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November 5th, 2001

Dr. Andrew Rawicz
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Re: ENSC340 Design Specification for SensorMate Parking System

Dear Dr. Rawicz,

The enclosed document, *Design Specification for SensorMate Parking System*, outlines and defines the design specifications for our ENSC 340 project. The SensorMate Parking System is a parking lot status indication system that allows drivers to view the location of an open parking space on a large display device.

In the attached document, we will provide a system overview with detailed design requirements for the implementation of our project. The objective is to present our project design in various stages: sensory input, sensory processing, user interface and output. As well, the integration of these stages will be considered along with testing and verification methods.

Crystal Technologies is made up of four dedicated forth year engineering students – Jimmy Kan, Richard Fung, Steven Soong and Lawrence Tam. If you have any inquiries or concerns, please contact us at (604) 773-6658 or through email at sltam@sfu.ca.

Sincerely,

Lawrence Tam
CEO, Crystal Technologies

Enclosed: Functional Specification for SensorMate Parking System

CRYSTAL TECHNOLOGIES

Design Specification for
SensorMate Parking System

Submitted by
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Submitted to
Dr. Andrew Rawicz
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Date
November 5th, 2001

Abstract

The design specification is an extension to our functional specification. In this document, we develop our design along the functional parameters previously defined in the functional specification. In order to provide a detail system design, we have omitted consideration for the upgraded system in the document.

SensorMate Parking System is designed to allow drivers the ease of parking during the parking phase of driving. With our parking indication system, drivers will immediately know whether spaces are available in a parking lot. Drivers will not only know if the parking lot still has a vacancy, but they will also be able to locate where the vacant spaces are. The implementation of this system is aimed towards easy adaptations to other similar problems, such as luggage storage system, to allow movers to easily see which spaces can still hold additional luggage.

The system contains three major subsystems: sensory, control and display. Sensory components will be made up of reflective ultrasonic sensors that will relay space status to the controller. The controller will then interpret the data and output the result to a multi-display system consisting of a LED (Light Emitting Diode) cluster and a LCD (Liquid Crystal Display).

This document demonstrates the system design for the various components along with the system integration between each. A testing and verification section will be included to demonstrate how effective the system is in comparison to the functional requirements outlined earlier in our functional specification.

Four innovative forth year engineering students who have experience in analog circuit design, digital analysis, micro-controller and software programming, staffs Crystal Technologies. The project will be multi-phase, consisting of research, development and construction of the SensorMate Parking System. The completion date for this system is set on December 10, 2001.

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List of Illustrations

Introduction

This document details the design specification for the SensorMate Parking System. For an overview on the project, timeline and budgetary concerns, please refer to our *Project Proposal for SensorMate Parking System*. The functional requirements for our project can also be found in our *Functional Specification for SensorMate Parking System*.

First, the document gives a general overview of the system and the separate component stages of our project. Together with the design definitions, a testing method is outlined to provide verification steps in conforming to our requirement definitions. Testing methods are separated into unit testing, system testing and integration testing. Lastly, schematics, component part listings and diagrams are included in the appendix.

The component stages will flow in a linear manner from input to processing to output. For our sensory input, the ultrasonic sensor design will be documented in detail, as well as, considerations for the door sensor. In our main processing stage, the algorithm for interpreting sensory input and the addressing of the micro-controller will be considered. Finally, the output stage is designed based on LCD and LED displays.

In order to provide a detail system design, we have omitted consideration for the upgraded system in the document.

The objective of our project is to develop an indication system that provides drivers with vacancy status information of a parking lot. This project is not intended to restrict the driving behaviour of drivers; rather, it only serves as a device that assists drivers in locating a vacant parking space. With the aid of this system, a parking lot can operate in a much more efficient manner. The target goal of our team is to complete the basic system by December 10, 2001 with an estimated budget of $1000 Cdn. If time and resource permit, the upgraded system will also be developed as well.

System Overview

The SensorMate Parking System is an indication system designed to aid drivers in locating a vacant parking space. The physical layout of the system is shown in Figure 1. Sensors are installed at each parking space and door counters at the entrance and exit of a parking lot. A map of the parking lot is located at the entrance of the parking lot. Each parking space is represented by a LED on the map, and its vacancy status is also shown. Underneath the LED map is a 2-row LCD to display system messages.

