Human Proximity Sensing and Reduction of Power Consumption

ECE 480 Design Team 5
For Whirlpool Corporation

JUDGE’S COPY

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Final Report
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Executive Summary:

The drive to lower energy consumption and protect the environment has become a growing priority in consumers’ minds. The Environmental Protection Agency & U.S. Department of Energy’s ENERGY STAR compliance is anticipated to develop a new requirement that appliances must enter a standby mode and consume one watt of power or less. In light of the energy demands, Whirlpool Corporation is determined to design and manufacture the most customer friendly and energy efficient products. This has created a need for appliances that include proximity detection both in the same room and directly in front of the product. Near negligible cost is also necessary with respect to Whirlpool’s lower-end products.

ECE 480 Design Team 5 has developed an end design that includes a proof of concept for appliances to detect user proximity and minimize power consumption using standby mode. A passive infrared sensor was implemented for in-room detection. Inexpensive infrared sensors were integrated inside appliances to detect possible use, and ultrasonic sensors were interfaced with certain high-end appliances to enhance the user experience. The addition of these sensors into appliances will conserve energy and save consumers money on their utility bills by implementing a low power standby mode as well as optimize customer experience.
Acknowledgements:

ECE 480 Design Team 5 would like to express their greatest thanks to the following people for their help in integrating proximity sensors into home appliances:

**Whirlpool Corporation: Mr. Randy Jeffery,**
for his support and direction on appliance hardware and software features

**MSU College of Engineering: Dr. Virginia Ayres, Dr. Erik Goodman and Mr. Qaiser Malik,**
for their support and guidance throughout the design process

**MSU ECE Technical Services: Mr. Brian Wright, Mr. Gregg Mulder and Mrs. Roxanne Peacock,**
for their support in easily obtaining all necessary components
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1. **Introduction**
   
1.1. **Whirlpool Project**
   
The drive to lower energy consumption and protect the environment has become a growing priority in consumers’ minds. ENERGY STAR compliance is also expected to enact a requirement that appliances must enter a standby mode and consume one watt of power or less. In light of these energy demands and expectations, Whirlpool Corporation continues in its determination to design and manufacture the most customer friendly products. This has created a need for appliances that can smoothly enter and exit an energy ethical standby mode. Whirlpool’s novel approach is to use proximity detection in the same room and directly in front of the product. Near negligible cost is also necessary with respect to Whirlpool’s lower-end products.

1.2. **ENERGY STAR**
   
In 1992, ENERGY STAR was introduced as a voluntary labeling program to promote energy efficient products. It was a joint venture created by the U.S. Environmental Protection Agency and the U.S. Department of Energy. Corporations must follow strict energy efficiency guidelines in order to market their products as ENERGY STAR approved. By using products that adhere to these guidelines, last year Americans saved enough energy to avoid using as much greenhouse gas emissions as 29 million cars and saved $19 billion on utility bills.

1.3. **Whirlpool Corporation**
   
Whirlpool Corporation was founded in 1911 with the goal of creating the best home appliances for the American consumer through utilizing then-novel electrical technologies. Whirlpool, the world’s pioneer appliance manufacturer and marketer, grossed approximately $19 billion in annual sales in 2008. This performance continues to improve through their innovative and international business strategies in combination with a customer-oriented philosophy. Hence, Whirlpool Corporation took action for their eco-friendly production as early as the 1970’s with the creation of their Sustainability Office. This environmentalist attitude has piloted Whirlpool towards today’s energy and water-efficient appliance production. Along with the
Whirlpool brand, they also own and market many other major brands such as Maytag, KitchenAid, and Jenn-Air. Since 1956, Whirlpool has been headquartered in Benton Harbor, MI. At present, Whirlpool employs more than 70,000 employees. Whirlpool employs a large workforce in Michigan and is a premier partner with ENERGY STAR. Whirlpool is also a leading supporter of Habitat for Humanity. They are committed to providing energy efficient households for the Habitat for Humanity families and were recently the lead sponsor of a Habitat for Humanity build, at which 270 employees helped build more than 230 houses in Michigan. Other charitable and commendable actions include the donation of over 1 million dollars worth of money, products, and services after Hurricane Katrina in 2005, as well as over 175 washer-dryer units for use at the Houston Astrodome shelter. At the global headquarters in Benton Harbor, MI Whirlpool Corporation promotes high quality products and conducts green-living sustainable research projects.

