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Embedded System Design of a Real-time Parking Guidance System

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Embedded System Design of a Real-time Parking Guidance System

by

Omkar Dokur

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Electrical Engineering
Department of Electrical Engineering
College of Engineering
University of South Florida

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DEDICATION

To my loving family for their patience and support.

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ABSTRACT

The primary objective of this work is to design a parking guidance system to reliably detect entering/exiting vehicles to a parking garage in a cost-efficient manner. Existing solutions (inductive loops, RFID based systems, and video image processors) at shopping malls, universities, airports etc., are expensive due to high installation and maintenance costs. There is a need for a parking guidance system that is reliable, accurate, and cost-effective. The proposed parking guidance system is designed to optimize the use of parking spaces and to reduce wait times. Based on a literature review we identify that the ultrasonic sensor is suitable to detect an entering/exiting vehicle. Initial experiments were performed to test the sensor using an Arduino based embedded system. Detection logic was then developed to identify a car after analyzing the initial test results. This logic was extended to trigger a camera to take an image of the vehicle for validation purposes. This system consists of Arduino, ultrasonic sensor, and a temperature sensor. It was installed and tested in Richard Beard Garage at the University of South Florida for five days. The test results of each trial are provided and average error for all the trials is calculated. The error cases occur due to golf carts, straddling cars on both entry/exit lanes, and people walking under the sensor. The average error of the system is 5.36% over five days (120 hrs). The estimated cost for one detector per lane is approximately \$30.

CHAPTER 1 : INTRODUCTION AND MOTIVATION

Parking a car is becoming a challenge to drivers. Drivers are frustrated while waiting for a long time in a queue or will just drive through the entire parking lot but still unable to find a parking spot [3]. While searching for a vacant parking spot, fuel is lost, and time is wasted; this also increases the traffic due to slow moving vehicles that are driving around the parking garage [3]. Further it contributes to green house gas emissions (CO_2 emissions). A study from Boston University states that more than 30% of the drivers take around 7.8 minutes to park their vehicle [4]. Parking spaces are necessary to park the vehicle, and the need is increasing day by day as there are more cars on the road than the number of parking spaces [5]. The only way to optimize the use of parking space and reduce the parking wait time is to install a proper parking guidance system. For this reason, University of South Florida (USF) Center for Urban Transportation and Research (CUTR) proposed a smart parking guidance system project to improve the parking experience for students, faculty, and visitors on campus. The project is funded by Student Green Energy Fund (SGEF). This thesis focuses on designing of an embedded system that detects vehicles when they enter/exit the parking garage. This system is part of an overall parking guidance system that can facilitate the drivers to know the available number of spaces in a parking lot/garage before entering via a smart phone app.

1.1 Motivation for Smart Parking

The University of South Florida (USF) has four parking garages and eighty eight surface lots providing 20,000 parking spaces. However, students and faculty still find difficulty in parking their vehicles during rush hours leading to excess fuel consumption. The Center for Urban Transportation and Research (CUTR) surveyed (unpublished) three parking lots (CBG, 29A, 29B) at USF to estimate the average time taken by drivers to park their vehicle. On average, each student takes 3.76 minutes to park their vehicle in the above three garages which produces approximately 332 metric tons of CO_2 emission annually into the campus environment. Fuel and time can be saved by informing users about the space availability well in advance. With a reliable parking guidance system, we can reduce the time taken by students to park and decrease CO_2 emissions, thus protecting the environment. According to the CUTR surveys, if the parking time is reduced by 2 minutes, the CO_2 emissions would be reduced from the three garages to 155 metric tons (53% annual reduction). Figure 1.1 is the preliminary estimation done by CUTR. This primarily motivated us to research a parking guidance system that is reliable, efficient, and economical.

1.2 Proposed Embedded System

This section discusses the embedded system researched in this project. An overview of the embedded system is given. The advantages and disadvantages are also discussed.

1.2.1 Overview

The idea of using a ready made embedded platform led us to choose Arduino, an open source platform that has easy to use hardware and software. We selected Arduino UNO because of its

Figure 1.1: Preliminary CO_2 estimation by CUTR

excellent features and low price. Ultrasonic sensor HC-SR04 is the sensor used for detecting vehicles.

Temperature sensor TMP-36 is used to measure the temperature of the air.

1.2.2 Advantages/Disadvantages

This section lists the advantages and disadvantages of the proposed embedded system.

1. Advantages

- Consumes less power
- Easy to install in the garage
- Cost efficient

2. Disadvantages

- Detects people as a car

- Detects golf cart as a car

These can be overcome by further extending the design as discussed in future work section.

1.3 Novelty and Contributions

The proposed parking guidance system presents a unique method of vehicle detection using an ultrasonic sensor. Although researchers have used ultrasonic sensor to detect empty parking spaces, to best of our knowledge, no prior researcher have used it to detect vehicles in motion. We also show the logic involved in detecting the vehicle using flowcharts. The system is cheaper than any other available parking technologies. We built a working prototype and demonstrated its efficacy in detecting vehicles reliably in an on-campus garage over 5 days. We survey extensively the possible sensors and compare them in detail. This is useful for future researchers working on this problem.

1.4 Organization of Thesis

The rest of the thesis is organized as follows. Chapter 2 presents a literature survey on sensor to detect a vehicle, discusses existing parking technologies and the commercial systems considered by CUTR. Chapter 3 describes the proposed vehicle detection system with the logic involved in identifying a vehicle. It also estimates the power consumption of the system, and cost of the system. Chapter 4 details the experimental set up used, and provides the initial experimental data collected for vehicle detection. It also reports and analyzes the data collected in a 5-day trial. Chapter 5 concludes the thesis and outlines the future work.

1.5 Chapter Summary

In this chapter, the challenges involved in parking a vehicle in a high demand parking lot are explained. The motivation behind this project is also discussed. The overview of the embedded system is presented.

CHAPTER 2 : RELATED WORK

We review existing vehicle detection sensor technologies and compare them with the proposed system. CUTR has considered a few commercial technologies to be installed at USF. We will also review these commercial systems.

2.1 Study of Existing Vehicle Detection Sensor Technologies

The existing systems use the following sensor technologies: 1) Active infrared sensor; 2) Passive infrared sensor; 3) Microwave radar; 4) Ultrasonic sensor; 5) Inductive loops; and 6) Radio frequency identification. Below we will briefly explain the operating principles of each technology.

1. Active Infrared Sensor: In active infrared sensors, a light emitting diode transmits infrared light and a photodiode receives the reflected light back [6]. Photodiode registers an object only if the path of the light is distorted. Here the transmitter, i.e., the permit, should be mounted on top of the windshield as the beam cannot penetrate the windshield. There is a possibility of theft of the tag if it is placed on the windshield of the car.
2. Passive Infrared Sensor (PIR): The passive infrared sensor works on the basis of ambient temperature. It detects incident infrared radiation that varies in proportion to the temperature difference between the vehicles and surrounding environment [7]. This sensor sends a pulse if the temperature difference is greater than 4°C. The reliability of this sensor is questionable under dynamic weather conditions as dust, gases, or vapor can cause inaccuracies in measure-

ment and may damage sensor lenses [8]. This sensor may detect person as a car which leads to unreliable parking count.