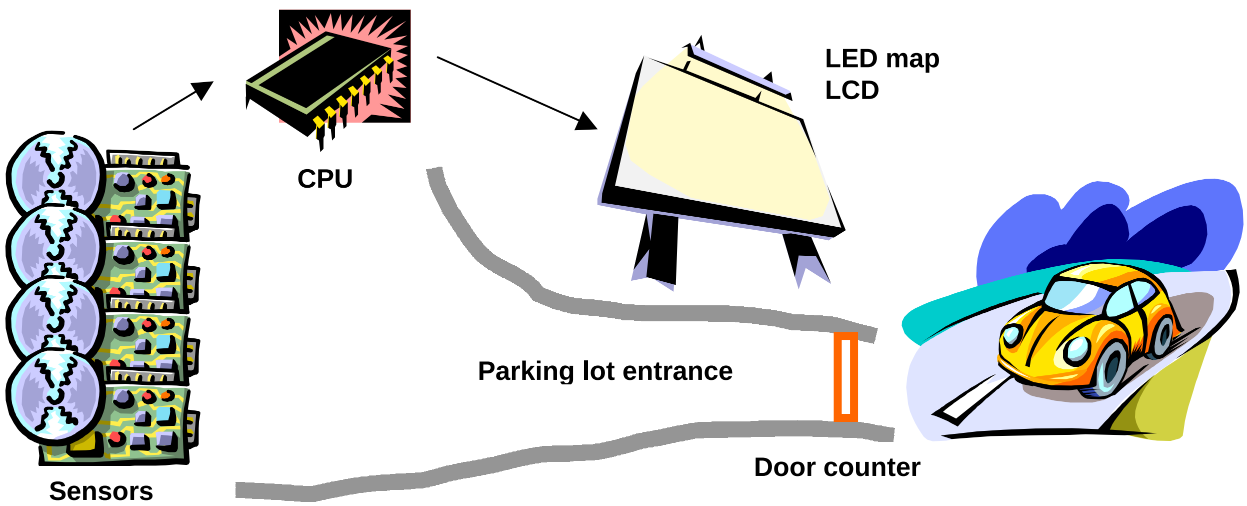

Figure 1 Physical Layout

The SensorMate Parking System acquires the parking lot status from the sensors and the door counters, and displays appropriate messages and information on the LED map and LCD. For the purpose of demonstrating the concept of this product, we will simplify the scenario and consider a parking lot having only 8 parking spaces. However, the system is designed such that it can be easily expanded. Also, a door counter has a simple functionality, but it is an expensive device. Therefore, we decide to simulate the door counters in this demonstration with push buttons. Figure 2 shows a detailed block diagram that gives an overview of the operation of the SensorMate Parking System.

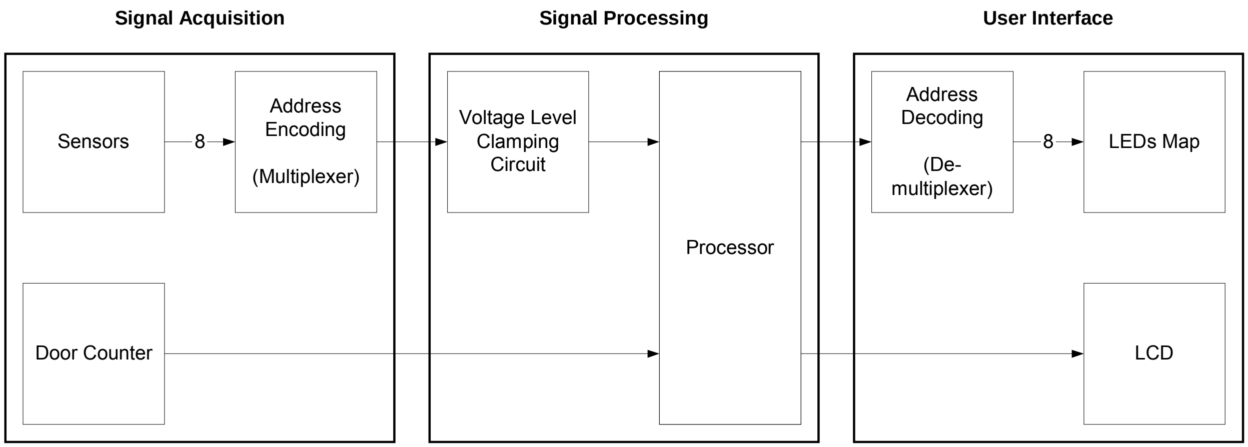

Figure 2 System Block Diagram

First of all, the vacancy status of parking spaces are obtained from the sensors. The output of each sensor is connected to a 8-to-1 mulitplexer. The door counter sends a signal to the processor every time when a car drives by. Next, in the signal processing stage, the processor cycles through all parking spaces and analyzes the signal sent from each sensor. The incoming signal from the multiplexer is compared with a voltage reference and then clamped to a voltage level required by the processor. If the space is empty, the processor selects and turns on the corresponding LED on the LEDs map to indicate that this parking space is available. A 1-to-8 de-multiplexer is employed to interface between the processor and the LEDs map. Similarly, if the parking space is occupied, the processor will turn off its corresponding LED. The processor also keeps track of the number of car in the parking lot and display it in the LCD. The LCD is to be updated every second.

Signal Acquisition

The signals to be processed and monitored will be supplied by the ultrasonic sensors located at the parking spaces. The sensors may be placed at the front of the space or on the ground. Figure 3 displays the possible sensor arrangements.

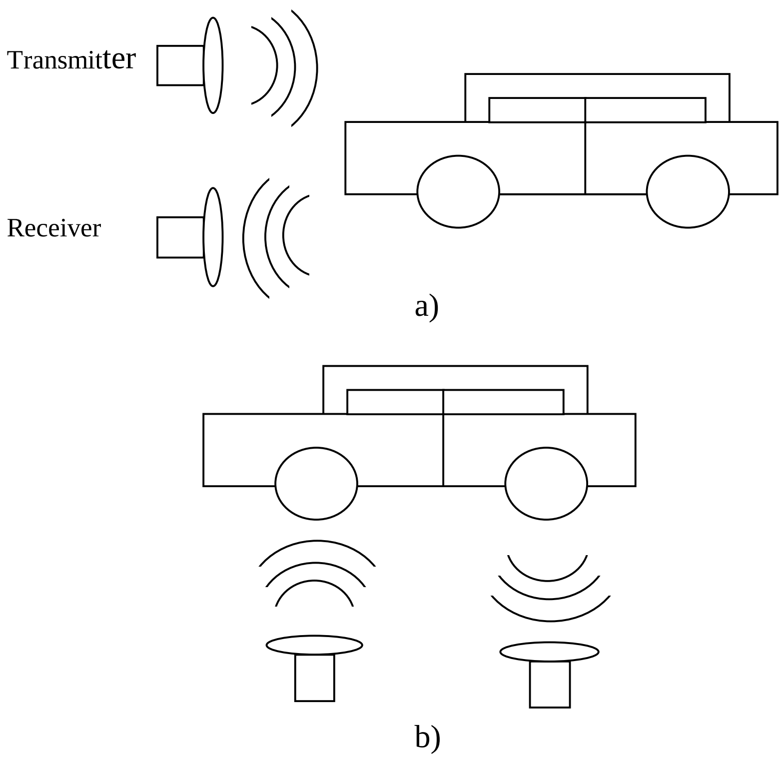

Figure 3 Various Sensor Placements

In the presence of a vehicle in the space, the ultrasonic waves generated by the transmitter will reflect off the surface of the vehicle and be detected by the receiver. The receiver will then let the processor know that there is a vehicle in the space. It lets the processor know by changing the output of the circuit. In the absence of a vehicle, the output monitored by the processor will be a sine wave of approximately 80KHz and amplitude 5V. When the sensors detect an object this signal changes to a square wave of approximately 40KHz and amplitude 5V.