1.3.1. Whirlpool in Association with ENERGY STAR
Whirlpool has been an active ENERGY STAR partner since August 1998. During that time, they have won ten ENERGY STAR awards, including the Partner of the Year Award seven times, as well as the 2006 through 2009 ENERGY STAR Sustained Excellence Award. They continue to create innovative products that not only match, but surpass, ENERGY STAR guidelines in order to save consumers money and help the environment. Whirlpool presently designs, manufactures, and markets over 590 ENERGY STAR appliances.

Figure 1.3.1a. Whirlpool Corporate Headquarters located in Benton Harbor, MI
1.4. Advantages of the Proximity Sensor Approach
Whirlpool does not currently implement a standby mode in its appliances. The reason for this is due to their focus on optimizing customer experience with their products. The majority of consumers do not want to press a button on their oven in order to view the time on the clock. They also do not want to have press a button on their washing machine and then wait a period of time before they can use it. The addition of various proximity sensors into appliances will solve these issues as well as carry over into multiple benefits for the consumer aside from customer satisfaction. To put it simply, when the consumer walks into their kitchen, their kitchen will turn on without them ever knowing that it was off. In the general situation, a passive infrared sensor will detect the user entering the room. It will communicate to the appliances to exit complete standby mode and power on just enough to turn on any typical displays such as a clock. When the consumer moves into range of actually using the appliance, an infrared sensor will detect their presence and exit standby mode entirely for customer use. In certain high-end appliances such as those with LCD touch-screen displays, a slightly more expensive ultrasonic sensor will be used in place of the infrared sensor. This will allow for detection of the precise distance the user is from the appliance. As the user moves closer to the appliance, the LCD will display more and more relevant information ending in button displays available for use. The integration of sensors into appliances will create an enhanced user experience as well as conserve energy and save consumers money on their utility bills by implementing a low power standby mode.

2. Solutions
2.1 Design Solution Matrices

The problem posed to Design Team 5 by the Whirlpool Corporation was unique in the sense that it demands two separate designs; one for low-to-mid range appliances and one for high-end appliances. The initial meeting with the sponsor, Mr. Jeffery, revealed a project scope with three stages. The first stage was the
selection of the sensing technology for user detection. The second stage was interfacing the sensor code and circuitry onto the WIDE bus in order to be able to communicate with other control boards within the appliance. The final stage was wireless communication between appliances. It was mentioned that the third stage was the least important and the team may choose to focus more on the sensor design and bus interfacing stages of the project. Also revealed at the first meeting were the design specifications for power, size, cost, flexibility, accuracy, and finally safety. Power consumption for the user detection sensor and its accompanying circuitry should not exceed one watt while the appliance is in standby mode. The device should fit aesthetically into the sometimes limited available space of an appliance. The cost of the sensing unit was dependent on the price range of the appliance. The ultimate design should be flexible enough to be integrated into both existing and future appliances. The device needs to be accurate so as to not interfere with the appliance functionality and robust as to not be susceptible to outside interference. Also, each device should be able to detect distance when a user is simply within a room and also when near an appliance. Finally, the device should not pose any safety threats as it will be used by the general public.

After the initial meeting with Mr. Jeffery, Design Team 5 developed the Voice of Customer (VoC) interview as a first step to exploring the design solution space. The intention of the interview was to identify the most and least important aspects of the project as well as to understand what was expected of the final outcome. From this information the Team was able to identify the Critical Customer Requirements (CCRs) for the design project. Through the VoC, it was discovered that for the low-to-mid range appliances energy efficiency, cost, and robustness of design were the most important aspects. For the high-end appliances robustness of design was still high on the priority list but cost was no longer a top consideration. And, while energy efficiency fell in importance, user experience rose in importance. User experience rises in importance due to the idea of information density proposed by
the sponsor. Information density is a concept that an LCD module within the user interface of an appliance will display an increasing amount of information as a user approaches it.

With this information, the Team was able to develop design solution matrices that would help indicate the best design solutions. Two separate matrices were created for the different design requirements of the low-to-mid range and the high-end appliances. These matrices can be found below as Tables 2.1a and 2.1b. The Design Criteria was chosen from the design specifications mentioned in the first meeting. The Possible Solutions include the potential types of sensors to be used, integration with the WIDE bus, and wireless communication. In these matrices, the Importance column ranks the level of importance of the Design Criteria to the left from one to five, with one being the lowest and five the highest importance. Each cell is rated on how well the Possible Solution meets the Design Criteria. One point indicates a weak rating, three points indicate a moderate rating, and 9 points indicate a strong rating. Finally, the totals were calculated by taking the sum of the ratings of each Possible Solution multiplied by the Design Criteria level of Importance.