3. Microwave Radar: Microwave sensors are based on the Doppler Effect. The transmitter emits a radio wave on the surface of the object and a receiver embedded in the sensor receives the reflected wave. Using the frequency shift of the wave reflected from a moving surface, microwave sensors can calculate speed and distance of the object. Passive microwave sensors detect naturally emitted microwave energy within its field of view. All objects emit microwave energy of some magnitude, which is related to the temperature and moisture properties of the emitting object. These sensors are typically radiometers or scanners that use an antenna to detect and record the microwave energy [6]. These sensors can be affected by noise.
4. Ultrasonic Sensor: Most of the present technologies use an ultrasonic sensor to detect a vehicle [5, 9, 10]. Ultrasonic sensors transmit sound pulses to the ground and detect reflected pulses [6]. A sensor is used in each parking spot, and the status of each space is transmitted to the central control unit using Zigbee network configurations. This kind of a parking system requires installation of the sensor at each spot. Maintenance of Zigbee network configurations involves manpower and requires high installation costs.
5. Inductive Loops: Inductive loops detect metal objects using electromagnetic principle [11]. The system requires installation of sensors into the pavements at each entrance/exit to maintain the count of the vehicles, and at each spot for space indication. This requires massive amounts of labor if it is to be done on a large scale.
6. Radio Frequency Identification (RFID): RFID technology requires a tag for each vehicle and a reader where reader detects the tag [6, 8]. The system needs drivers to drive their car under

the reader. In this case, there are chances of the reader missing the tag. Moreover, the reader may not be able to detect a vehicle without a tag. All these factors can give an error in the aggregate count in the parking lot for this kind of system.

2.2 Comparison of Existing Systems with the Proposed System

Table 2.1 compares the proposed system with the existing systems. The current sensor technologies (active infrared, passive infrared, microwave, inductive loop, ultrasonic, and RFID) are compared with the proposed parking guidance system. The metrics considered for comparison are installation, maintenance, cost, and accuracy of the systems. These factors are examined to analyze the advantages and disadvantages of the existing parking technologies with the proposed parking guidance system (Table 2.2).

Table 2.1: Comparison of sensor technologies

Sensor Technology	Installation	Maintenance	Cost	Accuracy
Active Infrared Sensor	Ceiling Mount	Medium	Expensive	Accurate
Passive Infrared Sensor (PIR)	Ceiling Mount	Low	Expensive	Unreliable
Microwave Sensor	Ceiling Mount	Medium	Expensive	Accurate
Inductive Loop Sensor	Surface Pavements/ Ceiling Mount	Low	Very Expensive	Highly Accurate
Ultrasonic Sensor	Ceiling Mount	Medium	Expensive	Accurate
RFID	Ceiling Mount	Medium	Expensive	Accurate in controlled situations
Proposed System	Ceiling Mount	Low	Economical	Accurate

As Table 2.2 indicates, inductive loops give high accuracy, but can be costly. RFID technology has high precision, but it detects only cars with tags. This may lead to an inaccurate count over time. Also, the price of readers is very expensive. The parking count with infrared and ultrasonic sensor technologies is estimated by installing these sensors in each space. Installing sensors for each space is costly and requires maintenance. Also, the PIR sensor is affected by climatic conditions and is unreliable. Microwave sensor technology gives an accurate count, but is very expensive. The proposed system is economical, requires low maintenance, easy to install and is accurate. The only disadvantage of the system is that it can incorrectly counts golf carts and peoples walking under the sensor as vehicles.

Table 2.2: Advantages and disadvantages of sensor technologies

Sensor Technology	Advantages	Disadvantages
Active Infrared Sensor	<ul style="list-style-type: none"> - Easy to mount receiver on the ceiling - Accurate 	<ul style="list-style-type: none"> - Permit tag to be mounted on top of wind shield which may lead to theft of the tag - Costly
Passive Infrared Sensor	<ul style="list-style-type: none"> - Requires low maintenance 	<ul style="list-style-type: none"> - May detect person as a car which leads to unreliable parking count - Costly
Microwave Sensor	<ul style="list-style-type: none"> - Low maintenance 	<ul style="list-style-type: none"> - Affected by noise - Can detect anything as a car
Inductive Loop Sensor	<ul style="list-style-type: none"> - High Accuracy - Low Maintenance 	<ul style="list-style-type: none"> - Surface installation may be too complex and difficult to change once installed - Very Expensive
Ultrasonic Sensor	<ul style="list-style-type: none"> - High Accuracy 	<ul style="list-style-type: none"> - Requires installation in each space - Very expensive
RFID	<ul style="list-style-type: none"> - High Accuracy 	<ul style="list-style-type: none"> - Detects only cars with RFID tags - Very expensive as four readers required which costs up to \$7,000 each
Proposed System	<ul style="list-style-type: none"> - Economical - Low Maintenance - Easy to install - Optimum Accuracy 	<ul style="list-style-type: none"> - Detects golf cart as a car - Detects people as a car

2.3 Commercial Systems Considered by CUTR

The commercial systems considered by CUTR are: 1) Inductive loops; 2) Individual space sensors; 3) RFID; and 4) License plate recognition cameras. The hardware costs, maintenance, installation, advantages, and disadvantages of each system are discussed below.

1. Inductive Loops

This system includes installation of inductive loops (electro-magnetic sensors) into the pavements in surface lots or affixed to the ceiling in the garages and gives an aggregate count of the vehicles entering/exiting the garage. Hardware costs are around \$10,000 - \$15,000 per entrance/exit. It has low maintenance and minimal monitoring software costs. It is a tried and tested technology and can give the accurate aggregate count. CASE Systems and TCS International are the vendors offering this technology. The advantages of this system are:

- (a) High accuracy
- (b) Low maintenance, and
- (c) Minimal monitoring and software costs

The disadvantages of the system are:

- (a) High cost
- (b) Low flexibility

2. Individual Space Sensors

Each space in the garage is equipped with an individual space sensor. Electromagnetic sensor technology is used which can be cut into pavements or affixed to the ceiling. This system

is very expensive and costs \$200 - \$250 per parking space. It has a high level of accuracy and requires minimal monitoring software costs. Streetline, Inc. offers this technology. The advantages of this system are:

- (a) High accuracy
- (b) Low maintenance, and
- (c) Minimal monitoring and software costs

The disadvantages of the system are:

- (a) High cost if installation in garages is widespread
- (b) Alteration in infrastructure needed if space designations are changed

3. RFID

In this technology, a microchip is embedded into permit types and the RFID reader identifies the permit of the vehicles entering/exiting the garage. The reader is mounted on the ceiling of the garage or near to entrance/exit. To ensure accurate vehicle count, lane dividers are required to determine the direction of the traffic. The permit costs \$15 - \$20 and \$7,000 per reader. It has high accuracy in only controlled situations. TransCore offers RFID smart parking system. The advantages of this system are:

- (a) High level of accuracy when lane dividers are used
- (b) Readers can be installed in any parking lot

The disadvantages of the system are:

- (a) Cannot detect vehicles without a permit

- (b) More chances of reader missing the tag, and
- (c) High cost as it requires at least four readers for a garage

4. License Plate Recognition (LPR) Cameras

Infrared digital cameras and dedicated software are used in license plate recognition to detect and read the letters on car's license plate. The detected license number is compared with stored license plate number registered with the institution to determine the permit type related to the vehicle. AutoVu is the dedicated software used and requires a minimum of two cameras per entrance/exit installed above the entrances/exits where the cost of each camera is \$10,000. The cameras need a direct line of sight to maintain an accurate count. Genetec offers this technology. The advantages of this system are:

- (a) Gives 93% - 95% of accuracy
- (b) AutoVu is adaptable with the USF server applications

The disadvantages of the system are:

- (a) Adaption of new software includes additional costs
- (b) Using cameras may raise privacy issues
- (c) Very expensive as minimum of two cameras required per entrance/exit, and
- (d) Cannot read the license plate number if there is no line of sight

After analyzing the present technologies, further study was conducted to find an economical sensor, that would be most reliable, efficient, and accurate.

2.4 Chapter Summary

This chapter discussed existing vehicle detection sensor technologies. Characteristics of these sensors are discussed and are compared to better understand their behavior. In summary, several technologies have trade-offs in terms of accuracy, cost, and installation.

CHAPTER 3 : PROPOSED PARKING GUIDANCE SYSTEM

We present in detail the proposed parking guidance system based on ultrasonic sensor and Arduino. We will describe the design flow used to arrive at the proposed system configuration. Briefly the tasks are:

1. Determination of sensor
2. Initial trials to consolidate detection logic
3. System prototyping, and
4. Cost and power analysis

3.1 Proposed System Overview

The overall system detects a car entering the garage and triggers a camera to capture an image of the windshield as shown in Figure 3.1. The image is used to identify the type of vehicle decal and therefore to count vehicles by permit type. After determining the decal type, parking count is updated in real-time on the server as shown in Figure 3.2. The parking count is accessible to the drivers through a smart phone app.