The operation of all the sensors used will be identical. The range of the sensors was experimentally found to be 1 – 2 feet. The sensing area is conical with a total angle of 60˚. The effective range is shown in Figure 4. A concern that we had about the sensors interfering with one another is no more due to the limited range and narrow sensing area of the sensors.

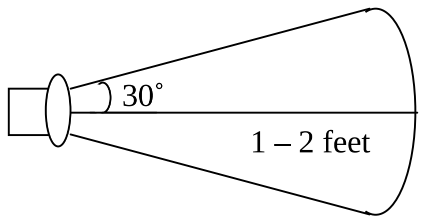

Figure 4 Sensing Area

Ultrasonic vs. Other Sensor Types

Many different sensors that were also capable of detecting the presence of a vehicle were considered before the ultrasonic sensor was chosen. Ultrasonic sensors were chosen for the prototype for their satisfactory performance, practical cost (~$15 each), and ease of installation. The main categories of those not chosen were infrared, magnetic, and weight sensors.

Infrared detectors are practical sensors that are commonly used in many applications, but were not chosen for our purposes for several reasons. Infrared detectors generally operate with a beam-breaking system. A transmitter generates a beam of light and a receiver directly across from the transmitter detects the beam. When an object blocks the beam by going in between the transmitter and receiver, the receiver notices the absence of the beam and recognizes that there is something there. It will then produce the appropriate signal. Infrared detectors are generally inexpensive and possess good range, but they were not chosen because they require the transmitter and receiver to be directly opposite each other. This system will work well for sheltered parking, such as in underground lots, where the transmitter can be on the ceiling and the receiver on the ground directly below, but the Sensormate Parking system was planned to be used in general parking lots. Accommodating general lots would require the use of two poles with the transmitter on one and the receiver on the other. This would result in the sensors located awkwardly and getting in the way.

Weight and magnetic sensors are designed to sense the presence of vehicles, but were not chosen for the prototype for several reasons. Weight sensors inherently do not possess several problems that ultrasonic sensors have. They are designed to sense vehicles. These sensors are installed under the concrete of the parking space and when they are subjected to additional pressure when something heavy goes onto the parking space, they generate a signal. Therefore, if an object, a person for example, goes onto the parking space, the sensor can be configured to not generate a signal. The weight sensor is also less prone to interference from environment factors because it is sheltered. Magnetic sensors are also excellent for detecting vehicles. These coils are installed under the parking space and when a large metal object passes over a current is produced in the coil and the sensor recognizes that a vehicle is on the space. Like the weight sensors, a non-metallic object, such as a person, will not trigger the magnetic sensor. Furthermore, the sensors are sheltered like weight sensors. However, there are good reasons the prototype version of the parking lot system will not use these sensors. Since pressure sensors need to be underground to work, installation of these sensors will require a lot of work. Magnetic sensors are large and would be difficult to work with if they are not installed underground. Cost is the other reason these two types of sensors are not being used. Each of these sensors is several times more expensive than ultrasonic sensors or more depending on the model. Having said this, these sensors may be justified to be used in the future if the prototype proves to be successful.

Door Vehicle Counter

Another piece of data gathered for processing is the total number of vehicles present in the parking lot, parked or moving.

The technology to keep track of the number cars in a lot is readily available. Most common system involve pressure or infrared-beam sensors at the entrance and exit of the lot that send signals when a vehicle passes. We do not believe installing one of these systems will greatly enhance the validity of the prototype. Since the technology is commonly used and trivial to obtain and implement, we decided to bypass the cost associated with this feature. Instead, we will employ switches that will be manually pressed to simulate the presence of a gate counter.

Signal Processing

Addressing

In this prototype, we consider the scenario where a parking lot has only eight parking spaces. The microprocessor communicates with the sensors by assigning each one of them an unique address. A multiplexer is used to interface between the sensor outputs and the microprocessor, and similarly a de-multiplexer between the processor and the LEDs map. Both multiplexer and de-multiplexer are connected to a same address bus, and the microprocessor can select the destination by placing an address onto the address bus. This implementation allows the system to be extremely expandable. Because we are interested in monitoring eight spaces, the address bus requires 3 bits in order to represent each spot individually. If we want to add more parking spaces in the future, we can do so by increasing the address bus width. The hardware limit of the address bus width in this system is 13 bits, which can decode into 8192 parking spaces!

The Algorithm

The flow chart shown in Figure 5 illustrates an overview of the algorithm of the main program.

We will implement the main program in a round-robin fashion. First the processor will select the first sensor, which is the one that has the smallest address. The multiplexer, therefore, will route the output of this sensor to a filter, which is used to interpret the sensor signal. The output of the filer is either HIGH or LOW, which represents “vacant” and “non-vacant” respectively. Next, this binary signal is adjusted to a voltage level required before it is fed to the microprocessor. The data will then gets stored in the main memory, and the next sensor will be selected. After one complete cycle through all sensors, the microprocessor will then process the stored data. Using the processed data, the processor will update the LCD and LEDs map accordingly.

