Implementation of an Economical Parking Helper Device Using Ultrasound Sensors

Tariq Jamil

Department of Electrical and Computer Engineering
Sultan Qaboos University
Al-K
Sultanate of Oman
Email: tjamil@squ.edu.om

Abstract. Every motorist dreams of a car that will take the stress out of parking by finding a suitable space and then maneuvers itself into the space with minimal assistance from the driver. This paper describes a parking helper device using ultrasound sensors, mounted on the car, to monitor both sides of the street for a suitable parking space, and when a large enough parking space is detected, the helper instructs the driver to stop the car and guides him/her via a display screen and voice about steering maneuvers which will ultimately result in the car being properly parked in the given parking space. Ultrasound sensors mounted on the front and rear bumpers of the car will ensure that a safe distance is maintained to other vehicles and objects and the driver will need to operate only the accelerator and the brake pedals. A warning signal sounds if the vehicle gets too close to other objects in the parking space.

Keywords: Parking, sensor, microcontroller, ultrasound, vehicle.
PACS: 84.30.-r, 84.30.Sk, 89.20.Ff, 89.20.Kk.

INTRODUCTION

In highly populated areas it can be difficult to find available parking spots. In addition to traffic rushing by and multiple drivers competing for the same space, another challenge is that parking spaces are tight and difficult to maneuver into. This paper presents design and implementation of a device called "Parking Helper" which can detect a parking space and then instruct the driver to park into the space with minimum effort. The Parking Helper can be used as a tool to help people with disability, beginner drivers, and even just for the fun of it. When a driver wants to park, he or she switches the system ON to start the parking process. Ultrasonic sensors are used to detect the space and the system calculates the size of the space and compares it with the size of the car. After that the driver is informed through LCD screen and speakers to stop the car and follow the steps which lead him or her to park the car in the parking space safely and with minimum effort. In addition, the device gives the driver a warning message when the vehicle gets too close to other objects in the parking space.

CP1247, *IAENG Transactions on Engineering Technologies – Volume 4,* edited by S.-I. Ao

This paper is organized as follows: Firstly, a survey of current technologies available to assist motorists with the parking process is presented. This is followed by the justification for using ultrasonic sensors in our design and detailed circuit design of parking helper device. Then testing of each circuit within the parking helper device is presented followed by the cost analysis of the device. Finally, summary and conclusion are given which are followed by Acknowledgments and References.

CURRENTLY AVAILABLE TECHNOLOGIES FOR PARKING ASSISTANCE

Over the past few years, a number of automobile manufacturers have started incorporating modern technologies within the vehicles for parking assistance. Among them are Valeo's Parking Slot Measurement System, Siemens' Park-Mate, Volvo's Evolve, Mercedes' Parking Assistance System, and BMW's Self-Parking System.

Valeo's Parking Slot Measurement System

Valeo has developed the sensor-based parking slot measurement system by applying its proven and renowned Ultrasonic Park-Assist (UPA) technology [1]. The innovative parking slot measurement system can evaluate the length of a parking slot chosen by the driver and perform an accurate comparison with the length of the driver's car to indicate if the car will fit into the space.

The parking slot measurement system consists of two ultrasonic sensors. These sensors are integrated into the left and right hand side of the front bumper of the car and communicate the requested parking slot measurement information to the driver via existing visual displays located on the dash board.

With the system switched ON, the driver simply drives up to an empty parking space between two cars. As the driver passes the parking slot at a distance of less than 0.5 meters, the system measures the size of the space. If the car will fit into the space, the driver simply continues as in a normal parking maneuver employing the UPA system to judge the available parking distance in relation to a parked car or a static obstacle.

Siemens' Park-Mate

Park Mate [2] uses ultrasound sensors mounted on the side of the car to monitor both sides of the street when the vehicle is traveling at speeds less than 35km/h. When a large enough parking space is reached, the driver is instructed to stop and the Park Mate checks to confirm that it has identified a parking space rather than an intersection or side street.

Once the parking process has begun, the system tells the driver via a display screen and voice output whether to put the car in reverse or drive. It then conducts all steering maneuvers automatically. Ultrasound sensors mounted on the front and rear bumpers determine the distance to other vehicles and objects; the driver therefore only needs to operate the accelerator and brake pedals. An audio signal warns if the vehicle gets too close to other objects.