The proposed embedded system detects a vehicle, triggers the camera to capture images and maintains the count of the vehicles. The system uses an ultrasonic sensor, an Arduino microcontroller board, and a temperature sensor. The system maintains the count of the vehicles, which provides the number of parking spots available in the parking lot. Also, a camera is triggered to take 2-5

Figure 3.1: Recognition of decal type

Figure 3.2: Real time parking information to drivers

images the moment a vehicle is detected. These images were used for further research and also to verify the system's efficiency. The two versions of the system are: counter version which maintains

the overall count of the garage and, trigger version which triggers camera for decal recognition. This thesis reports the counter version.

3.1.1 Block Diagram

Figure 3.3 shows the block diagram of the parking guidance system. Arduino Uno, ultrasonic sensor, and temperature sensor are used to build the system. Ultrasonic sensor works on the principle of sound waves and the speed of sound is sensitive to air temperature. Temperature sensors estimates the speed of sound which removes the error due to changing weather conditions. First, ultrasonic and temperature sensors are connected to the Arduino microcontroller. The controller detects the vehicle by triggering the sensor, and then it counts the vehicle and triggers the camera to send images to the web server.

Figure 3.3: System block diagram

3.1.2 Counter Version

The working model of a counter version is shown as simple count system in Figure 3.3. Here, the microcontroller checks for obstacle by triggering the ultrasonic sensor. Whenever an obstacle is

detected, the controller determines if the obstacle is a vehicle or not by triggering more pulses. The logic involved in vehicle detection and count is thoroughly explained in Section 3.5. Once the vehicle is detected, the web server is updated with increment/decrement in the number according to entry/exit as shown in dotted lines. For the overall count of the parking lot, this kind of system is installed at each entry and exit and is integrated with the web server. The web server calculates the overall count by subtracting the number of vehicles exited from the number of vehicles entered.

3.1.3 Triggering Camera

The parking guidance system is designed to trigger an external camera to take a video/image when a vehicle is detected. Axis Q1614, a network camera is used in this system. It has four I/O ports as shown in Figure 3.4, in which one of them is trigger input. Once the processor detects a vehicle, it sends a pulse to the camera through the I/O pin 3 of the camera.

Figure 3.4: I/O pins of Axis Q1614 (Source: [1])

An nMOSFET transistor (IRF510) is used to implement the switch as shown in Figure 3.4. The trigger input from the processor is connected to the gate terminal. Drain and source terminals are connected to the I/O pins 3 and 1 of the camera respectively. The source terminal is grounded via pin 1. When trigger input is high, video or image is captured. Camera trigger system was used to test the system's efficiency which will be discussed in Chapter 4.

3.2 Research of Sensor Technologies

The selection of a sensor for this kind of application is a challenging task. Sensor technology can be classified as *visual* and *non-visual*. Visual based sensors include still and video cameras, while non-visual based sensors includes infrared, ultrasonic, and microwave sensors.

3.2.1 Visual Sensors

Visual based detection of a vehicle uses video cameras. Video image cameras use image processing and license plate recognition techniques to detect vehicles [6]. Cameras installed at both the entrance and exit of the parking lot are used to maintain an overall vehicle count. Image processing techniques are used to detect a vehicle [9]. A vacant spot is detected by installing a camera for three spots. License plate recognition identifies the vehicle and its information [12]. Using this system on a large scale involves high installation costs.

Visual based detection methods have a drawback in accuracy as they are easily affected by environmental conditions. The primary problems are occlusion effects, shadow effects [9] and improper lighting conditions. A fully occupied space can be counted vacant in high lighting conditions, and an empty space may be considered occupied in poor lighting conditions due to shadow effects [9]. Further research has been done in identifying a reliable sensor to detect a vehicle.

3.2.2 Non-Visual Sensors

A detailed study of sensors that can be mounted on the roof of the parking garage are considered. Specific sensor technologies are active and passive infrared sensors, ultrasonic sensors, and microwave sensors. The characteristics of these sensors studied are supply voltage, current consumption, power consumption, output type, accuracy, cost, operating temperature, range, and sensing area of the sensor (Table 3.1).

After a thorough review of characteristics from Table 3.1, these sensors are compared in Table 3.2 that helps in the proper selection of the sensor. The system requirements are 5 m range, 4-5 m^2 of sensitive area and few dollars cost. Active infrared, passive infrared (PIR) and microwave sensors are ruled out for our application for several reasons. Active infrared has a short range of detection of 1.5 m. Standard PIR has a excessively wide sensing area of 41.92 m^2 . Slight PIR has poor range of detection of 2 m. 10-meter detection PIR has large sensing area of 195.57 m^2 , which is too high for this application. Ideally we want the sensing area to be wide enough to accommodate a standard vehicle. Microwave sensor requires external installation of an antenna that requires its maintenance. Ultrasonic sensor stands out to be the most reliable, efficient, and economical sensor. It has an acceptable range of detection of 4.5 m and a safe operating range of temperature of -10°C to $+50^{\circ}\text{C}$. It is efficient because it has a fast response time of 25 milliseconds and sensing angle of 15° . It is economical because it is available for less than \$2 and easy to install in the field.

Table 3.1: Characteristics of sensors

Sensor	DC Supply (Volts)	Current mA	Power mW	Output Type	Accuracy	Cost (\$)	Operating Temp (°C)	Range (m)	Area m^2
Active Infrared Sensor	4.5 to 5.5	33	165	Analog	10 cm to 30 cm	\$14	-10° to +60°	0.2 to 1.5	-
Passive Infrared Sensor (Standard Detection Type)	4.5 to 5.5	0.1	2	Digital and Analog	Accurate within range	\$15	-20° to +60°	0 to 5	41.9 m^2
Passive Infrared Sensor (Spot Detection Type)	3 to 6	0.17	0.57 to 0.85	Digital and Analog	Accurate within range	\$15	-20° to +60°	0 to 5	2.8 m^2
Passive Infrared Sensor (Slight Detection Type)	5	0.17 to 0.3	0.85 to 1.5	Digital and Analog	Accurate within range	\$15	-20° to +60°	0 to 2	19.6 m^2
Passive Infrared Sensor (10 m Detection Type)	5	0.17 to 0.3	0.85 to 1.5	Digital and Analog	Accurate within range	\$15	-20° to +60°	0 to 10	196 m^2
Microwave Sensor	4.75 to 5.25	30 to 40	15 to 100	Digital and Analog	Accurate within set frequency	\$10	-15° to +55°	Varies on set freq.	-
Ultrasonic Sensor	5	20	100	Digital	High accuracy up to 3 mm	\$2	-10° to +50°	0.02 to 4.5	1.1 m^2

3.3 Vehicle Detection by Ultrasonic Sensor

Vehicle detection in this system is achieved with HC-SR04, an ultrasonic sensor. This sensor offers an excellent non-contact range detection with high accuracy. HC-SR04 consists of a transmitter

Table 3.2: Comparison of sensors considered for vehicle detection

Sensor	Power Consumption	Analysis of Range	Analysis of Cost	Installation	Sensing Area
Active Infrared Sensor	High	Poor	Low	Easy to install	-
Passive Infrared Sensor (Std. Detection Type)	Low	Good	High	Easy to install	Medium
Passive Infrared Sensor (Spot Detection Type)	Low	Good	High	Easy to install	Smaller
Passive Infrared Sensor (Slight Detection Type)	Low	Poor	High	Easy to install	Smaller
Passive Infrared Sensor (10m Detection Type)	Low	Good	High	Easy to install	Larger
Microwave Sensor	Low/ Medium	Good	Medium	Requires antenna to be installed	-
Ultrasonic Sensor	Medium/ High	Good	Low	Easy to install	Smaller

head that converts electric pulse to sound pulse, and a receiver head that converts sound pulse back to an electric pulse. The transmitter head sends a sound pulse and the receiver head receives it back if any obstacle is present within its range of detection.

