PIR Motion Sensor – Monitoring the Flow of Pedestrian on Bridges

Overview

In the modern age, the term ‘Smart Cities’ has gained a lot of popularity. There is still an ongoing debate about what the exact definition of this smart city may be and what categorizes a city as being ‘smart’ but data analytics has been a major contributor to the evolution of this term. Urban areas are constantly being instrumented with digital devices and sensors in order to collect wide ranges of data (Kitchin, 2014). This data is being used to quantify the various characteristics of a city which can make a city much more intelligent and innovative resulting in a ‘Smart City’.

As the collection of all kinds of data for the purpose of analytics becomes more attractive for city developers, it is necessary to keep in mind the cost being invested in these data collection methods. As cheaper electrical components are now easily available, it has become possible to deploy sensors all across the city. This has led to the beginning of a community where data provides a means of analyzing small everyday patterns throughout the urban environment. It has set the notion of quantifying daily activities that occur in a city by analyzing data and coming up with innovative ideas for development based on this quantification.

Urban science has become one of the most emergent fields and it has become a challenge to now define various phenomenon that occur throughout a city in the form of mathematical formulae similar to those in Physics, Chemistry and Biology. However, a large aspect of urban science also involves the inclusiveness of social sciences because in order to quantify human activity it is necessary to take into account behavioral factors. Hence, urban science is a study of both fields combined. An important component of urban science is studying the flow of entities throughout the city. This includes the flow of pedestrians across the urban environment.

Monitoring the flow of pedestrians is becoming an increasingly popular topic for data analysis. Macroscopic models of pedestrian flow patterns use data to form an analogy of a moving crowd with that of a continuum medium characterized by averaged quantities such as density and mean velocity (Twarogowska, Goatin, & Duvigneau, 2014). This modern research
has labeled pedestrians in a crowd as ‘thinking fluids’ (Hughes, 2003) and aims to improve the flow of pedestrians in different situations. Unlike modeling a vehicular traffic flow throughout the city, pedestrians have fewer limitations in their movement which makes the pedestrian model much more sophisticated. In many cases, the behavioral aspect is also dominant in the model. These additional features of pedestrian flow modeling are what make it an intriguing field of research.

**Urban Challenge**

As the ‘thinking fluids’ model becomes more and more popular, it is necessary to collect more data that can reinforce the results that are being generated from the different approaches being used to develop this model. This can be done by implementing urban sensors in different parts of the city as the crowd characteristics vary in different areas. The purpose of this project has been to be a part of this challenge and come up with a low cost sensor that can be deployed in the urban environment in order to collect pedestrian data.

New York City is one of the most crowded cities in the world. The flow of pedestrians is very dense throughout the city, especially within the areas which are the common tourist attractions. One of the most common tourist attractions is the Brooklyn Bridge. During the summer time it is flooded with pedestrians throughout the day. Alongside it is the Manhattan Bridge, which also has a walkway for pedestrians. The idea proposed in this project was to design a motion detecting sensor in order to get a count of people entering the bridges and then comparing this data to get a picture of what the variation in pedestrian traffic is on both these bridges.

After conducting a detailed review on the various motion detecting sensor components that are available, the PIR (Passive Infra-Red) sensor is found to be economical and relatively efficient in its ability to sense motion. This sensor is currently being used for multiple practical purposes which make it a reliable choice for this project.

One of the main uses of this sensor is in wireless sensor networks for surveillance systems that are used to detect intruders. The PIR sensor is optimal for this purpose because it does not require a receptor device on the object that it is detecting and it also works well in the darkness (Song, Choi, & Lee, n.d.). Both of these features make the PIR sensor an ideal component to be used to track pedestrians walking across the bridges. Its ability to detect objects in the dark is an added advantage because the bridge walkways are open to the public 24/7 allowing this sensor to count pedestrians even during the night.