The main program is designed to run forever (i.e. the algorithm is constituted of an infinity loop). This design is justified because of the nature of this project – an embedded system that has a high availability.

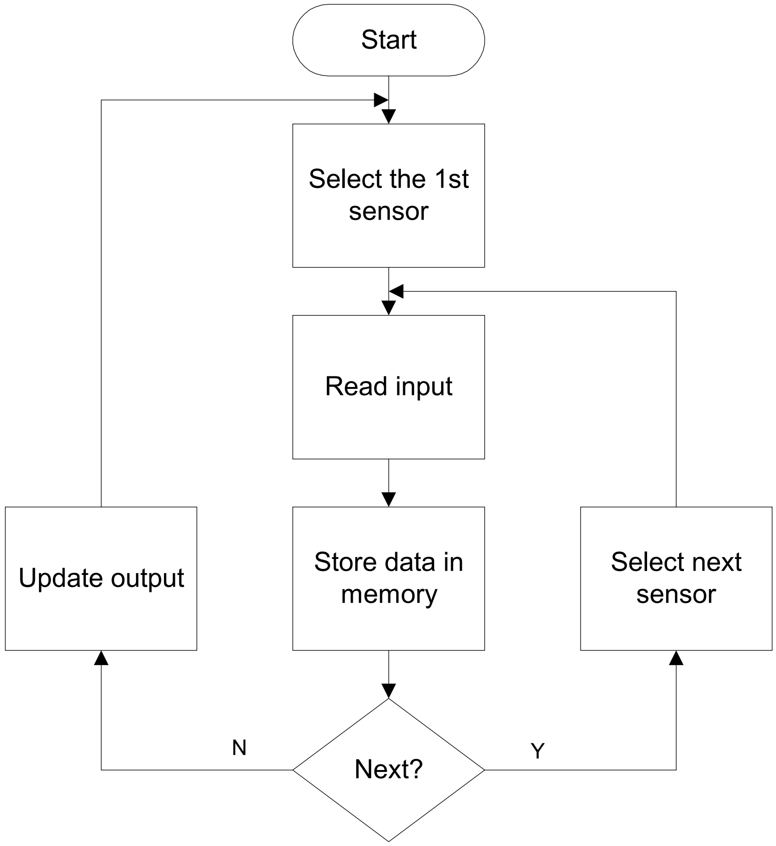

Figure 5 Flowchart of Main Program Algorithm

The program also needs to keep track of the total number of vehicles present in the parking lot, parked or roaming. A door counter is a device that is used to implement this function. When the counter detects a vehicle entering a parking lot, it will send a signal to the microprocessor. If a car leaves the parking lot, the counter will send another type of signal so that two signals are distinguishable by the processor. Because cars move in and out of the parking lot frequently, the program has to be able to collect the data in real time. It also means that the microprocessor has to sample the data immediately when the door counter sends it. Therefore, two interrupt lines are used to get the processor's attention right away. In practice, the interrupt subroutine should be small so that it will not interfere with the normal operation of the program. The algorithm is shown in Figure 6.

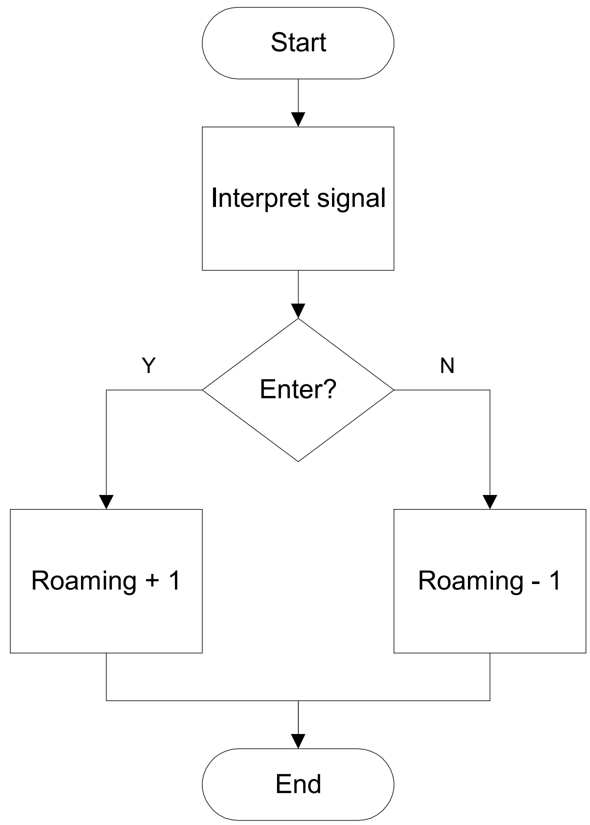

Figure 6 Flowchart of Interrupt Subroutine

Microprocessor Selection

An appropriate microprocessor is required to carry out the signal processing. A number of factors are considered when selecting a microprocessor.

- **Clock speed:** The system operates in real-time. Therefore, speed is a critical requirement. However, in this prototype the microprocessor monitors only eight sensors. Even a 1 MHz processing speed is more than enough. As the system expands, though, more processor power will be needed.

- **Memory:** In order to ease the system design, we prefer microprocessor that includes internal memory. In addition, the memory should be fast enough to handle the program. This means that the memory type is either Flash or EEPROM. We predict the size of the program will be at least 2Kbytes. Data memory size is not a big concern for this system, because we only need one bit for each parking space and some integer values which store the number of vehicles present in the parking lot.

- **Interrupt:** The microprocessor has to provide at least two external interrupts to implement the door counter function.

