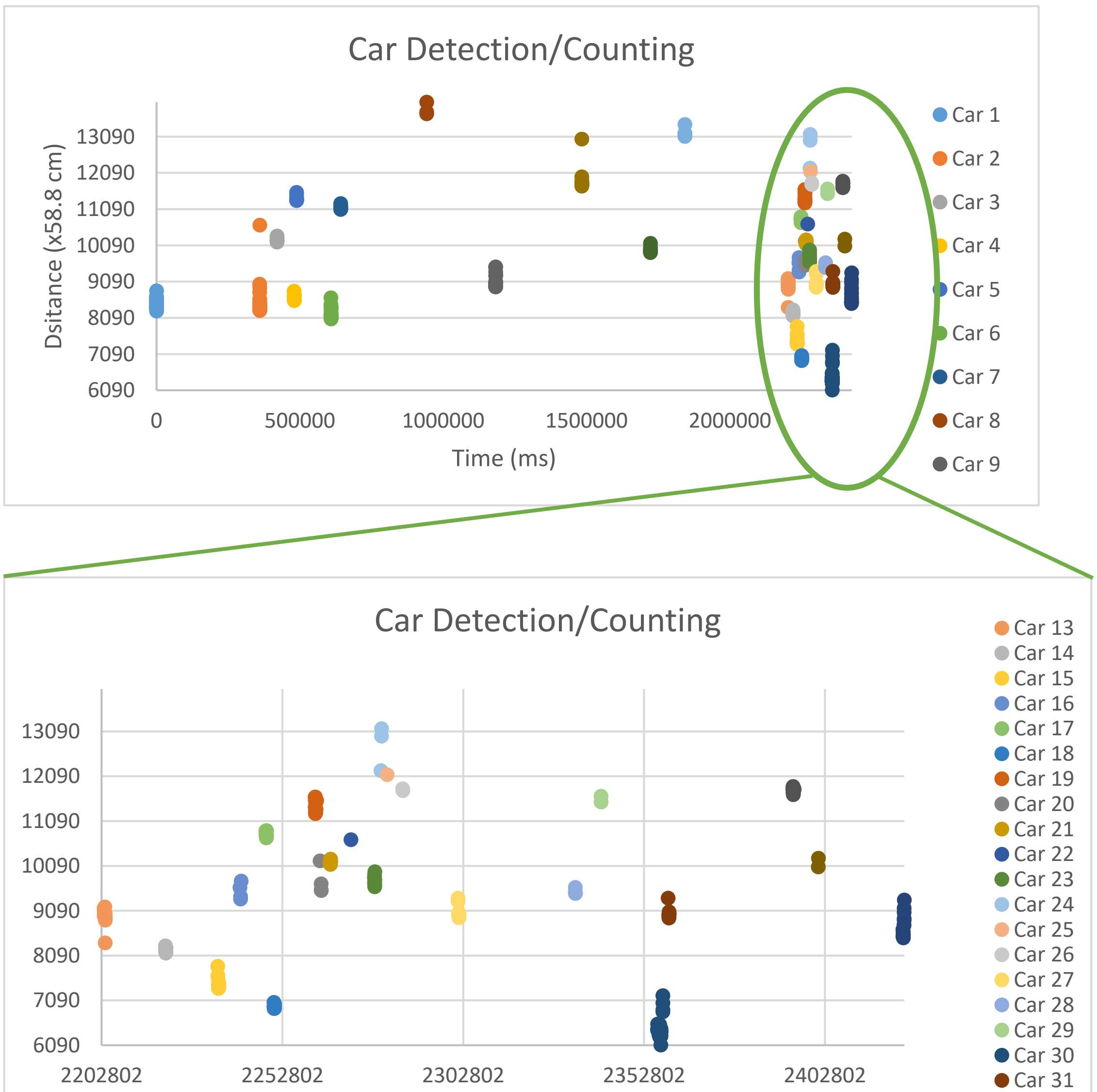

Figure 6: Detection of Cars Passing by

The minimum time elapsed between two consecutive cars passing by is 1.472 seconds. This number was determined after plotting the time it took between two consecutive cars to pass by. The results are shown in figure 7.