Furthermore, an array of these low-cost PIR sensors can be used to track human motion (Zappi, Farella, & Benini, 2007). This enhances the spatial resolution being sensed by the sensor so that two individuals who are too close to each other can be sensed separately. This can be implemented in order to increase the accuracy of the number of people being logged in by the data. It also allows for a more directional detection of motion, that is, it can be used to count the number of pedestrians entering the bridge as well as the number of pedestrian leaving the bridge.
Design

The initial stage on the project was to understand the basic working of the PIR sensor. Figure 1 gives the dimensions of the PIR sensor module. It can be seen that it is a small and compact sensor. Due to its portable size, this sensor can be deployed into the urban environment with ease.

Figure 1: The dimensions of the PIR sensor module

Figure 2 shows the pin layout for the PIR sensor. The positive and negative terminal represent the 5 volt power supply and the ground terminal respectively. The third pin labelled ‘OUT’ is the output signal generated by the sensor when motion is detected.

Figure 2: Pin Layout

The yellow knob in figure 3 is the control for the potentiometer that is used to control the on time of the sensor. The potentiometer is all the way to the right which means that the on time

Figure 3: The PIR sensor module potentiometer to control ‘on time’
for the PIR sensor is only on for one second. This is important because if the sensor is on for longer it may miss out on people who pass by during this on time.

The second yellow knob on the PIR sensor is the control for the potentiometer which is responsible for the adjustment of sensitivity. The position shown in figure 4 represents the most sensitive case. In this state, the sensor can detect movement from over 10 steps away.

![Figure 4: The PIR sensor module potentiometer to control ‘sensitivity’](image)

After these adjustments are made, it takes about a minute for the PIR sensor to adjust to its environment and start detecting any kind of motion. Figure 5 shows the basic principle being used by the PIR sensor to detect motion. The infra-red waves detect object which are not in thermal equilibrium with the surroundings. Hence, the human body which is at a different temperature is sensed by the PIR and the signal pin of the PIR generates an output signal which represents a detection of motion.

![Figure 5: Basic principle of motion detection](image)

The prototype being created in this experiment consists of two PIR motion sensors connected at a certain angle to each other as shown in figure 6. The circuit has been designed in such a way that it will sense a one-directional movement of a pedestrian. The sensor marked ‘1’ detects an incoming pedestrian. The output signal generated from the first sensor will trigger the sensor marked ‘2’. If there is an output signal from the second sensor also then both the output signals will be TRUE which will result in an increment in the count. However, in the case where there is no output generated from sensor ‘2’, meaning that the pedestrian has not crossed both the sensors, the result will be read as a FALSE and there will be no increment in the pedestrian count.
Data Collection

The sensor designed for the purpose of this project has been used to collect data on the Brooklyn Bridge and the Manhattan Bridge. The prototype that was developed was deployed on both the bridges and a small sample of data was collected in order to check whether the sensor was working as expected and to carry out a further analysis on the data to see if there could be any trends observed.

Figure 6: Two PIR sensors at an angle for detection in one-way

Figure 7: Pedestrian crossing the PIR sensor

Figure 8: Data Collected on Brooklyn Bridge
The prototype that was deployed to collect the experimental data can be seen in figure 8 and figure 9. Both the figures show two images which show the state of the sensor before it has detected any motion, and then in the following image the LED turns on which signifies that a movement has been detected. In figure 8, the sensor is placed on the Brooklyn Bridge and the pedestrian in the blue shirt is seen to be detected as the LED turns on.

Since the sensor has been developed at a very basic level, the accuracy of this sensor is still low. If masses of people go past it, there will be a confusion as to whether a count should be incremented or not. In order to take into account this problem, a manual count was also done alongside the count from the sensor. This manually collected data was used to check the efficiency of the sensor.

**Real World Data Analysis**

Since there was a need to collect the data in a way that it included timestamps, the software ‘CoolTerm’ was used to keep a log of the data. This software automatically sends all the data that is being collected to a text file and then the data can be formatted in a csv file according to various fields.