- **I/O pins:** This is the most important feature that we have to consider. Because this system is built around many peripherals, the microprocessor must have at least 25 I/O pins to support all required pin connections.

- **Programming:** We want to be able to develop codes immediately without having to write extra software to program the microprocessor. Ideally, all necessary hardware circuitries are in place to give us a quick start. This means that an evaluation board and development software tools of the microprocessor must be available from the manufacturer.

The Atmel AT90S8535 8-bit AVR microprocessor meets all the requirements stated above. With its extensive online documentation, low cost and high availability, we decide to make this the processor of our system. Even though it has a small amount of RAM, the 512 bytes will be sufficient to store sampled pre-processed data.

User Interface

Interface Overview

As detailed in our *Project Proposal for SensorMate Parking System* and *Functional Specification for SensorMate Parking System*, the output of our system is based upon a LCD display and a LED billboard. The function of the LED billboard is to provide status indication for each parking space within the parking lot [R33]. As well, per to requirement [R34], the LCD display is used to present the total number of vacant spots in the parking lot, as well as other miscellaneous information.

Due to budgetary concerns, we cannot obtain an industrial size LCD display; thus a small-scale LCD display documented in the following section will be used. As well, per to requirement [R4], the LED display for the prototype device will only display status indication for eight parking spaces.

Prototype Liquid Crystal Display (LCD)

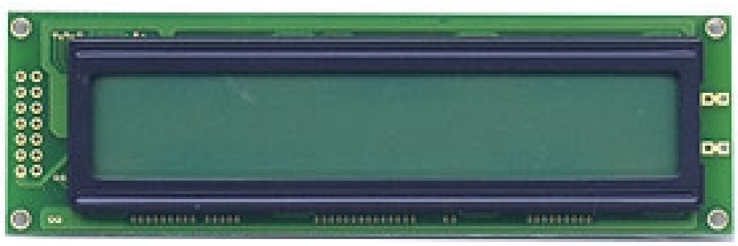

Figure 7 Liquid Crystal Display

The LCD display chosen for our project is a single colour, twenty-four characters by 2 line display, part number: LM-B3-025. The device requires a 5V power supply voltage with a voltage swing from 0V to 5V. It has a 14-pin connection using 8-pins for data bus line. While the device is not designed for industrial use, it can operate in temperature conditions of -20 ^{0}C to 70 ^{0}C with a lifetime of 50,000 hours.

Normal Operation Mode

Normal operation Mode is the condition for the LCD display while in operation as the display device for the *SensorMate Parking System*. While operating, the LCD display will show the number of available spots along with the number of cars currently roaming the parking lot. The following figure illustrates the designed output of the LCD display.

Figure 8 LCD – Normal Operation Mode

Within Normal operation Mode, there are two different display schemes. In the figure above, the operation screen for available spots is shown. The other display scheme is shown below when all parking spaces are occupied.

Figure 9 LCD – All Spaces Occupied

Debug Mode

Debug Mode is the condition for system designers and technicians to unit test the display modules and to system test the *SensorMate Parking System*. Under the unit testing condition, a set of characters and numerals will be displayed from the LCD to indicate the unit is operational. For system testing, the LCD device will display all output parameters for monitoring purposes.

Prototype LED Map

The Billboard component of *SensorMate Parking System* consists of both the LCD device and the LED display board. The LED display is designed for operation in an eight spot parking lot, as per requirement [R4]. Two LED's will be use to display the status of each parking space. A red-lit LED will indicate the parking space has been occupied, while a green-lit LED will indicate a vacant parking space. For demonstration purposes, our LED display will not be built to full-scale. The LED chosen for this project can withstand a supply voltage of 4.0 V and a power rating of 70 mW.

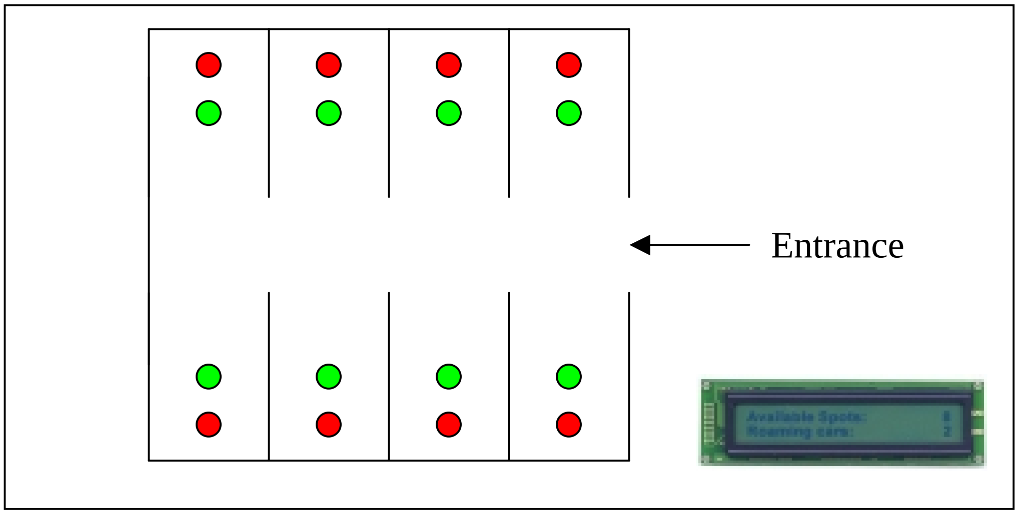

Figure 10 Billboard Design

The above diagram shows the configuration of our billboard with LED display and LCD combined. In order to implement the LED display, a circuit for the LED's has to be designed and built. The following diagram shows the logic design of our circuit to drive the LED's on the billboard. In this implementation, the output from the micro-controller is read by a one to eight selector, which will feed a network of LED's. The two LED's for each parking space are inverted such that only the green or the red LED can be turned on at any one time. In Figure 11, a circuit for the logic inverter is shown with a green LED as the load device.