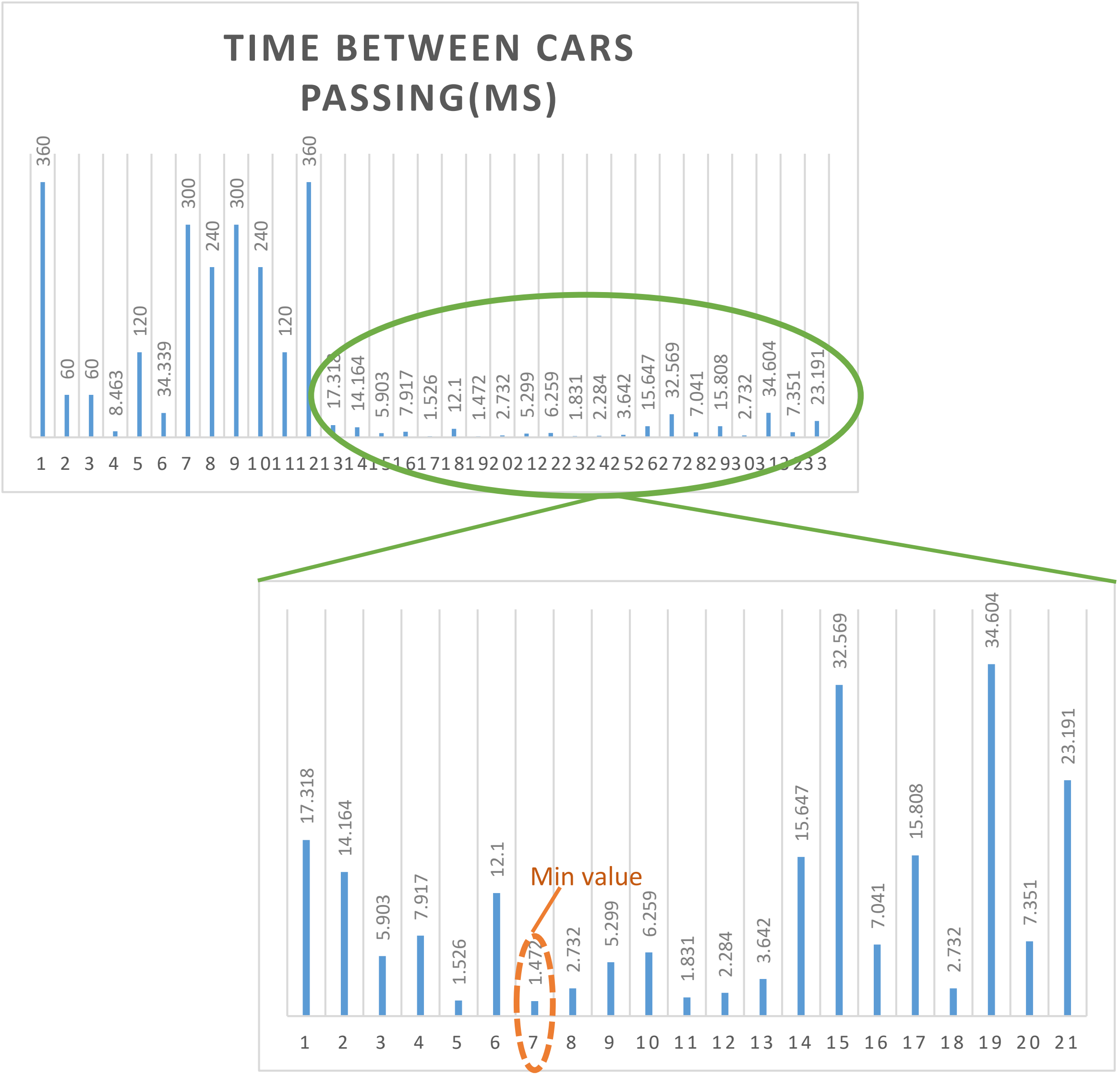

Figure 7: Plot of Time between Two Consecutive Passing Cars

Hence, to detect a car, there should be a period of minimum 1.472 seconds where the distances read are out of range. After that, if the sensor reads a value within the distance range, a car is detected and the car counter is incremented. Those two rules were implemented in the car counting sensor block's code. This data can be used in future work to train machine learning algorithms and have more precise predictions for the green light intervals

Machine Learning (Cloud Server)

To simulate the benefits of the machine learning algorithm, experiments were conducted on an intersection in Irvine to count the needed time of green light based on the number of cars present. Data was collected for different lanes for one traffic light: one going straight and another turning left. After plotting the data collected, a logarithmic equation was extracted for both types of lanes as shown in figure 8. These logarithmic equations were then used by the cloud server to decide whether to increase or decrease the time of green. If the predicted number of seconds needed is higher than the actual current green time, the decision would be to increase the green time stored in the Arduino controller.