Volvo's Evolve

At Linköping University in Sweden, in collaboration with Volvo [3], 17 students have developed this parking assistance system that will tell the driver if it has found a suitable space and then let him/her reverse without bothering about steering. Four ultrasound sensors have been fitted on a Volvo S60. When the driver initiates a parking space scan, the system reads the sensors. A number of clever algorithms turn the measurement data into knowledge about the space, position, and size. When the space is identified and is determined to be large enough for the car, the system tells the driver that a pocket exists. The driver stops and reverses and the prototype electric power steering as well as braking are controlled by the parking computer so that the car is driven into the pocket safely and automatically. The human-machine interface can also guide the driver in case where no electrical power steering exists but with maintained brake control.

Mercedes' Parking Assistance System

Mercedes has developed parking guidance system which uses radar technology to help the driver find a suitable parking space and park the vehicle [4]. When driving past at a speed of up to around 40 km/h, side-mounted radar sensors in the front and rear bumpers measure whether the parking spaces on the driver and front passenger sides are sufficiently large for the vehicle. Once the system has found a suitable parking space, a blue "P" symbol appears on the screen which is located at the front of the driver. Once the driver has stopped the car in the position shown on the display and engaged reverse gear, a camera shows the driver a symbolic shape to represent the parking situation. Colored guide lines show the driver how best to park: a red line indicates the current steering angle, while a yellow line shows the steering angle required for parking. The driver now turns the steering wheel until the two lines coincide, and can then begin to reverse slowly. As soon as the ideal and actual steering angles coincide, the guide lines on the display change to green. When reversing, an acoustic signal informs the driver when it is time to counter-steer. During the parking maneuver, the guidance system continuously monitors the steering angle and vehicle position. If the driver stops before reaching the recommended position, for example, the system automatically recalculates the ideal steering angle for smooth parking.

BMW's Self-Parking System

BMW has developed a parking-assist technology that can park the car without any help from the driver [5]. But this technology does not work everywhere because some components are required to be installed in the car and some in the designated parking spot. One has to install a reflective lens against the wall of the parking space and a video camera on the car's front windshield which measures the distance and angle of the car in relation to the lens, while other sensors ensure that there is at least 8 inches of space on the left and right sides of the car. Through information gathered from these input devices, the gas pedal and steering wheel are controlled.

DESIGN OF PARKING HELPER DEVICE

An important consideration while designing parking helper has been the use of appropriate technology for the detection of obstacles while parking a vehicle. There are several technologies available in the market today to solve this problem. These include various types of radar, digital camera, infrared sensors, and ultrasound sensors [6][7]. Each technology has its advantages and disadvantages and, after careful consideration of all available options, we decided to use ultrasound sensors in our design of parking helper device. The advantages of using ultrasound sensors are [8]: (i) Sensitive to almost all types of motion. (ii) No coverage gaps. (iii) Can detect movements that are not in their line-of sight. The disadvantages of using ultrasound sensors are: (i) They tend to be more expensive than infra-red sensors. (ii) They are more prone to false signals. (iii) Obstructions can reduce their effectiveness. (iv) Care must be taken to avoid overlapping sensors.

In the ultrasonic sensor, the resonator emits short ultrasonic pulses (0.4 milliseconds) and receives the reflected signal. The transient period of resonator fading is (1.5-1.8 milliseconds).This is the primary limiting factor with regard to minimum distance detection. The included electronic control pulse generator excites the resonator and performs signal processing. The time between pulse transmission and detection of a reflected signal is used to calculate the distance to an obstacle (Eq.1):

$$S = \frac{Vt}{2} \tag{1}$$

where S is the distance to the obstacle, V is the speed of the sound wave and t is the time between pulse transmission and the detection of the reflected signal. The speed of the sound wave depends upon several factors, which include temperature, density, and air composition, and is given by Eq. 2:

$$V = \sqrt{\frac{\gamma R T}{\mu}} \tag{2}$$

where γ is the adiabatic constant, R is the absolute gas constant, T is the air temperature in degrees Kelvin and μ is the molecular gas weight. Typically, Eq. 2 is simplified into Eq. 3 which only takes into account air temperature:

$$V = 20.046\sqrt{T} \tag{3}$$

where V is in m/s and T is in degrees Kelvin. The nominal speed of sound wave at 10ºC is around 335 m/s.

Our parking helper device consists of three main circuits (Fig. 1): The sensors controlling circuit, voice recording/playback circuit and distance measuring circuit. The sensors controlling circuit, as the name implies, is used to control and process inputs coming from ultrasound sensors using a microcontroller, and to output result on the LCD screen placed in front of the driver. Voice recording/playback circuit is used to record maneuvering commands and to playback them during the parking process. Distance measuring circuit is used to measure the distance that the car has traveled using color detecting sensor (the reflective object sensor).