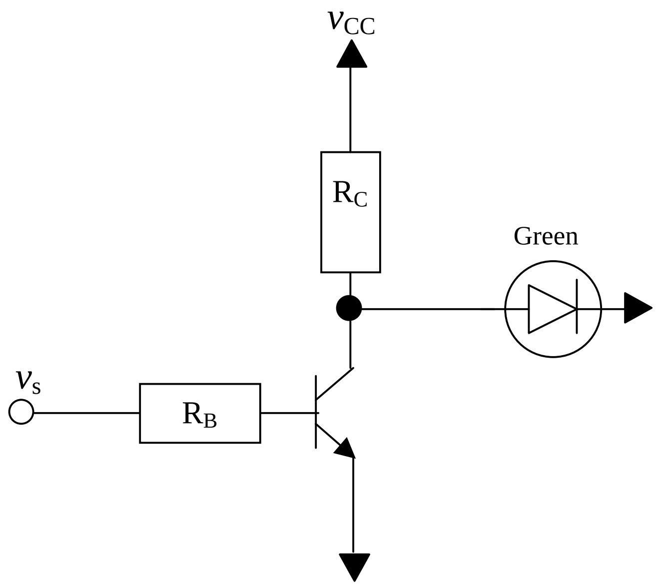

Figure 11 BJT Inverter Implementation

Testing

Visual Inspection

The first and simplest test that shall be done is the visual test. The prototypes shall have neat wiring, clean solder joints, rounded edges, sturdy ultrasonic sensor casing, and correct orientations for all components of the system. If any errors are detected at this point then all other tests shall be halted until they can be resolved.

Firmware Testing

The firmware of our system is going to be the routines and functions used by the microcontroller. This code contains the sensor activation detection algorithms, input/output controls, and the LCD display algorithms.

During the development phase of the firmware, we shall use incremental testing to test the functionality of each functions or components. When all the components are completed, we shall have integration testing to ensure that all components work as specified. Finally, we shall have 'black box' test in order to verify if the firmware is process the outside signals and outputting the expected signal correctly.

Assume we have a parking lot size of two parking spaces. An example of a 'black box' test would be:

(1) Have parking lot initially empty, all LED's are off indicating all free spaces, LCD have "Parking lot open – 2/2 free spaces".
(2) Have a car park in one of the space to activate the ultrasonic sensor.
(3) One LED is now switched on indicating one space is being occupied, LCD have "Some spaces available – 1/2 free spaces".
(4) Have another car park in another space to activation another sensor.
(5) Another LED is now switched on indicating another space is being occupied, LCD have "Parking lot closed – 0/2 free spaces".
(6) Have both cars leave the parking lot at the same time.
(7) Parking lot now empty, all LED's are off indicating all free spaces, LCD have "Parking lot open – 2/2 free spaces".

We this test is successful completed, we know that our system is working according to the functional specifications since we got the information we wanted.

Ultrasonic Sensor Testing

Interference Tests

We have stated in our Functional Specification that our ultrasonic sensors have a range of 60 degree sensitivity range, but it turns out that our prototype sensor has a much narrower range than that. In fact, we have estimated that it has a 10 degree range. We have changed the orientation of the sensor to be on the ground encased by a sturdy case so that it is only activated when something passes over the sensor on top. Given the changes we have made, they is little room for interference of one sensor to the operation of another.

Sensitivity Tests

We will have cars of different heights pass over the sensors to ensure the compatibility of the system to the real world. The ultrasonic sensors should be sensitive enough that it will detect a lowered sports car all the way to a pickup truck.

Stress Tests

The Ultrasonic sensor casing shall be able to withstand dust and sand. For the prototype model however, it may not stand up to water, heat, force of car running over it, human stomping on the casing, or the forces of earthquakes, etc.

Stability Testing

Given the simplicity of our prototype model and the small number of parking spaces that the system will support, our system will stay on and functional for at least 24 hours. During this period the system will be tested for consistency and functionality.

Usability Testing

In usability testing, we will randomly hire 5 students in the student body to use and evaluate the effectiveness of our parking system. Issues such as intuitiveness of system outputs (i.e. message from LCD, LED signals, etc.), ease of use of system interface, overall usefulness of the system, and time issues will be discussed with the users after they have been put through a set of scenarios.

Conclusion

This document provides a detailed design specification for a prototype of the SensorMate Parking system. This document, along with an operational prototype, shall provide enough information for manufacturers to build a manufacturing plan from.

This design specification details the functionalities R[1] through R[76] in the Functional Specification Document. All the work specified here will have a projected completion date of December 10, 2001.

References

1. Digikey Website, www.digikey.com

2. AVR AT90LS8535 Datasheet, Atmel, www.atmel.com/atmel/products/prod200.htm

3. STK500 User Manual, Atmel, www.atmel.com/atmel/products/prod202.htm

4. LCD Datasheet, Nan Ya Plastics Corp.

5. DM74LS151 8-to-1 Multiplexer Datasheet, Fairchild Semiconductors, www.fairchildsemi.com

6. DM74LS138 1-to-8 De-multiplexer Datasheet, Fairchild Semiconductors, www.fairchildsemi.com

7. Online ultrasonic sensor resources, www.circuitos.terra.cl

8. *A Functional Specification for SensorMate Parking System*, R. Fung, J. Kan, L. Tam, S. Soong, October 15, 2001.