Figure 3.5: HC-SR04 ultrasonic sensor (Source: [2])

3.4 Arduino Microcontroller Board

Arduino UNO is the microcontroller board used in this application. It has easy to use hardware for prototyping, low cost and has simple software development interface. It contains ATmega328 microcontroller chip with a clock speed of 16 MHz, which accelerates the system response time. ATmega328 is a low power AVR 8-bit microcontroller with 2 KB SRAM. It has 23 programmable I/O lines of which Arduino UNO provides 12 digital I/O pins (2 - 13) and 6 analog I/O pins (A0 - A5) as shown in Figure 3.6.

The trigger and echo pins of the ultrasonic sensor are connected to the digital pins 2 and 3 of the board respectively. After the system is powered on, the processor sends a pulse, starts an internal timer, and waits for a given timeout. If an obstacle is detected within the timeout, the processor receives the pulse through the echo pin and stops the timer. The processor returns the time taken by pulse to travel in microseconds. This time is used to calculate the distance of the obstacle, as explained in Section 3.5 later. If no obstacle is detected, the timer stops after the timeout and sends a pulse again.

Figure 3.6: Arduino UNO

3.5 Vehicle Detection Logic

As discussed the controller pulses the ultrasonic sensor and calculates the time taken by the pulse to return. The distance of the obstacle is calculated using the speed of sound in air as the ultrasonic sensor works on the principle of sound waves. The speed of sound (m/s) in dry air at a given temperature (in Celsius) is given by Equation 3.1.

$$Estimated_Speed_of_Sound = 331.5 + (0.6 * Temperature) \quad (3.1)$$

As the speed of sound varies with the air temperature, a temperature sensor is used to correct the errors due to changing weather conditions. The distance calculated is twice the actual distance as the pulse travels from the transmitter to an obstacle, bounces back from the obstacle, and finally reaches the receiver. The distance of obstacle is given by Equation 3.2.

$$2 * Distance_of_Obstacle = Speed_of_Sound * Time_Elapsed \quad (3.2)$$

The ultrasonic sensor is installed to the ceiling at entrance/exit in a parking garage so that it detects the ground as an obstacle. The distance between the sensor and ground is considered as Maximum Range. When the system is powered on, the processor pulses the sensor and calculates the maximum range. After calculating the maximum range, the processor pulses the sensor continuously and checks for a change in the range. When an obstacle enters/exits the garage, the obstacle height is calculated by comparing obstacle distance with maximum range. The obstacle height calculated is used for vehicle detection and is explained further in Section 3.5.1.

3.5.1 Vehicle Detection and Count

The flow chart of logic to detect and count vehicles using an ultrasonic sensor is shown in Figure 3.7. After initial field tests the minimum vehicle height is 50 cm, and considered to be the minimum threshold height. The controller calculates the temperature of the air and calculates the speed of sound from it. Then it generates a pulse and calculates the maximum range as discussed in above section. Next, the controller calculates the obstacle height by subtracting new obstacle distance from the maximum range. The minimum height of the vehicle is set as minimum threshold height, and the obstacle height is compared with it. If the obstacle height is greater than threshold height, then it is considered to be an obstacle that can be a vehicle. This loop repeats for every five milliseconds and checks for the presence of an obstacle (vehicle).

After detecting an obstacle, the count logic checks whether it is a vehicle or not. A vehicle is a lengthier object, so time taken by it to cross the sensor will be more than time taken by the processor to complete one loop. The processor is so fast that it can complete a loop within 5 milliseconds, as discussed above for obstacle detection. For this reason, experiments are conducted to determine a minimum number of pulses a vehicle can take to cross the sensor, and minimum pulse width threshold

Figure 3.7: Flow chart of the logic to count the number of vehicles

is calculated. These calibration experiments are discussed in Chapter 4. Figure 3.7 shows the logic employed for vehicle count. First, an obstacle is detected using the detection logic. If no obstacle is detected, the processor stays in the inner loop to detect the obstacle. If any obstacle is detected, then the processor enters the outer loop and checks the obstacle for minimum pulse width threshold by

sending a set number of pulses. The processor exits out of this loop, if obstacle does not satisfy the condition specified. If the obstacle satisfies the required condition, i.e., it is present for minimum pulse width threshold, then processor determines that it is a vehicle and increments/decrements vehicle count. If vehicle stays under the sensor for a longer time, the processor enters the outer loop, waits until the vehicle leaves the sensor arena. This logic is accurate which can record overall count of the parking garage.

3.5.2 Camera Trigger

The parking guidance system is used to trigger a camera as discussed above in Section 3.1.3. This section explains the logic involved in triggering the camera. The same logic used for vehicle detection and count is used to trigger the camera.

The logic is same except that when a vehicle is detected, a digital pin on Arduino is set high which is connected to the I/O pin of the Axis Q1614 camera. Upon receiving the pulse, the camera can be configured to send a video/image to the web server. These images are used to validate the system as discussed in Chapter 4.

3.6 Power Consumption

The current consumption of the devices used by the system components are given in Table 3.3. The supply voltage is 5V. Arduino consumes 232.5 mW, ultrasonic sensor consumes 100 mW, and temperature sensor consumes 0.25 mW. The overall power consumption of the vehicle detection and count system is 332.75 mW.

Table 3.3: Current consumption of the components used in the system

Name of the component	Low power mode	Working current	Idle mode
Arduino UNO	34.4 mA	46.5 mA	-
Ultrasonic Sensor	10.0 mA	20 mA	15 mA
Temperature Sensor	0.5 μ A	50.0 μ A	-

3.7 System Cost

The proposed parking guidance is cost-efficient. TMP-36 is the temperature sensor used, and IRF510 is the nMOSFET used. The cost of each component is given in Table 3.4.

Table 3.4: Cost of the components used in the system

Name of the component	Cost of the component
Arduino UNO	\$25
HC-SR04	\$1
TMP-36	\$1.50
IRF510	\$1

The cost of different features of the system are given in Table 3.5. The overall cost of the system to detect and count the number of vehicles entering the parking lot is less than \$30 per each entrance/exit. Triggering a camera uses the same system used for vehicle detection and count. The cost of the system for this is less than \$30 per each entrance/exit. All these costs can be still reduced by designing custom PCB with ATmega328 microcontroller for their application.

Table 3.5: Cost of different features of the system

	Simple count system	Decal detection type based system
Arduino UNO	1 per entrance/exit	1 per entrance/exit
HC-SR04	1 per entrance/exit	1 per entrance/exit
TMP-36	1 per entrance/exit	1 per entrance/exit
IRF510	Not Required	1 per entrance/exit
System Cost	\$28	\$30

3.8 Chapter Summary

We presented in detail the designed parking guidance system. The different features of the system are shown in system block diagram and the logic involved for each of them is discussed. Also, research on sensor technologies was done to select a reliable sensor for this application. The hardware used for the system is also discussed. The power consumption of the system is calculated. The overall cost of the system is estimated.

CHAPTER 4 : EXPERIMENTAL RESULTS

After a thorough study of the ultrasonic sensor, experiments were conducted to test the sensor. Experimental setup required was designed to test the sensor in the field. The sensor was calibrated and initial feasibility tests were performed at Richard Beard Garage at the University of South Florida during weekends. Initial test data collected was by driving cars at various speeds. These results were analyzed and logic was developed for vehicle detection and count. Later, this system along with Axis Q1614 camera was deployed on the west entrance of Richard Beard Garage to run several trials to validate system.