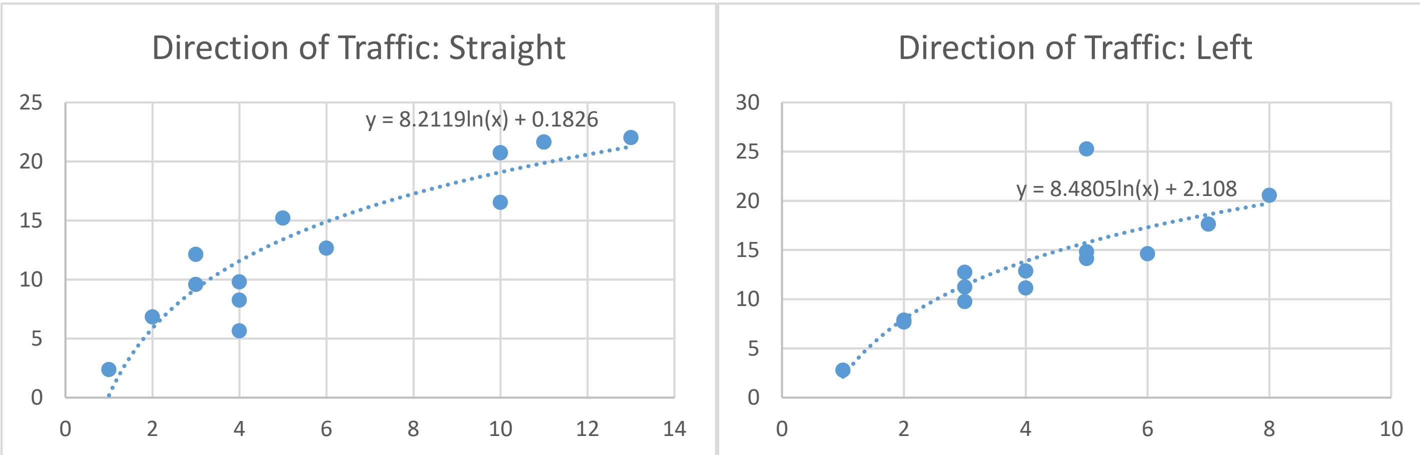

Figure 8: Seconds of Green for a Specific Number of Cars

Software Setup

The software responsible for the functionality described previously is provided along with the book. Figure 9 explains the relation and order of the code files.

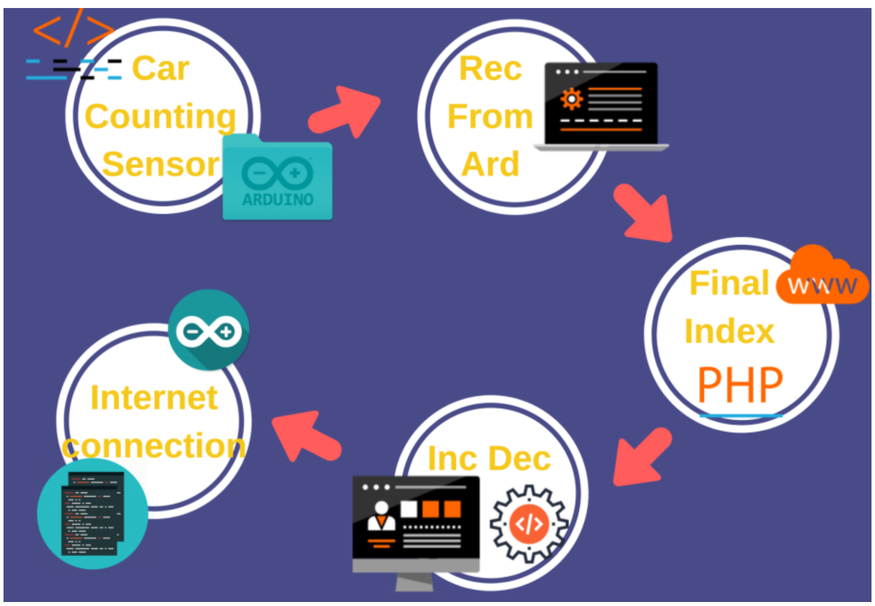

Figure 9: Software Architecture

Hardware List and Cost

Only the following two components were used in this proof of concept's final circuit design and they were purchased from Amazon as shown in figure 10 and 11.

1- Arduino Uno: $16

Figure 10: Arduino Package Purchase

2- Ultrasonic Sensor HC: $3.19

Figure 11: Ultrasonic Sensor Purchase

It is assumed that the client requesting the product would already have a local server that has a Wi-Fi connection because for this project a personal laptop was used and hence an estimated cost doesn't apply to that component.