<table>
<thead>
<tr>
<th>Engineering Criteria</th>
<th>Importance</th>
<th>Possible Solutions Features</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ultrasonic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Compact Size</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Cost</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Choice of Microprocessor</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Appliance Versatility</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Speed of Response</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Robustness to Environment</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>
The sections that are highlighted indicate the design choices that were made by Design Team 5. For the low-to-mid range solution, it was found that a combination of a passive infrared sensor (PIR) and an active infrared (IR) sensor will best satisfy the CCRs. The PIR is capable of long range user detection and is very low on power consumption. In standby mode, the system will wait until motion is detected by the PIR. Once motion is detected by the PIR, the IR will turn on to detect if a user comes within close proximity to the appliance. When motion has been detected by the IR, the information is sent on the WIDE bus and existing control boards on the appliance will return from standby mode. For the high-end solution, it was found that a
combination of an ultrasonic sensor and a PIR would best suit the CCRs. Again, in standby mode the system will wait until motion is detected by the PIR. Once motion is detected by the PIR, the ultrasonic sensor will turn on. The ultrasonic sensor is capable of calculating proximity of the user to the appliance. As the user approaches the appliance an LCD on the user interface will display and increasing amount of information. This distance information will also be sent on the WIDE bus to bring other control boards out of standby mode. For the proof of concept, the sponsor determined that it is unnecessary to attempt to program an actual LCD module. It was suggested that the Design Team simulate the concept of information density on a computer instead. From this information the Team developed a Function Analysis System Technique (FAST) Diagram, which is a powerful design tactic for analyzing the functional strategy structure of a technical system. This diagram can be found below in Figure 2.1a.

![Figure 2.1a: FAST Diagram](image-url)
2.2 Gantt Chart

The next stage in exploring the design solution space was for Design Team 5 to develop a Gantt chart. The initial Gantt chart can be found below in Figure 2.2a. The Gantt chart served as a timeline estimate that should be followed in order to meet the project goals by the deadline. The initial Gantt chart allotted some time for the development wireless communication. This was due to the fact that wireless communication was listed as part of the product scope by the sponsor and the Team would therefore attempt to include it in the project if the other aspects had been completed successfully.
After a few weeks of working on the project the Design Team reevaluated the Gantt chart and made some adjustments for the new developments that had arisen. It was decided that the Team would no longer pursue wireless communication in order to have a more complete product that utilized the multiple sensors and WIDE bus interfacing. Other changes in the Gantt chart were due to delays in acquiring parts and unexpected difficulties with some systems.