4.1 Experimental Setup

A simple detection box is enough for data collection of vehicle detection as shown in Figure 4.1. The detector includes an ultrasonic sensor, temperature sensor, connecting wires, and an Arduino microcontroller board. The sensor was connected to an Arduino microcontroller board using connecting cables. An external battery was used to power the system during the initial feasibility tests. A computer compiled code to the microcontroller board. This detector is mounted temporarily at a height of 2.4 meters. Vehicles driven exactly under the detector yielded good results. The system was powered by pulling power lines from the camera.

Figure 4.1: Parking system experimental setup

4.2 Calibrating the Sensor

The ultrasonic sensor works on the principle of acoustics. The speed of sound varies with the temperature of the air. A temperature sensor (TMP-36) is used to estimate the speed of sound. Also, when the system is powered on, the sensor should detect the ground surface first to calculate the maximum range. There should be no obstacle underneath the sensor during the system startup.

4.3 Results from Initial Feasibility Tests

After installation of the sensor for vehicle detection, cars at various speeds drove underneath the sensor, the distances detected were analyzed, and variation of obstacle distances were calculated by the controller. ATmega328 triggers the pulse and calculates the echo time. The distance of the obstacle is calculated every 5 ms. When a vehicle approaches the sensor, the distance of the obstacle changes and if we plot those distances on a graph we can expect an inverted shape of the car. The test results are shown in Figure 4.2 and Figure 4.3. The results attained from the first set of experiments to detect a vehicle using ultrasonic sensor were as expected. Three cars drove underneath the sensor and distances detected were plotted with distance in meters as Y axis and time in milliseconds as X axis. Figure 4.2 is the plot for the first trial and Figure 4.3 is the plot for the second trial. The curved portions of both plots indicate the presence of a car and flat region shows the absence of a car.

Figure 4.2: Plot of distances of slow moving vehicles (5 mph)

Figure 4.3: Plot of distances of fast moving vehicles (20 mph)

After analyzing the results acquired from preliminary tests, the minimum time taken by a fast moving vehicle to cross the sensor was less than 100 milliseconds (Figure 4.3). These preliminary tests gave a minimum number of pulses a vehicle can encounter. This data was used to set a minimum number of pulses, i.e., threshold pulse width, for vehicle count. This can eliminate the error of counting a person as a vehicle, because the pulse width of a vehicle is greater compared to a person.

4.4 Field Trials

The detector along with Axis Q1614 camera was deployed at the West entrance of Richard Beard Garage as shown in Figure 4.4 to test the working of the system. The power to the detector box was pulled from the camera. As discussed, Axis Q1614 is a network camera that can send images from the camera to the database when it is triggered. When a vehicle enters the garage, the sensor system triggers the camera, and the camera would send the images to the local database set up at Center for Urban Transportation and Research (CUTR).

Figure 4.4: System installation at West entrance of Richard Beard Garage

Figure 4.5: Example of a golf cart entering the garage

Tables 4.1 - 4.5 show the number of cars detected by the system for five days during trials. In the tables, “Golf Carts” are small vehicles as shown in Figure 4.5. “Exiting Cars” are cars exiting from the garage and detected as cars entering the garage as shown in Figure 4.6. “People” are persons entering the garage and detected as cars as shown in Figure 4.7. “Cars Detected” are the total number of vehicles identified as cars by the system and “Actual Cars” are the cars that actually

Figure 4.6: Example of cars exiting from the garage

Figure 4.7: Example of people walking under the sensor

entered the garage excluding the golf carts, exiting cars, and people. Error percentage is calculated for each day and shown in each table. The Richard Beard Garage has a total of 3000 spots. It was determined that 5% to be an acceptable margin of error with system reset every month.

Table 4.1 shows the data collected for April 15 to April 16, 2015. By end of 24 hours, there was an error of 4.56%. 21% of error was due to Golf carts, 66% of the error was due to exiting cars and 13% error was due to people entering the garage. The "Cars Detected" and "Actual Cars" detected of Table 4.1 are compared and plotted against the "Hour" and shown in Figure 4.8.

Table 4.1: Day 1 - April 15 to April 16, 2015

Hour	Cars detected	Actual cars	Golf Carts	Exiting Cars	People	Error	Percent Error
6.40-7.40 pm	19	17	2	0	0	2	11.76
7.40-8.40 pm	19	16	1	2	0	3	18.75
8.40-9.40 pm	20	17	0	3	0	3	17.64
9.40-10.40 pm	34	28	1	3	2	6	21.42
10.40-11.40 pm	26	23	1	2	0	3	13.04
11.40-12.40 am	19	18	0	1	0	1	5.55
12.40-1.40 am	16	13	0	3	0	3	23.07
1.40-2.40 am	8	8	0	0	0	0	0
2.40-3.40 am	8	8	0	0	0	0	0
3.40-4.40 am	1	1	0	0	0	0	0
4.40-5.40 am	1	1	0	0	0	0	0
5.40-6.40 am	7	5	1	1	0	2	40
6.40-7.40 am	31	31	0	0	0	0	0
7.40-8.40 am	82	81	0	0	1	1	1.23
8.40-9.40 am	167	166	0	0	1	1	0.60
9.40-10.40 am	125	124	0	1	0	1	0.80
10.40-11.40 am	150	148	0	2	0	2	1.35
11.40-12.40 pm	160	157	1	2	0	3	1.91
12.40-1.40 pm	101	98	1	2	0	3	3.06
1.40-2.40 pm	90	85	3	2	0	5	5.88
2.40-3.40 pm	65	62	1	2	0	3	4.83
3.40-4.40 pm	54	46	0	5	3	8	17.39
4.40-5.40 pm	69	63	0	6	0	6	9.52
5.40-6.40 pm	33	32	0	1	0	1	3.12
24 hours	1305	1248	12	38	7	57	4.56

Table 4.2 shows the data collected from April 21 to April 22, 2015. By the end of 24 hours, there was an error of 4.75%. 13% of error was due to Golf carts, 84% of the error was due to exiting cars and 3% error was due to people entering the garage. The "Cars Detected" and "Actual Cars" detected of Table 4.2 are compared and plotted against the "Hour" and shown in Figure 4.9.

Figure 4.8: Day 1 plot

Figure 4.9: Day 2 plot

Table 4.3 shows the data collected from April 22 to April 23, 2015. By the end of 24 hours, there was an error of 4.64%. 20% of error was due to Golf carts, 62% of the error was due to exiting

Table 4.2: Day 2 - April 21 to April 22, 2015

Hour	Cars detected	Actual cars	Golf Carts	Exiting Cars	People	Error	Percent Error
4-5 pm	70	65	0	5	0	5	7.70
5-6 pm	35	31	0	4	0	4	12.90
6-7 pm	31	30	0	1	0	1	3.33
7-8 pm	23	18	1	4	0	5	27.80
8-9 pm	32	29	0	3	0	3	10.34
9-10 pm	20	14	0	6	0	6	42.85
10-11 pm	24	22	0	1	1	2	9.10
11-12 am	27	24	0	3	0	3	12.50
12-1 am	13	13	0	0	0	0	0
1-2 am	13	12	0	1	0	1	8.33
2-3 am	7	7	0	0	0	0	0
3-4 am	5	5	0	0	0	0	0
4-5 am	3	3	0	0	0	0	0
5-6 am	3	3	0	0	0	0	0
6-7 am	13	12	0	1	0	1	8.33
7-8 am	81	80	0	1	0	1	1.25
8-9 am	104	103	1	0	0	1	0.98
9-10 am	140	137	1	2	0	3	2.19
10-11 am	155	153	1	1	0	2	1.31
11-12 pm	72	70	0	2	0	2	2.86
12-1 pm	103	101	0	1	1	2	1.98
1-2 pm	105	101	1	3	0	4	3.96
2-3 pm	57	55	1	1	0	2	3.64
3-4 pm	77	70	1	6	0	7	10
24 hours	1213	1158	7	46	2	55	4.75

cars and 18% error was due to people entering the garage. The "Cars Detected" and "Actual Cars" detected of Table 4.3 are compared and plotted against the "Hour" and shown in Figure 4.10.