Appendix

Parts List

Item	Manufacturer	Part Number	Quantity
AVR Starter Kit	Atmel	STK500	1
LCD	Nan Ya Plastics Corp.	LM-B3-025	1
8-to-1 multiplexer	Fairchild Semiconductor	DM74LS151	1
1-to-8 de-multiplexer	Fairchild Semiconductor	DM74LS138	1
Green LED			1 per sensor x 8 sensors
Red LED			1 per sensor x 8 sensors
Transducers			2 per sensor x 8 sensors
NPN BJT transistors		2N3904	2 per sensor x 8 sensors
Timer		LM555	1 per sensor x 8 sensors
470nF capacitor			2 per sensor x 8 sensors
10nF capacitor			2 per sensor x 8 sensors
2nF capacitor			1 per sensor x 8 sensors
100kΩ trimpot			1 per sensor x 8 sensors
220kΩ resistor			2 per sensor x 8 sensors
22kΩ resistor			1 per sensor x 8 sensors
2.2kΩ resistor			2 per sensor x 8 sensors
1kΩ resistor			1 per sensor x 8 sensors
270Ω resistor			1 per sensor x 8 sensors

Table 1 Parts List

Product Brief of the Atmel AVR EVB

The Atmel AVR Starter Kit (STK500) is a complete development system for the Atmel AVR Flash microcontroller family. With this starter kit, we can readily develop code on the AVR microprocessor to prototype and test our designs. The list below highlights the features of this starter kit that are most important and beneficial to our system.

- RS232 interface to PC for programming and control
- Regulated power supply
- Serial In-System Programming (ISP)
- 8 push buttons for general use
- 8 LEDs for general use
- All AVR I/O ports easily accessible through pin header connectors
- On-board 2-Mbit nonvolatile data storage
- Software tools used for communicating with the starter kit