According to the design of the sensor, the sensor 1 detecting the incoming pedestrian printed out a ‘1’ if it sensed motion and subsequently if sensor 2 got triggered and also detected motion it printed out a ‘-1’. This combination of ‘1’ and ‘-1’ has been considered to be an increment in the pedestrian count.
The following table shows how the data was being logged into the csv file:

<table>
<thead>
<tr>
<th>Timestamps</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015-07-22 18:48:48</td>
<td>1</td>
</tr>
<tr>
<td>2015-07-22 18:49:22</td>
<td>1</td>
</tr>
</tbody>
</table>

Several plots have been created to give a general idea of what the data collected looked like and whether any conclusions could be drawn from it.

Figure 10: Time Series of Pedestrian Count on Brooklyn Bridge

Figure 11: Time Series of pedestrian count on Manhattan Bridge
The time series plots show how the number of pedestrians walking on to the bridge varied with time. Figure 10 shows the data for Brooklyn Bridge and figure 11 shows the data for the Manhattan Bridge. It can be seen that the overall pattern for the Brooklyn Bridge remains constant and it is higher than the count for the Manhattan Bridge. Data collected over a longer period of time could show a more detailed pattern.

Another analysis that was done on the data collected was to see the distributions of the frequency of the pedestrians per minute count for each bridge. Figure 12 shows these distributions for both the bridges. It can be observed that the Brooklyn Bridge had an overall higher count as compared to the Manhattan Bridge. This may be explained by a couple of factors including the fact that the Brooklyn Bridge is a Landmark and it is visited by many tourists every day. The Manhattan Bridge may mostly be used by people who work close to it and walk across it to get home. Such external factors that are taken into account to explain the trends in the data are what constitute of the urban science aspect of this project.

**Improvements**

In every project, there is always room for improvement. Given more time, there could be some additional features that could have been incorporated into the design which could have improved the design to a great extent. Currently, only two PIR sensors have been placed at angles to detect the pedestrians but if more of these PIR sensors were places in an angled array, it would greatly increase the accuracy at which the pedestrians are being detected and counted.

Furthermore, if separators are placed between each of these PIR sensors, it will focus the rays of the sensor in a more directed way. These focused infrared rays are theoretically more likely to detect movement as compared to a more dispersed sensor ray.

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**Figure 12: Distribution of pedestrians per minute**
These separators can be installed along with a proper casing for the sensor circuit. A Printed Circuit Board (PCB) implementation can make the circuit more compact as there will be no hanging wires. An SD card can be used to log the data and a battery pack can provide power for the Arduino Board. These two components will make the sensor even more portable and allow for it to be deployed in more complex areas. The casing can also provide stability to the sensor which will remove any random movements that can occur because of the inefficient placement of the circuit.

If the steps mentioned above are accomplished this will enable the more robust implementation of the sensor in the real world. Subsequently, it will allow for the collection of data over a longer period of time.

**Future Work**

The implementation of these sensing networks can further be expanded to other public areas as well, such as park and mall entrances. This can help provide the concerned authorities with an overview of the amount of people visiting these areas at different times of the day as well as at different occasions. Likewise, such systems can also provide the number of people at any place at any given time so that in case of an emergency evacuation, a physical headcount can be matched against the sensor provided numbers to check if all people have been evacuated.

Similarly, these sensor networks may also be used at subway emergency exits. This will keep track of the people who do not exit through the turn-slides. This will enable the City to collect additional data for the outflow of people from different subway stations. Using this data combined with the turn-slide data, a more detailed map of the flow of people throughout the subway system can be analyzed. This can allow the NYC Metropolitan Transportation Authority to better allocate their trains to stations where there is a higher number of passengers.

From the current research that is being conducted by people on pedestrian flow modeling, it is evident that this is an important aspect of urban science. Therefore, this project can be a useful tool in order to develop this research, not only because the designed circuit is economical, but also because it is possible to optimize PIR sensors further to collect urban data in an efficient way.
References


Links:

http://content.solarbotics.com/products/datasheets/pirsensor-v1.2.pdf
http://letsmakerobots.com/content/motion-tracking-head-using-4-pirs-servo-and-arduino-uno
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