Table 4.3: Day 3 - April 22 to April 23, 2015

Hour	Cars detected	Actual cars	Golf Carts	Exiting Cars	People	Error	Percent Error
5-6 pm	26	19	0	7	0	7	36.84
6-7 pm	35	27	0	7	1	8	29.63
7-8 pm	25	23	0	2	0	2	8.70
8-9 pm	23	22	0	1	0	1	4.55
9-10 pm	23	20	0	1	2	3	15
10-11 pm	53	47	2	3	1	6	12.77
11-12 am	14	14	0	0	0	0	0
12-1 am	15	11	0	1	3	4	36.36
1-2 am	7	4	0	2	1	3	75
2-3 am	12	9	1	0	2	3	33.33
3-4 am	6	6	0	0	0	0	0
4-5 am	2	2	0	0	0	0	0
5-6 am	2	2	0	0	0	0	0
6-7 am	4	3	0	1	0	1	33.33
7-8 am	52	52	0	0	0	0	0
8-9 am	80	78	2	0	0	2	2.56
9-10 am	172	170	1	1	0	2	1.18
10-11 am	159	158	0	1	0	1	0.63
11-12 pm	82	80	1	1	0	2	2.5
12-1 pm	153	152	1	0	0	1	0.66
1-2 pm	123	120	0	3	0	3	2.5
2-3 pm	56	54	1	1	0	2	3.70
3-4 pm	61	58	2	1	0	3	5.17
4-5 pm	55	54	0	1	0	1	1.85
24 hours	1240	1185	11	34	10	55	4.64

Table 4.4 shows the data collected from April 23 to April 24, 2015. By the end of 24 hours, there was an error of 7.51%. 20% of error was due to Golf carts, 69% of the error was due to exiting cars and 11% error was due to people entering the garage. The "Cars Detected" and "Actual Cars" detected of Table 4.4 are compared and plotted against the "Hour" and shown in Figure 4.11.

Figure 4.10: Day 3 plot

Figure 4.11: Day 4 plot

Table 4.5 shows the data collected from April 24 to April 25, 2015. By the end of 24 hours, there was an error of 8.33%. 9% of error was due to Golf carts, 63% of the error was due to exiting

Table 4.4: Day 4 - April 23 to April 24, 2015

Hour	Cars detected	Actual cars	Golf Carts	Exiting Cars	People	Error	Percent Error
5-6 pm	37	30	0	7	0	7	23.33
6-7 pm	29	27	0	1	1	2	7.40
7-8 pm	28	25	0	3	0	3	12
8-9 pm	18	15	0	3	0	3	20
9-10 pm	19	19	0	0	0	0	0
10-11 pm	27	23	1	2	1	4	17.40
11-12 am	24	22	0	0	2	2	9.09
12-1 am	19	16	0	2	1	3	18.75
1-2 am	15	15	0	0	0	0	0
2-3 am	11	9	0	2	0	2	22.22
3-4 am	4	4	0	0	0	0	0
4-5 am	3	2	1	0	0	1	50
5-6 am	4	4	0	0	0	0	0
6-7 am	6	6	0	0	0	0	0
7-8 am	42	40	0	2	0	2	5
8-9 am	57	56	1	0	0	1	1.79
9-10 am	76	74	1	1	0	2	2.70
10-11 am	69	64	2	3	0	5	7.81
11-12 pm	67	67	0	0	0	0	0
12-1 pm	46	43	0	3	0	3	6.98
1-2 pm	58	53	3	1	1	5	9.43
2-3 pm	59	55	1	3	0	4	7.27
3-4 pm	33	29	1	3	0	4	13.79
4-5 pm	22	21	0	1	0	1	4.76
24 hours	773	719	11	37	6	54	7.51

cars and 28% error was due to people entering the garage. The "Cars Detected" and "Actual Cars" detected of Table 4.5 are compared and plotted against the "Hour" and shown in Figure 4.12.

4.4.1 Hourly and Peak Hour Times

This section analyzes the error accumulating hourly and analyzes the system efficiency during peak hour times. Tables 4.6 - 4.10 show the error accumulating for each hour over 24 hours.

Table 4.5: Day 5 - April 24 to April 25, 2015

Hour	Cars detected	Actual cars	Golf Carts	Exiting Cars	People	Error	Percent Error
5-6 pm	18	18	0	0	0	0	0
6-7 pm	15	12	0	1	2	3	25
7-8 pm	14	11	1	2	0	3	27.27
8-9 pm	17	17	0	0	0	0	0
9-10 pm	21	19	0	2	0	2	10.53
10-11 pm	14	12	1	1	0	2	16.67
11-12 am	21	19	0	1	1	2	10.53
12-1 am	10	10	0	0	0	0	0
1-2 am	14	12	0	0	2	2	16.67
2-3 am	7	7	0	0	0	0	0
3-4 am	12	12	0	0	0	0	0
4-5 am	1	1	0	0	0	0	0
5-6 am	1	1	0	0	0	0	0
6-7 am	13	13	0	0	0	0	0
7-8 am	9	8	0	1	0	1	12.5
8-9 am	13	12	0	1	0	1	8.33
9-10 am	33	33	0	0	0	0	0
10-11 am	16	14	0	1	1	2	14.28
11-12 pm	35	33	0	2	0	2	6.06
12-1 pm	29	26	1	2	0	3	11.54
1-2 pm	21	20	0	0	1	1	5
2-3 pm	38	35	0	3	0	3	8.57
3-4 pm	20	19	0	1	0	1	5.26
4-5 pm	24	20	0	2	2	4	20
24 hours	416	384	3	20	9	32	8.33

Table 4.6 shows the data collected from April 15 to April 16, 2015. Here the error started with an error of 11.76% and accumulated over the time. By the end of the test, the accumulated error decreased to 4.56%.

Figure 4.12: Day 5 plot

4.4.2 Days

This section discusses the average error for trials conducted for five days. Table 4.11 shows the average error percentage occurred over a period of time and Table 4.12 shows the average error occurred over five days.

The total number of cars detected were 4,947 out of which 4,694 were actual cars. We can see that 70% of the error is due to exiting cars. This is because the sensor is installed over the entrance lane however the cars straddled over entrance/exit lanes. This error can be removed by separating the entry and exiting pathways by a medium so that cars stay in their lanes.

4.5 Chapter Summary

This chapter presented the experimental set up used to test the selected sensor, calibration of the sensor, and initial feasibility test results. After initial feasibility tests, plots (Figure 4.2 and Figure

Table 4.6: Day 1 (accumulated) - April 15 to April 16, 2015

Hour	Cars detected	Actual cars	Golf Carts	Exiting Cars	People	Error	Percent Error
6.40 pm-7.40 pm	19	17	2	0	0	2	11.76
6.40 pm-8.40 pm	38	33	3	2	0	5	15.15
6.40 pm-9.40 pm	58	50	3	5	0	8	16
6.40 pm-10.40 pm	92	78	4	8	2	14	17.95
6.40 pm-11.40 pm	118	101	5	10	2	17	16.83
6.40 pm-12.40 am	137	119	5	11	2	18	15.13
6.40 pm-1.40 am	153	132	5	14	2	21	15.91
6.40 pm-2.40 am	161	140	5	14	2	21	15
6.40 pm-3.40 am	169	148	5	14	2	21	14.18
6.40 pm-4.40 am	170	149	5	14	2	21	14.09
6.40 pm-5.40 am	171	150	5	14	2	21	14
6.40 pm-6.40 am	178	155	6	15	2	23	14.84
6.40 pm-7.40 am	209	186	6	15	2	23	12.36
6.40 pm-8.40 am	291	267	6	15	3	24	8.99
6.40 pm-9.40 am	458	433	6	15	4	25	5.77
6.40 pm-10.40 am	583	557	6	16	4	26	4.67
6.40 pm-11.40 am	733	705	6	18	4	28	3.97
6.40 pm-12.40 pm	893	862	7	20	4	31	3.60
6.40 pm-1.40 pm	994	960	8	22	4	34	3.54
6.40 pm-2.40 pm	1084	1045	11	24	4	39	3.73
6.40 pm-3.40 pm	1149	1107	12	26	4	42	3.79
6.40 pm-4.40 pm	1203	1153	12	31	7	50	4.34
6.40 pm-5.40 pm	1272	1216	12	37	7	56	4.61
6.40 pm-6.40 pm	1305	1248	12	38	7	57	4.56

4.3) were drawn, logic to detect the vehicle was developed, more experiments were conducted to debug the system. Then, the system was deployed at the West entrance of Richard Beard Garage, and field trials were performed for five days continuously. Results of each trial are provided in tabular form showing the percentage error for each hour, percentage error accumulated over the day, percentage error of five days, and percentage error accumulated over five days. Error cases of golf carts, exiting cars, and people are also shown to better understand the error. Also, a counter measure to reduce the error has been proposed.