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Definition</td>
<td>10 days</td>
<td>Wed 9/2/09</td>
<td>Mon 9/14/09</td>
</tr>
<tr>
<td>Project Assignment</td>
<td>3 days</td>
<td>Wed 9/2/09</td>
<td>Fri 9/4/09</td>
</tr>
<tr>
<td>1st group meeting</td>
<td>1 day</td>
<td>Wed 9/9/09</td>
<td>Wed 9/9/09</td>
</tr>
<tr>
<td>1st contact with facilitator</td>
<td>1 day</td>
<td>Wed 9/9/09</td>
<td>Wed 9/9/09</td>
</tr>
<tr>
<td>Meeting with Sponsor</td>
<td>1 day</td>
<td>Mon 9/14/09</td>
<td>Mon 9/14/09</td>
</tr>
<tr>
<td>Initial Research</td>
<td>28 days</td>
<td>Tue 9/15/09</td>
<td>Thu 10/22/09</td>
</tr>
<tr>
<td>Sensor Research</td>
<td>7 days</td>
<td>Tue 9/15/09</td>
<td>Wed 9/23/09</td>
</tr>
<tr>
<td>Wireless Research</td>
<td>1 day</td>
<td>Tue 9/22/09</td>
<td>Tue 9/22/09</td>
</tr>
<tr>
<td>Industry contact</td>
<td>1 day</td>
<td>Thu 10/8/09</td>
<td>Thu 10/8/09</td>
</tr>
<tr>
<td>WIDE training</td>
<td>1 day</td>
<td>Thu 10/8/09</td>
<td>Thu 10/8/09</td>
</tr>
<tr>
<td>Conceptual Design</td>
<td>31 days</td>
<td>Fri 9/4/09</td>
<td>Fri 10/16/09</td>
</tr>
<tr>
<td>Develop individual ideas</td>
<td>7 days?</td>
<td>Fri 9/4/09</td>
<td>Sun 9/13/09</td>
</tr>
<tr>
<td>Team brainstorm</td>
<td>3 days</td>
<td>Mon 9/14/09</td>
<td>Wed 9/16/09</td>
</tr>
<tr>
<td>Narrow down choices</td>
<td>8 days</td>
<td>Thu 9/17/09</td>
<td>Mon 9/28/09</td>
</tr>
<tr>
<td>Finalize Design</td>
<td>0 days</td>
<td>Fri 10/16/09</td>
<td>Fri 10/16/09</td>
</tr>
<tr>
<td>Component Acquisition</td>
<td>40 days</td>
<td>Mon 10/5/09</td>
<td>Fri 11/27/09</td>
</tr>
<tr>
<td>Acquire Sensors</td>
<td>5 days</td>
<td>Fri 10/9/09</td>
<td>Thu 10/15/09</td>
</tr>
<tr>
<td>Acquire User Interfaces</td>
<td>13 days</td>
<td>Mon 10/5/09</td>
<td>Wed 10/21/09</td>
</tr>
<tr>
<td>Acquire RF Devices</td>
<td>7 days</td>
<td>Mon 10/12/09</td>
<td>Tue 10/20/09</td>
</tr>
<tr>
<td>Circuit Components</td>
<td>26 days?</td>
<td>Fri 10/23/09</td>
<td>Fri 11/27/09</td>
</tr>
<tr>
<td>Testing and Analysis</td>
<td>22 days</td>
<td>Fri 10/16/09</td>
<td>Mon 11/16/09</td>
</tr>
<tr>
<td>Initial sensor testing</td>
<td>7 days</td>
<td>Fri 10/16/09</td>
<td>Mon 10/26/09</td>
</tr>
<tr>
<td>Evaluate sensor performance</td>
<td>2 days</td>
<td>Tue 10/27/09</td>
<td>Wed 10/28/09</td>
</tr>
<tr>
<td>WIDE integration</td>
<td>14 days</td>
<td>Fri 10/23/09</td>
<td>Wed 11/11/09</td>
</tr>
<tr>
<td>Wireless Tx &amp; Rx</td>
<td>14 days</td>
<td>Wed 10/28/09</td>
<td>Mon 11/16/09</td>
</tr>
<tr>
<td>Finalized Product production</td>
<td>18 days</td>
<td>Tue 11/17/09</td>
<td>Thu 12/10/09</td>
</tr>
<tr>
<td>Finalized Product Design</td>
<td>4 days</td>
<td>Tue 11/17/09</td>
<td>Fri 11/20/09</td>
</tr>
<tr>
<td>PCB Layout</td>
<td>4 days</td>
<td>Mon 11/23/09</td>
<td>Thu 11/26/09</td>
</tr>
<tr>
<td>Assembly of final components</td>
<td>2 days</td>
<td>Mon 11/30/09</td>
<td>Tue 12/1/09</td>
</tr>
<tr>
<td>Final testing</td>
<td>7 days</td>
<td>Wed 12/2/09</td>
<td>Thu 12/10/09</td>
</tr>
<tr>
<td>Final Product completion</td>
<td>0 days</td>
<td>Thu 12/10/09</td>
<td>Thu 12/10/09</td>
</tr>
</tbody>
</table>

Figure 2.2a: Design Team 5 Initial Gantt Chart
2.3 Budget
The final step in exploring the design solution space was for Design Team 5 to create an initial budget for the project. The anticipated budget can be found below in Table 2.2.a. This budget was developed as an estimate of the cost to Michigan State University to build the proof of concept prototype. The sponsor had indicated that he would be able to provide many of the items needed to develop the product at no cost. Just as in the initial Gantt chart, the initial budget allocated funds for wireless
communication research. The initial budget can be found below in Figure 2.3a. The final budget can be found in figure 2.3b.