Schematics

Ultrasonic Transmitter

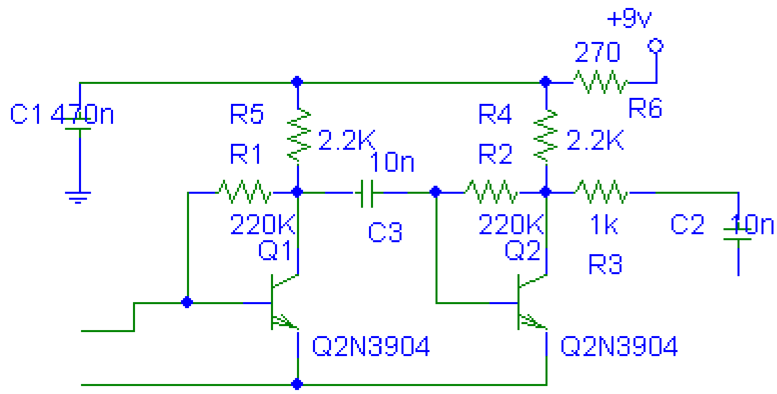

Figure 12 Schematic of Ultrasonic Transmitter

Ultrasonic Receiver

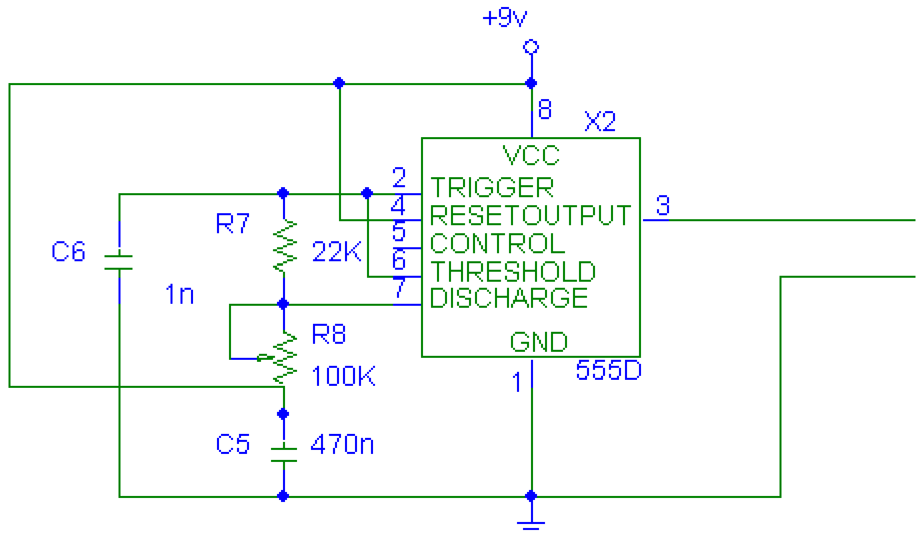

Figure 13 Schematic of Ultrasonic Receiver

Mulitplexer Circuitry

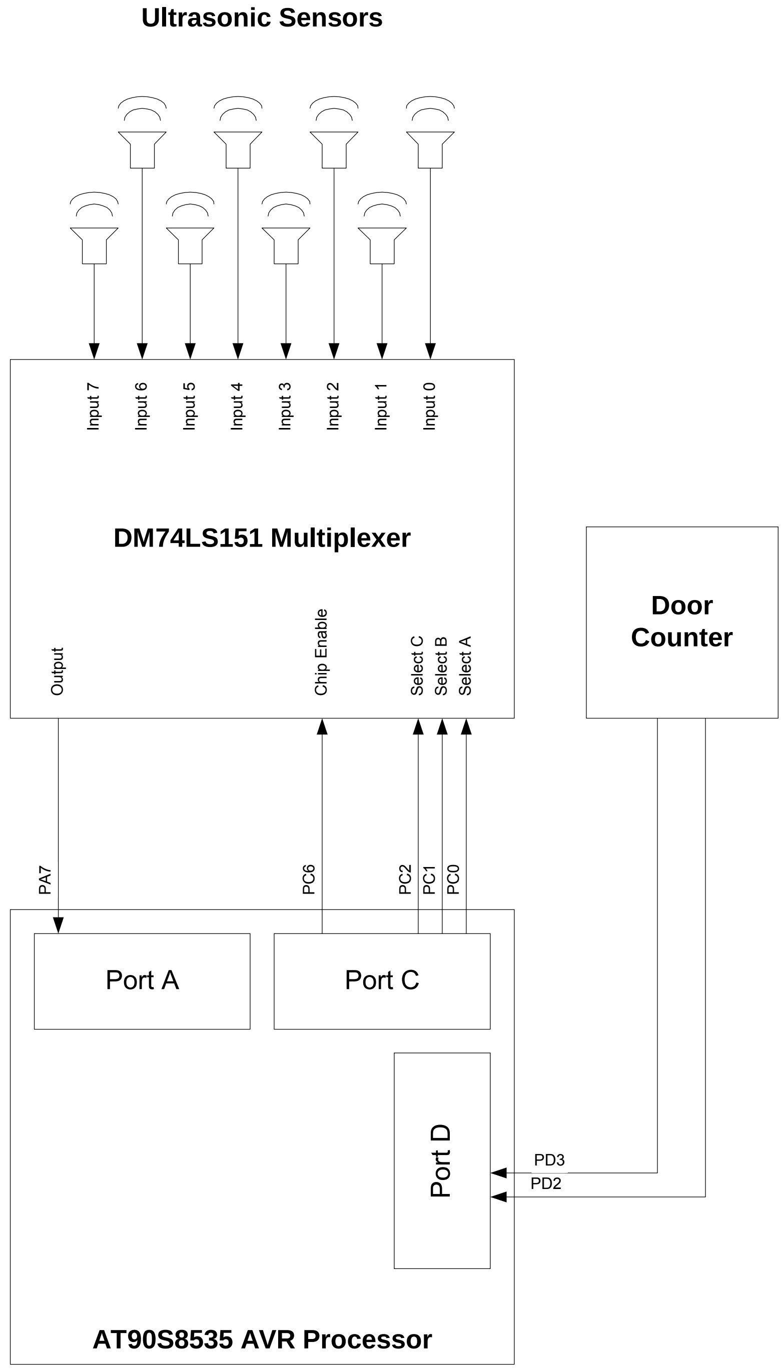

Figure 14 Multiplexer Block Diagram

De-Multiplexer Circuitry

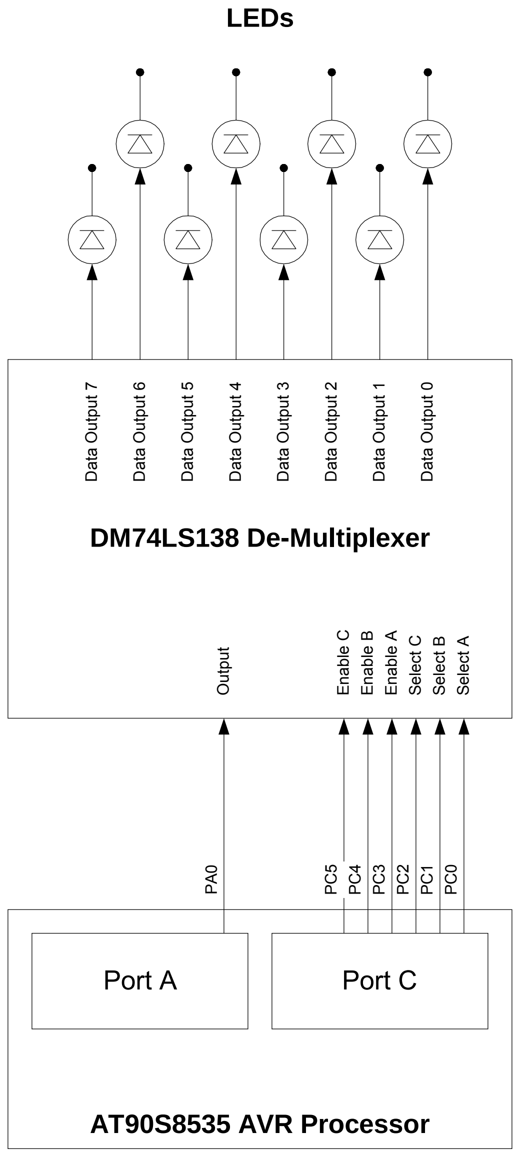

Figure 15 De-Multiplexer Block Diagram

LCD Interface

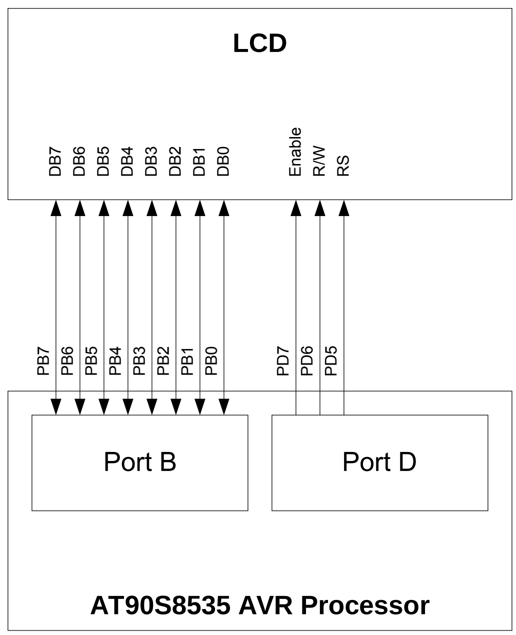

Figure 16 LCD Interface Block Diagram