Table 4.7: Day 2 (accumulated) - April 21 to April 22, 2015

Hour	Cars detected	Actual cars	Golf Carts	Exiting Cars	People	Error	Percent Error
4 pm-5 pm	70	65	0	5	0	5	7.70
4 pm-6 pm	105	96	0	9	0	9	9.38
4 pm-7 pm	136	126	0	10	0	10	7.94
4 pm-8 pm	159	144	1	14	0	15	10.42
4 pm-9 pm	191	173	1	17	0	18	10.40
4 pm-10 pm	211	187	1	23	0	24	12.83
4 pm-11 pm	235	209	1	24	1	26	12.44
4 pm-12 am	262	233	1	27	1	29	12.45
4 pm-1 am	275	246	1	27	1	29	11.79
4 pm-2 am	288	258	1	28	1	30	11.63
4 pm-3 am	295	265	1	28	1	30	11.32
4 pm-4 am	300	270	1	28	1	30	11.11
4 pm-5 am	303	273	1	28	1	30	10.99
4 pm-6 am	306	276	1	28	1	30	10.87
4 pm-7 am	319	288	1	29	1	31	10.76
4 pm-8 am	400	368	1	30	1	32	8.70
4 pm-9 am	504	471	2	30	1	33	7
4 pm-10 am	644	608	3	32	1	36	5.92
4 pm-11 am	799	761	4	33	1	38	4.99
4 pm-12 pm	871	831	4	35	1	40	4.81
4 pm-1 pm	974	932	4	36	2	42	4.51
4 pm-2 pm	1079	1033	5	39	2	46	4.45
4 pm-3 pm	1136	1088	6	40	2	48	4.41
4 pm-4 pm	1213	1158	7	46	2	55	4.75

Table 4.8: Day 3 (accumulated)- April 22 to April 23, 2015

Hour	Cars detected	Actual cars	Golf Carts	Exiting Cars	People	Error	Percent Error
5 pm-6 pm	26	19	0	7	0	7	36.84
5 pm-7 pm	61	46	0	14	1	15	32.61
5 pm-8 pm	86	69	0	16	1	17	24.64
5 pm-9 pm	109	91	0	17	1	18	19.78
5 pm-10 pm	132	111	0	18	3	21	18.92
5 pm-11 pm	185	158	2	21	4	27	17.09
5 pm-12 am	199	172	2	21	4	27	15.70
5 pm-1 am	214	163	2	22	7	31	16.94
5 pm-2 am	221	187	2	24	8	34	18.18
5 pm-3 am	233	196	3	24	10	37	18.88
5 pm-4 am	239	202	3	24	10	37	18.32
5 pm-5 am	241	204	3	24	10	37	18.14
5 pm-6 am	243	206	3	24	10	37	17.96
5 pm-7 am	247	209	3	25	10	38	18.18
5 pm-8 am	299	261	3	25	10	38	14.56
5 pm-9 am	379	339	5	25	10	40	11.80
5 pm-10 am	551	509	6	26	10	42	8.25
5 pm-11 am	710	667	6	27	10	43	6.45
5 pm-12 pm	792	747	7	28	10	45	6.02
5 pm-1 pm	945	899	8	28	10	46	5.12
5 pm-2 pm	1068	1019	8	31	10	49	4.81
5 pm-3 pm	1124	1073	9	32	10	51	4.75
5 pm-4 pm	1185	1131	11	33	10	54	4.77
5 pm-5 pm	1240	1185	11	34	10	55	4.64

Table 4.9: Day 4 (accumulated) - April 23 to April 24, 2015

Hour	Cars detected	Actual cars	Golf Carts	Exiting Cars	People	Error	Percent Error
5 pm-6 pm	37	30	0	7	0	7	23.33
5 pm-7 pm	66	57	0	8	1	9	15.79
5 pm-8 pm	94	82	0	11	1	12	14.63
5 pm-9 pm	112	97	0	14	1	15	15.46
5 pm-10 pm	131	116	0	14	1	15	12.93
5 pm-11 pm	158	139	1	16	2	19	13.67
5 pm-12 am	182	161	1	16	4	21	13.04
5 pm-1 am	201	177	1	18	5	24	13.56
5 pm-2 am	216	192	1	18	5	24	12.50
5 pm-3 am	227	201	1	20	5	26	12.94
5 pm-4 am	231	205	1	20	5	26	12.68
5 pm-5 am	234	207	2	20	5	27	13.04
5 pm-6 am	238	211	2	20	5	27	12.80
5 pm-7 am	244	217	2	20	5	27	12.44
5 pm-8 am	286	257	2	22	5	29	11.28
5 pm-9 am	343	313	3	22	5	30	9.58
5 pm-10 am	419	387	4	23	5	32	8.27
5 pm-11 am	488	451	6	26	5	37	8.20
5 pm-12 pm	555	518	6	26	5	37	7.14
5 pm-1 pm	601	561	6	29	5	40	7.13
5 pm-2 pm	659	614	9	30	6	45	7.33
5 pm-3 pm	718	669	10	33	6	49	7.32
5 pm-4 pm	751	698	11	36	6	53	7.59
5 pm-5 pm	773	719	11	37	6	54	7.51

Table 4.10: Day 5 (accumulated) - April 24 to April 25, 2015

Hour	Cars detected	Actual cars	Golf Carts	Exiting Cars	People	Error	Percent Error
5 pm-6 pm	18	18	0	0	0	0	0
5 pm-7 pm	33	30	0	1	2	3	10
5 pm-8 pm	47	41	1	3	2	6	14.63
5 pm-9 pm	64	58	1	3	2	6	10.34
5 pm-10 pm	85	77	1	5	2	8	10.39
5 pm-11 pm	99	89	2	6	2	10	11.24
5 pm-12 am	120	108	2	7	3	12	11.11
5 pm-1 am	130	113	2	7	3	12	10.17
5 pm-2 am	144	130	2	7	5	14	10.77
5 pm-3 am	151	137	2	7	5	14	10.21
5 pm-4 am	163	149	2	7	5	14	9.40
5 pm-5 am	164	150	2	7	5	14	9.33
5 pm-6 am	165	151	2	7	5	14	9.27
5 pm-7 am	178	164	2	7	5	14	8.54
5 pm-8 am	187	172	2	8	5	15	8.72
5 pm-9 am	200	184	2	9	5	16	8.70
5 pm-10 am	233	217	2	9	5	16	7.37
5 pm-11 am	249	231	2	10	6	18	7.8
5 pm-12 pm	284	264	2	12	6	20	7.58
5 pm-1 pm	313	290	3	14	6	23	7.93
5 pm-2 pm	334	310	3	14	7	24	7.74
5 pm-3 pm	372	345	3	17	7	27	7.83
5 pm-4 pm	392	364	3	18	7	28	7.70
5 pm-5 pm	416	384	3	20	9	32	8.33

Table 4.11: Average error for five days

Days	Cars detected	Actual cars	Golf Carts	Exiting Cars	People	Error	Percent Error
Day 1	1305	1248	12	38	7	57	4.56
Day 2	1213	1158	7	46	2	55	4.75
Day 3	1240	1185	11	34	10	55	4.64
Day 4	773	719	11	37	6	54	7.51
Day 5	416	384	3	20	9	32	8.33
5 days	4947	4694	44	175	34	253	5.39

Table 4.12: Average error accumulated for five days

Days	Cars detected	Actual cars	Golf Carts	Exiting Cars	People	Error	Percent Error
Day 1	1305	1248	12	38	7	57	4.56
Day 2	2518	2406	19	84	9	112	4.65
Day 3	3758	3591	30	118	19	167	4.65
Day 4	4531	4310	41	155	25	221	5.13
Day 5	4947	4694	44	175	34	253	5.39

CHAPTER 5 : CONCLUSION AND FUTURE WORK

We draw conclusion and outline the future work. Future work proposes vehicle space availability feature, which can help the driver to know location of the available parking spot after entering the garage. We also propose installation of the system on each floor of Richard Beard Garage to determine the number of parking spots available on each floor.