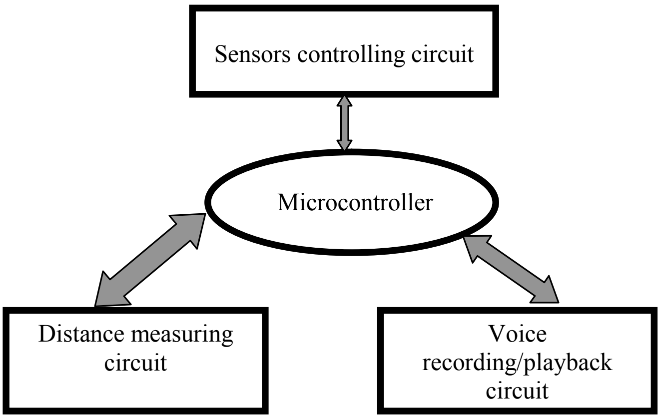

FIGURE 1. Parking Helper Device Block Diagram

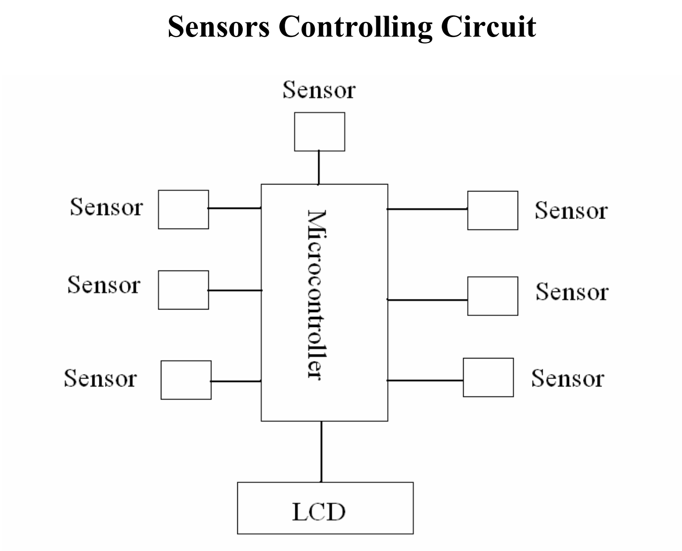

FIGURE 2. Sensors Controlling Circuit Block Diagram

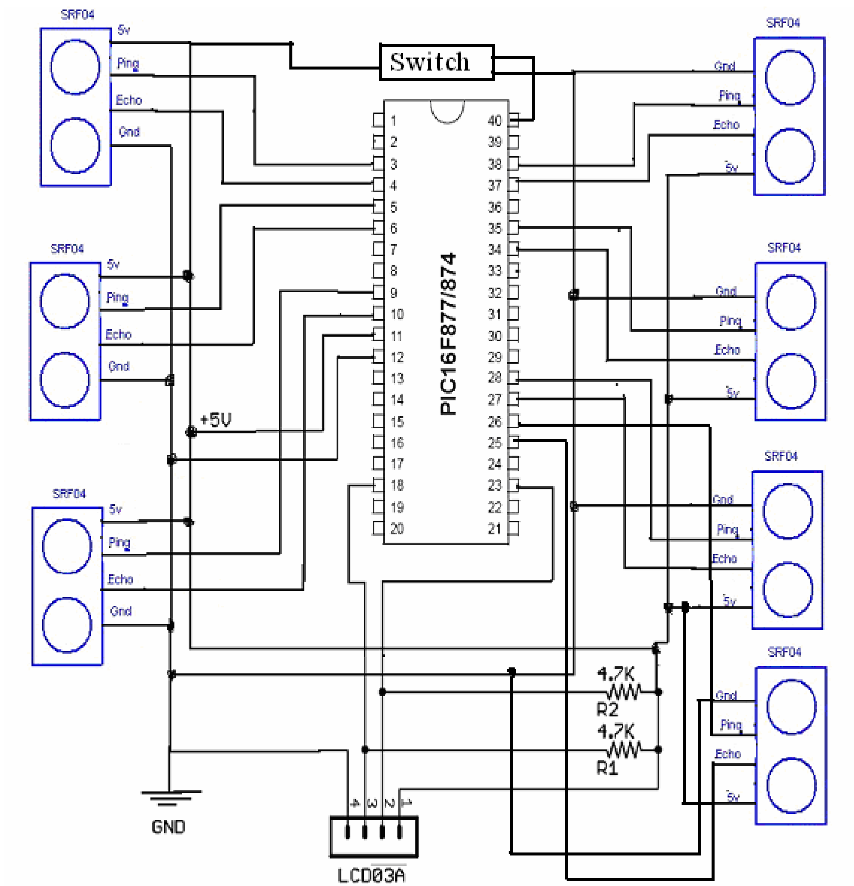

FIGURE 3. Sensors Controlling Circuit Connection Diagram

The block diagram and connection diagram of sensors controlling circuit are given in Fig. 2 and Fig. 3 respectively. We have chosen the (PIC16F877A) microcontroller which has 40 input/output pins and 20MHz clock frequency. The microcontroller controls all seven sensors and uses their outputs to calculate the parking space and to instruct the driver to park the vehicle safely. It uses the LCD to display the results and the parking instructions. The sensors used are SRF04 [9] (Fig. 4) because they are the cheapest and their range satisfied our desired distance range (3cm to 3m). Technical specifications of SRF04 sensors are given in Table 1.

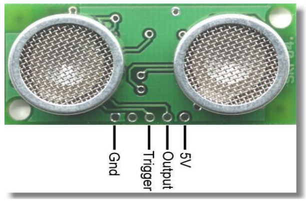

FIGURE 4. SRF04 Sensor

TABLE 1. SRF04 Range Finder Technical Specifications

Voltage	5V
Current	30 mA Typical. 50mA Max.
Frequency	40 kHz
Max Range	3 m
Min Range	3 cm
Sensitivity	Detect 3 cm diameter broom handle at > 2m
Input Trigger	10 µs Minimum. TTL level pulse
Echo Pulse	Positive TTL level signal, width proportional to range
Small Size	43 mm x 20 mm x 17 mm height

FIGURE 5. LCD Screen

The LCD [10] (Fig. 5) has two modes of operations; I2C mode and serial mode. The I2C along with serial display driver provides easy operation of a standard 20x4 LCD text display. It requires only a 5-volt power supply and two data connections. There is a 64-byte FIFO buffer to ensure a minimum of delay in writing to the display. The LCD has a mode jumper to select serial or I2C mode. When the jumper is present (factory default) the module is in serial mode. When the jumper is removed the module is in I2C mode. The mode jumper is checked only during the power-on process, so if the jumper is changed while the display is on, nothing happens. The LCD has a FIFO buffer to overcome the difference in speed between the communication in I2C/serial mode and the display. The buffer is 64 byte in size. The LCD has four registers; three of them are read only information registers while the other is a dual register. This means that the latter is the command register where all instructions from the commands should be sent, when written, and it returns the number of free byte in the buffer, when it is read.

Voice Recording/Playback Circuit

Sometimes it is difficult for some people to read the commands from the screen so we have designed a circuit to record those commands and playback them in parallel with the LCD display. As shown in Fig. 6 this circuit consists mainly of a microcontroller, voice record/playback chip, microphone and speakers.