Real Time Evaluation

The processing time limit can be determined by the time needed to detect a fast passing car. At 200 Km/h, a car needs about 54 milliseconds to pass the sensor and hence be detected. The Arduino is working at 16 MHz with very small data, the machine learning algorithm used would maybe take time for training (offline) but not for prediction, and the communication is dependent on the network congestion but should not exceed a few milliseconds for data exchange. Since, the sum of every module's performance results in an overall time which is still less that the limit (54 ms), the system is expected to have real time performance.

Cost issues and Market Survey

The ultrasonic sensor I am currently using for this project (HC-SR04) is a cheap and commonly used sensor. This sensor would have to be placed on the side of the street on some kind of a pole. This is why a weather proof sensor is needed (SEN0207), this would increase the price from $3 to $16. Also, this project utilizes Wi-Fi as the communication technology between the local and the cloud servers and serial communication between the controller and the local server. This may present some cost issues if the model was to be commercialized and further research may be needed to select the best technology that would fit the market.

The competing systems are

1- Siemens Intelligent Traffic Systems in Tyler, Texas which are reducing traffic delays by 22% [4].

2- SCATS (Sydney Coordinative Adaptive Traffic System) in Factoria Boulevard in Bellevue, Washington which was first developed and used in Sydney, Australia [5].

3- Surtrac's smart traffic-management system. A startup project by Carnegie Mellon University professor of robotics Stephen Smith in Pittsburgh's East Liberty neighborhood. The Surtrac system uses radar sensors and cameras at each traffic light then AI algorithms to build a timing plan and finally communicates with traffic intersections downstream so they can plan ahead [6].

4- Adaptive Control Decision Support System (ACDSS) in New York which is a joint project between KLD, traffic management company Transcore and the New York Department of Transportation. It utilizes field sensors, RFID readers (to scan E-Zpasses) and cameras [7].

Challenges and Solutions

Several challenges were faced during the implementation of the project:

1. Limited budget:
   As a graduate student my ability to test different technologies to see which is best is very limited.
   Solution:
   Off-the-shelf components were used to make proof of concept. Then other technologies were theoretically evaluated once their cost is available.

2. Lack of time:
   Time limitations and taking other courses with projects impeded my ability to do a thorough survey of the market to get quotes on real cost of parts and communication technologies.
   Solution:
   A theoretical evaluation of different technologies was included so that once costs are known numbers could be plugged in and cost determined.

3. Data Collection:
   Placing sensors on intersections is time consuming and needs permits.
   Solution:
   Only consider one intersection and collect as much data as possible, future work should expand the surveyed intersections.

Conclusion

Using an intelligent traffic light system has many advantages. Using smart traffic light controllers reduced travel times by 36% during peak rush hour in Bellevue, Washington [4]. It also lead to the decrease of heavy traffic by 43% from 2 p.m. to 6 p.m. Those reductions can be translated into real savings for drivers by estimating that a driver's time is worth $15 an hour, Bellevue officials estimate that the system saves drivers $9 million to $12 million annually.

It is important to note that although studies show high success rates when installing adaptive signals, this solution is not a magic potion for clogged roadways. "while smart lights can be particularly beneficial for some cities, others are so congested that only a drastic reduction in the number of cars on the road will make a meaningful difference" [8].

In this report, the solution of having smarter streets, particularly smart traffic light systems was proposed. A proof of concept design was created then tested and the results validated the feasibility of this solution. The design described in this report has a lot of room for growth and future work.

Future Work

Since this is a quarter course project, cheaper and less reliable sensors (HC-SR04 ultrasonic sensor) were used and more known communication technologies (Wi-Fi and serial) were implemented. In the future, more reliable and precise sensors can be integrated into the design and wireless technology can be implemented for communication. Also, the lack of precise and detailed knowledge in machine learning (ML) resulted in the use of basic ML algorithms in this project. Future extensions to the project could be to collect enough data so that the ML algorithms can be more accurate, and more sophisticated algorithms can be used. Finally, for this project, a one lane street in an intersection was considered. When expanding this project, more complex features can be considered such as: larger streets with more lanes, all the streets in an intersection, communication between the networks of intersections, and finally the integration of pedestrian scenarios to the project. Also, an interesting extension to this project would be to analyze data from neighboring intersections and determine its effect on the intersection being controlled. Moreover, this system could utilize image processing algorithms along with the cameras that are already being used on traffic lights for validation of the number of cars present. In conclusion, this project is just a proof of concept and hence includes the very initial steps in a project that has the potential to be expanded in the future.

References

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