5.1 Conclusion

The vehicle count feature monitors overall count of the parking lot in real time. This system can help the drivers to know the available number of parking spaces before entering the garage. The test results show that the system is accurate in the field. Moreover, the proposed parking guidance system is easy to install because of sensor's small size and low cost. Initially, the challenging task was to select a reliable sensor for this application, which was overcome by a thorough review of sensor technologies. Compared to other technologies, this system does not require installation of sensors into pavements and maintenance. Also, the system works in any weather condition. For this reason, it is suitable for all kinds of parking areas. In the future, the Arduino processor can be replaced by a PCB design using ATmega328 processor that can further reduce the cost of the system.

5.2 Future Work

The vehicle space availability indicator can be an add-on feature to the system. It is simple to indicate if there is a vehicle or not in a particular parking spot using the logic developed to detect a vehicle. This feature needs some additional logic to glow red or green lights. The processor glows red to indicate an occupied spot and green to indicate an available spot.

Figure 5.1: Flowchart of the logic to detect parking space availability

Figure 5.1 shows the flowchart of logic involved in indicating spots available. A single processor can monitor three parking spots using three ultrasonic sensors, three green lights, and three red lights. Initially, the processor calculates obstacle distance by triggering pulses to all three sensors. Then, it checks for an obstacle by triggering more pulses. When a vehicle occupies the parking space, the obstacle height is calculated by subtracting new obstacle distance from the maximum range. The

obstacle height is compared with the minimum threshold height of a vehicle. If the obstacle height is less than minimum obstacle height, then it is an empty spot/available spot, and a green light glows. If greater, then it is an occupied spot and a red light glows. The loop repeats for every two milliseconds to check for an obstacle. Number of available spots on each floor can be known by installing the system at each entrance/exit of each floor. If the system is installed at each floor, it can give us number of cars that have exited and entered each floor. This way, an overall count of each floor can be maintained.

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APPENDIX A: ARDUINO SOURCE CODE

```
#include <Array.h>          /* imports array */
#define echoPin 3           /* echoPin is connected to digitalpin 12 */
#define trigPin 2           /* trigPin is connected to digitalpin 13 */
#define MIN_OBSTACLE_HEIGHT 50 /* 50 cm */
#define MIN_OBSTACLE_PULSE_WIDTH 10
                             /* No. of pulses corresponding to vehicle */
                             /* length and speed */
const int temperaturePin =A0; /* Temperature sensor at Analog 0 */
double maximumRange;        /* Define the maximum range */

int init_flag = 0;
int dur,dis,duration2,distance2;
int counter = 0;            /* Gives the count of the car */
boolean carFound = false;   /* Variable used to if pulse_count satisfies
                             MIN_OBSTACLE_PULSE_WIDTH */
int currentState = 0;       /* sets the count */
int previousState = 0;
double D[30];               /* Array of Distances to be calculated */
int no_of_pulses =30;
int pulse_count = 0;

const int car_indicator = 6;
double obstacle_height = 0.0;
int obstacle_length = 0;
int index;

void setup()
{
  Serial.begin(9600);
  pinMode(trigPin,OUTPUT);
  pinMode(echoPin,INPUT);
  pinMode(car_indicator,OUTPUT);
}

void loop(){
  /* Calculate actual speed of sound using temperature sensor */
  float voltage_temperature_Pin, Voltage_in_Volts;
```



```

float temperature_celsius, speed_of_sound;
voltage_temperature_Pin = analogRead(temperaturePin) ;
Voltage_in_Volts = voltage_temperature_Pin * 0.004882814 ;
temperature_celsius = (Voltage_in_Volts - 0.5) * 100.0;
speed_of_sound = (0.6 * temperature_celsius ) + 331.5 ;

digitalWrite(trigPin, LOW);
delayMicroseconds(50);
digitalWrite(trigPin, HIGH);
delayMicroseconds(100);
digitalWrite(trigPin, LOW);
dur = pulseIn(echoPin, HIGH);
dis = (speed_of_sound* dur)/(20000);

/* Sets maximum range and calculates obstacle height */
if(init_flag == 0) {
    maximumRange = dis;
    init_flag = 1;
}
obstacle_height = maximumRange - dis;

/* initialize D array */
for(index = 0; index < 30; index++) {
    D[index] = 0.0;
}

/* checks for obstacle height */
if(obstacle_height > MIN_OBSTACLE_HEIGHT)
{
    for(pulse_count = 1; pulse_count < no_of_pulses; pulse_count++)
    {
        /* trigger pulse train */
        digitalWrite(trigPin, LOW);
        delayMicroseconds(50);
        digitalWrite(trigPin, HIGH);
        delayMicroseconds(100);
        digitalWrite(trigPin, LOW);
        /* send echo and measure distance to obstacle */
        duration2 = pulseIn(echoPin, HIGH);
        distance2 = (speed_of_sound* duration2)/(20000);

        /* obstacle height */
        D[pulse_count] = maximumRange - distance2;

        /* calculated D[pulse_count] is compared with obstacle_height */
    }
}

```

```

    if (D[pulse_count] < MIN_OBSTACLE_HEIGHT) break;
}

/* checks for MIN_OBSTACLE_PULSE_WIDTH */

if (pulse_count > MIN_OBSTACLE_PULSE_WIDTH)
{
    carFound = true;
    digitalWrite(car_indicator,HIGH);
    delay(10);
    digitalWrite(car_indicator,LOW);
}
}

if(carFound == true) {

    digitalWrite(trigPin, LOW);
    delayMicroseconds(50);
    digitalWrite(trigPin, HIGH);
    delayMicroseconds(100);
    digitalWrite(trigPin, LOW);
    dur = pulseIn(echoPin, HIGH);
    dis = (speed_of_sound* dur)/(20000);
    obstacle_height = maximumRange - dis;

    while ( obstacle_height >= 0) {
        /* trigger pulse train */
        digitalWrite(trigPin, LOW);
        delayMicroseconds(50);
        digitalWrite(trigPin, HIGH);
        delayMicroseconds(100);
        digitalWrite(trigPin, LOW);
        dur = pulseIn(echoPin, HIGH);
        dis = (speed_of_sound* dur)/(20000);
        obstacle_height = maximumRange - dis;
        delay(10);
        Serial.print("obstacle: ");
        Serial.println(obstacle_height);
        if(obstacle_height == 0) break;
    }
}

/* Count logic */
if((obstacle_height == 0) && (carFound == true))
{

```

```
        currentState = 1;
        carFound = false;
    } else {
        currentState = 0;
    }

    if(currentState != previousState) {
        if(currentState == 1) {
            counter = counter + 1;
            Serial.print("no.of cars:");
            Serial.println(counter);
        }
    }
    previousState = currentState;
    delay(5);
}
```

APPENDIX B: ARDUINO COPYRIGHT NOTICE

Figure 3.6 is an Arduino prototype board and its copyright permission is given below.

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