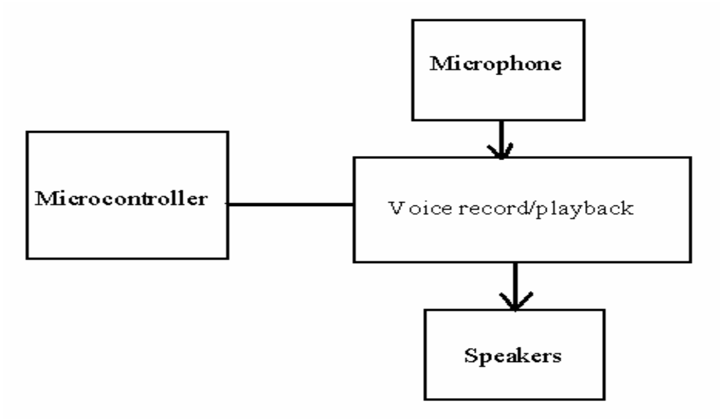

FIGURE 6. Voice Recording/Playback Circuit Block Diagram

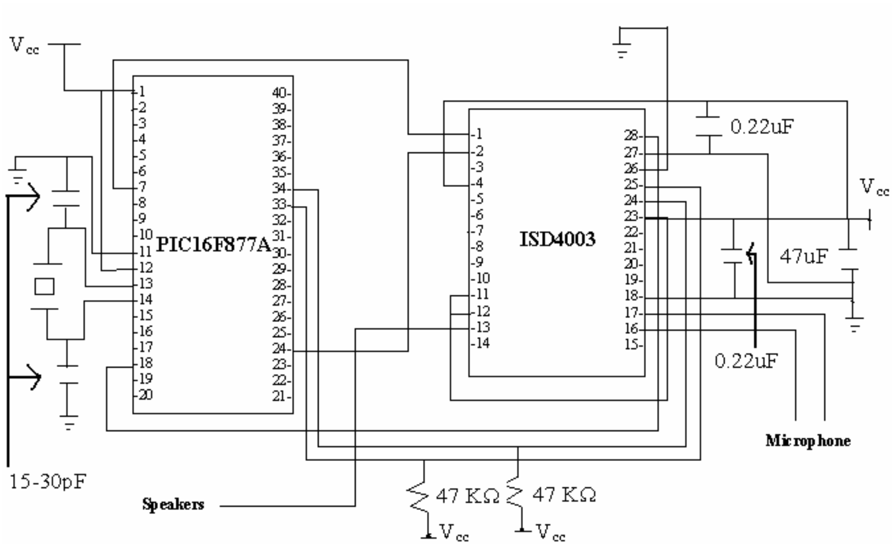

FIGURE 7. Video Recording/Playback Circuit Connection Diagram

The voice record/playback chip is ISD4003-04M chip which provides high quality, 3-volt, single chip record/playback solutions for 4-minute messaging applications [11]. It allows for the recording of analog audio on non-volatile memory in digital form and provides a mechanism to play back this audio stream. This chip is controlled with a Serial Peripheral Interface (SPI). The chip can be re-recorded typically over 100,000 times. It contains a total of 1920K flash memory cells, which is organized as 1200 rows of 1600 cells each. The microcontroller is PIC16F877A which communicates with the voice chip via SPI ports. The microphone is used to record sounds into the ISD4003 device and the speaker is used to playback the sound (Fig. 7).

Distance Measuring Circuit

After conducting driving experiments at various speeds, we found that parking helper will be most accurate in calculating parking spot size at speeds between 5 km/h to 10 km/h. To make the speed variable within a certain range, we have used an extra sensor called "a reflective object sensor".

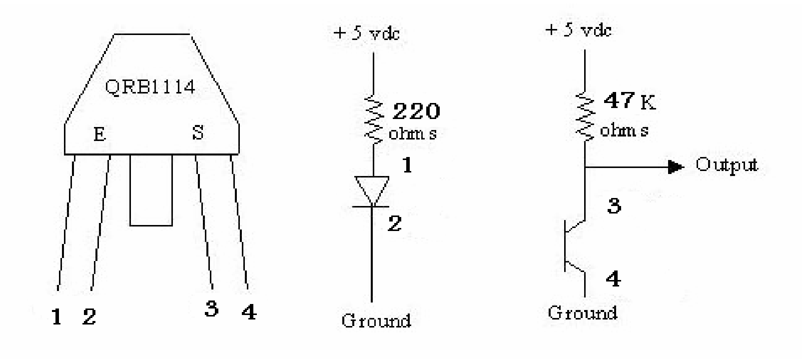

FIGURE 8. Reflective Object Sensor Schematic

The reflective object sensor which has been used in our project is QRB1114 [12] (Fig. 8). It consists of an infrared emitting diode (IR LED) and an NPN silicon phototransistor mounted side by side on a converging optical axis in a black plastic housing. The phototransistor responds to radiation from the emitting diode only when a reflective object passes within its field of view. When the LED is activated and the light is reflected from a nearby surface, the current flowing through the transistor is affected. The reflective object sensor QRB1114 works by shining an infrared LED on the rotating object and seeing the reflection with a phototransistor. The infrared LED is current limited to about 17mA by 220 Ω resistor. The sensitivity of the phototransistor is set by the 47kΩ resistor. The value of this resistor is directly proportional to the sensitivity of the phototransistor, increasing this value increases the phototransistor's sensitivity and vice versa. Other features of the reflective object sensor are: No contact surface sensing, phototransistor output, focused for sensing specular reflection, daylight filter on sensor, dust cover, and small size (18 x 23 x 5.5 mm). The sensor has four pins such that the first pair is connected to the emitter (LED) and the second pair is connected to the detector (phototransistor)(Fig.8). The reflective object sensor is mounted in the wheel housing underneath the vehicle and detects a white reflective strip placed on the tire of the car based on light and dark areas on the rotating object. The light and dark areas are made by placing a piece of white striper or by painting the object by a white color. The sensor outputs a pulse each time the strip from the tire passes across it.

Figure 9 and Figure 10 illustrate the block diagram and connection diagram of distance measuring circuit respectively.

FIGURE 9. Distance Measuring Circuit

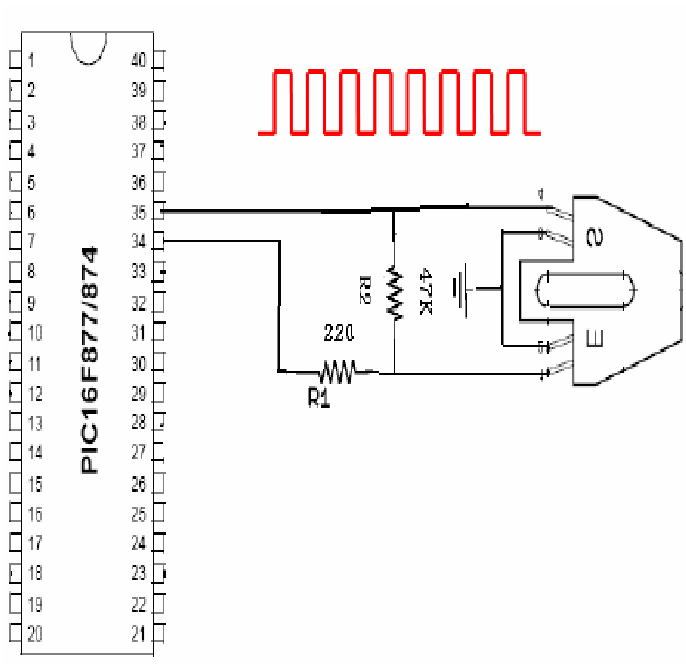

FIGURE 10. Distance Measuring Circuit Implementation

The microcontroller supplies five voltage levels to the reflective object sensor to switch it ON when we need to calculate a parking spot size. The sensor detects the light and dark areas on the object and sends pulses to the microcontroller to calculate the distance which is displayed on the LCD.

TESTING OF PARKING HELPER CIRCUITS

Sensors Controlling Circuit

The first step was to test the interface between the LCD and the microcontroller. We tested the LCD by writing a program to display the short message “Hello World” on the screen. After that, we wrote a small program to use one sensor to calculate the range between it and any obstacle, and then display the readings on the LCD. Then we examined the response of the sensor when a slow object was passing through its range.

We tested the accuracy of the sensor in calculating the range. We found that the sensor was very accurate in calculating the range. Next we tested the angular range detection of the sensor and found that the sensor could detect objects outside its line of sight. After we had written and tested several programs to control the sensor and the LCD, we moved to another level of testing. We wrote program to detect a space between two obstacles. We used a sensor to detect an object and when it detected more than a specific distance (the parking width), the microcontroller would start an internal timer. Then if the sensor detected another obstacle, the timer would stop. After that, the microcontroller would calculate the space between the two obstacles which is displayed on the LCD. We used in this test a small toy car and pushed it between the two obstacles. We observed that the speed of the car affected our calculations, so we set a constant speed in our calculations and tried to push the car to reach that speed. At the end of this test we found that we could detect the space between two obstacles when the speed of car was approximately 1km/h. After that we tried to increase the speed and saw what happened in our calculations. Then we tested our circuit with an actual car to examine if the calculation of the space was accurate. We noticed that if the speed of the car reached 20km/h, there were errors in our calculations. Those errors were caused by the microcontroller timers. We attempted to improve the microcontroller execution speed by changing the pre-scale value, but we could not get accurate results. So, we decided to change the default speed of the car to be 10km/h and then evaluated the results. The circuit worked perfectly at this speed and we got accurate results in calculating the space. We concluded, after multiple testing, that our circuit provided accurate results in calculating the parking space when the car was traveling at speeds between 5km/h and 10km/h, which is a logical speed range while searching for a parking space.

After this preliminary testing, we upgraded our circuit by using two sensors. One sensor was used for calculating the space while the other sensor was used to provide information for aligning the car exactly parallel to the other parked car (when sufficient parking space is detected). The circuit worked correctly and provided the expected results.

In the next level of testing, we added the instructions that we wanted to appear for the driver on the LCD when a parking space has been detected. We added a delay between each instruction to give the driver time to see and perform the instruction. We calculated by experiment required amount of time for processing all displayed parking- instructions by the driver and incorporated it in our interfacing software (written in C programming language). We considered some scenarios also that could happen during the parking process. For example, what would happen if the driver did not see some instruction or he/she did not perform one of the instructions properly. To overcome these situations we added a switch in our circuit to enforce the driver to perform the instructions step by step and in an accurate manner. This switch will confirm that the next instruction doesn't appear on the LCD until the previous instruction has been executed correctly. Furthermore, assuming that the parking process will not always be on the right-side of the road, we added a feature in our circuit to give the driver choice to select if he/she wants to park on the right or on the left side of the road. If the driver presses the switch, it means he/she wants to park on the left side of the road otherwise, by default, the circuit assumes that the driver wants to park the car on the right side of the road.

Finally, we mounted all seven sensors on the car and tested if the circuit calculated the parking space correctly and showed all instructions on the LCD when the switch was pressed. We noticed that the circuit was working perfectly in calculating the space at specific speeds (5 km/h to 10 km/h) and gave wrong results if the speed exceeded the given speed range. Figure 11 presents a flowchart of the parking procedure utilizing Sensors Controlling Circuit.

Voice Recording/Playback Circuit

The circuit was tested using function generator (input) and oscilloscope (output). An audio message was recorded using a microphone and played back through the speakers. After extensive recording and playback testing, parking instructions were recorded at various memory addresses of the ISD4003 chip and played back to ensure that these instructions appeared simultaneously both on the LCD and through the speakers during the parking process.

Distance Measuring Circuit

This circuit consists of an reflective object sensor, PIC microcontroller, and the LCD. The objective of using the reflective object sensor is to detect colored surfaces so that we can use this feature to measure the distance that the car has moved. To test this feature of the circuit, we put a white adhesive strip of paper on the wheel to make two different colored surfaces. The circumference of the wheel is $2\pi R$ which meant that the wheel moved $2\pi R$ distance each time the strip crossed the sensor. Total distance traveled was obtained using Eq. 4.

$$\text{Distance} = N \times 2\pi R \quad (4)$$

where N is the number of revolutions of the wheel measured in terms of zero pulses of the reflective object sensor and R is the radius of the wheel. During testing, we were able to confirm the accuracy of this circuit in measuring distances both by calculations and through comparison with physical measurement of the distance using a measuring tape.

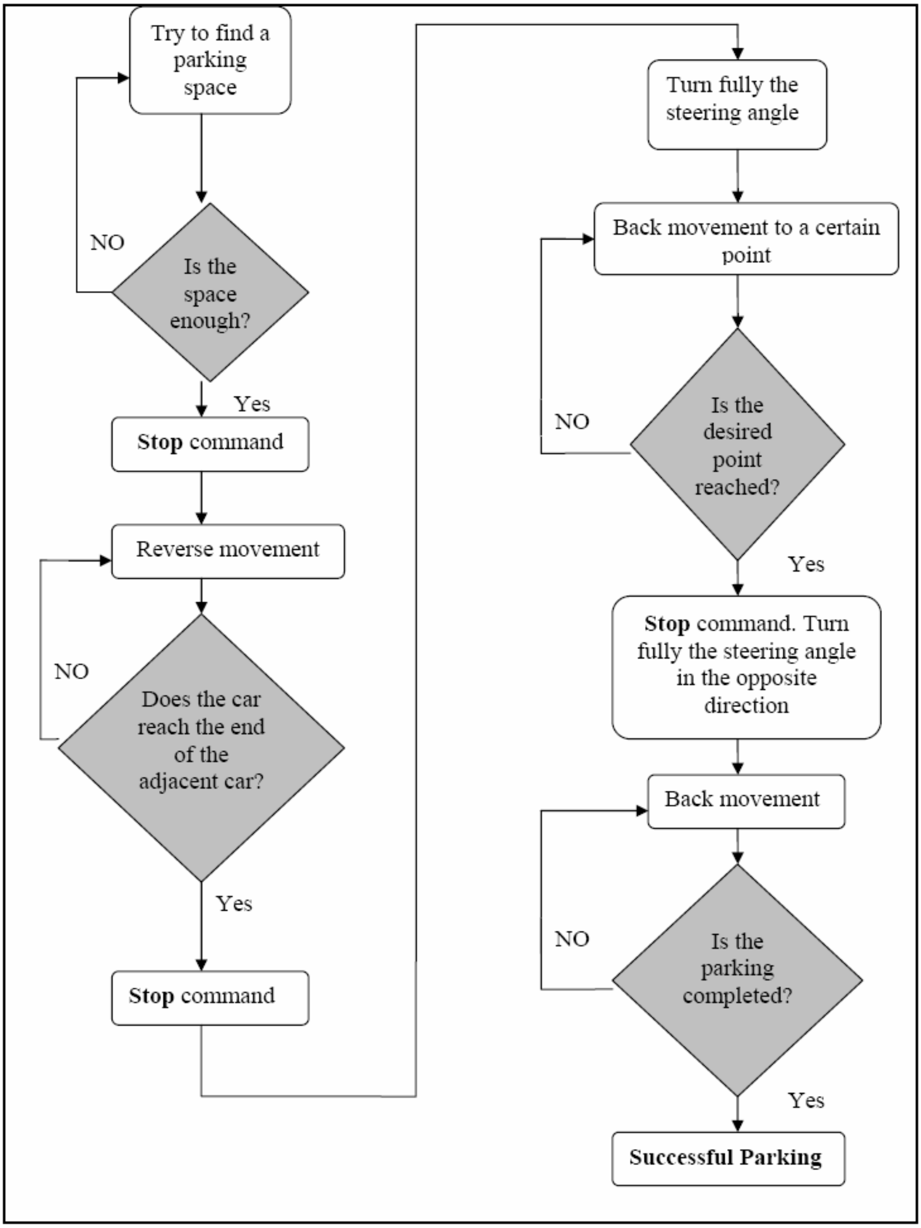

FIGURE 11. Flowchart of the Parking Procedure

COST ANALYSIS

Total cost of the parking helper device has been found to be US$228.50. This amount has been calculated as shown in Table 2.

TABLE 2. Cost Analysis of Parking Helper Device

Component	**Qty**	**Cost (US$)**
LCD	1	51.50
Microcontroller	1	7.20
Sensor (Ultrasonic)	7	128.90
Sensor (Reflective Object)	1	2.80
Record/Playback voice chip	1	25.75
Crystal	1	1.75
Speaker	1	3.87
Miscellaneous components	14	6.73
Total		**228.50**

SUMMARY AND CONCLUSION

The objective of this project was to design an economical and reliable parking helper using ultrasound technology which could easily be incorporated either during car manufacturing phase or installed by the automobile owner using simple tools. We have been successful in achieving not only this objective but have also been able to add an extra feature into the circuit design, i.e., voice record/playback circuit, which can be very helpful to those who cannot read instructions from the LCD screen for any reason.

The designed parking helper works best when the vehicle to be parked is traveling at speed between the range 5-10 km/h which is a logical speed at which the vehicle must be traveling if it requires to be parked. To increase this speed range will require extra number of high-speed sensors which will increase the cost and complexity of the design.

ACKNOWLEDGMENTS

This work was completed as a pilot project undertaken by Ahmed Al-Mahri, Hassan Al-Mahri, Khalil Al-Maawali, and Mohammed Al-Barwani, with the author as the supervisor of the project. We gratefully acknowledge the financial support provided by Sultan Qaboos University for this project.

REFERENCES

1. Valeo Industrial Group, "Valeo advances driver comfort and confidence with detection systems contracts," (2006), http://www.valeo.com/automotive-supplier/Jahia/pid/635, accessed September 2006.
2. The Institution of Engineering and Technology, "Park Mate," (2006), http://www.iee.org/oncomms/magazine.cfm?issueID=101&articleID=D5118623-E979-0E7A-D873F1FEC4DD7E1C, accessed September 2006.
3. Linköping University, "Evolve - A Student Project in Mechatronics in Collaboration with Volvo Cars," (2006), http://www.ikp.liu.se/evolve/, accessed October 2006.
4. The Auto Channel, "New Mercedes CL Coupe Uses Radar to Help the Driver Park," (2006), http://www.theautochannel.com/news/2006/08/28/020130.html, accessed October 2006.
5. P. Tan, "BMW demos a self-parking BMW 730i," (2006), http://paultan.org/archives/2006/07/12/bmw-demos-a-self -parking-bmw-730i/, accessed October 2006.
6. SwedeTrack System, "Some Theory behind Obstacle Detection", (2006), http://www.swedetrack.com/obstact.htm#8, accessed November 2006.
7. GreenSeal, "Occupancy Sensors," (2006), http://www.greenseal.org/resources/reports/CGR=Sensors.pdf , accessed November 2006.
8. Migatron Corporation, "Frequently Asked Questions About Ultrasonic Technology," (2006), http://www.migatron.com/overview.htm, accessed October 2006.
9. Robot Store (HK), "SRF04 - Ultra-Sonic Ranger Technical Specification", (2006), http://www.robotstorehk.com/srf04tech.pdf, accessed November 2006.
10. Robot Electronics (UK), "LCD03 - I2C/Serial LCD Technical Documentation," (2006), http://www.robot-electronics.co.uk/htm/Lcd03tech.htm, accessed November 2006.
11. MicroEngineering Labs, "Single-Chip Voice Record/Playback Device," (2006), http://www.melabs.com/downloads/ISD4003.pdf, accessed November 2006.
12. Fairchild Semiconductor, "Phototransistor Reflective Object Sensor," (2006), http://www.fairchildsemi.com/ds/QR/QRB1114.pdf, accessed November 2006.