<table>
<thead>
<tr>
<th>Item</th>
<th>Price</th>
<th>Quantity</th>
<th>Source</th>
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</thead>
<tbody>
<tr>
<td>Microcontrollers</td>
<td>$0.00</td>
<td>10</td>
<td>Whirlpool</td>
</tr>
<tr>
<td>IR Sensors</td>
<td>$0.00</td>
<td>5</td>
<td>Donated</td>
</tr>
<tr>
<td>PIR Sensors</td>
<td>$0.00</td>
<td>3</td>
<td>Donated</td>
</tr>
<tr>
<td>Ultrasonic Sensors</td>
<td>$24.99</td>
<td>2</td>
<td><a href="http://www.hobbyengineering.com/CatSULTRA.html">http://www.hobbyengineering.com/CatSULTRA.html</a></td>
</tr>
<tr>
<td>LCD Display</td>
<td>$0.00</td>
<td>1</td>
<td>Whirlpool</td>
</tr>
<tr>
<td>Whirlpool UI</td>
<td>$0.00</td>
<td>2</td>
<td>Whirlpool</td>
</tr>
<tr>
<td>Garage Door Receiver</td>
<td>$68.99</td>
<td>1</td>
<td><a href="http://www.usdoorcontrol.com/item-608.html">http://www.usdoorcontrol.com/item-608.html</a></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$168.95</strong></td>
<td><strong>1</strong></td>
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</tr>
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</table>

Figure 2.3a: Design Team 5 Initial Budget

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Price</th>
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</thead>
<tbody>
<tr>
<td>WIDE Development Board</td>
<td>2</td>
<td>$0.00</td>
</tr>
<tr>
<td>Whirlpool Refrigerator UI</td>
<td>1</td>
<td>$0.00</td>
</tr>
<tr>
<td>Whirlpool Clothes Washer UI</td>
<td>3</td>
<td>$0.00</td>
</tr>
<tr>
<td>Ultrasonic Range Finder - Maximolx LV-EZ1</td>
<td>2</td>
<td>$60.33</td>
</tr>
<tr>
<td>KIT, PIR-SENSOR - 2082927</td>
<td>2</td>
<td>$25.98</td>
</tr>
<tr>
<td>Sharp GP2D12 Detector Package</td>
<td>2</td>
<td>$81.95</td>
</tr>
<tr>
<td>9-Pin DB9 Female to 15-Pin HD15 Male VGA Video Adapter</td>
<td>2</td>
<td>$39.96</td>
</tr>
<tr>
<td>Parallax PIR Motion Sensor</td>
<td>1</td>
<td>$9.99</td>
</tr>
<tr>
<td>Devantech SRF05 Ultrasonic Range Sensor</td>
<td>1</td>
<td>$29.50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$227.73</strong></td>
<td>****</td>
</tr>
</tbody>
</table>

Figure 2.3b: Design Team 5 Final Budget

3. Technical Description
The following will investigate four primary efforts of the design concept; hardware design, hardware implementation, software and interface design, and software implementation.

3.1. Hardware Design
The hardware fabricated for the end design of this project is rather limited. The main components of each part of the design are as follows:
Washer User Interface:
- 5V DC Supply
- Whirlpool R&E Harpoon Relay Board
- Adapt9S12DP256 Microprocessor
- USB Multilink
- 15V AC Adapter
- Sharp GP2D12 Infrared Ranger

Refrigerator User Interface:
- 15V DC Supply
- Whirlpool R&E Harpoon Relay Board
- Adapt9S12DP256 Microprocessor
- USB Multilink
- 15V AC Adapter
- Sharp GP2D12 Infrared Ranger
- Parallax Passive Infrared Sensor

High-End Graphical Interface
- 5V DC Supply
- LV-MaxSonar-EZ1 Ultrasonic Ranger
- COM1 DB9 Serial Header
- Serial to USB adapter

The basic function of the end design is to have the sensors control the User Interfaces. To achieve this, the Infrared (IR) and Passive Infrared (PIR) sensors are connected to the Adapt9S12DP256 Microprocessor which is connected to the Whirlpool R&E Harpoon Relay Board which is connected between a PC and the User Interface. A basic layout of the concept for the washer and fridge UIs is as follows:

![Figure 3.1a. Basic Design Structure of Sensor UI Integration](image-url)
The washer UI has been provided by the Whirlpool Corporation and consists of three connectors: 5V, Ground, and Wide Communication. The fridge UI has also been provided by the Whirlpool Corporation and consists of three connectors: 14V, Ground, and Wide Communication. Communication with these UIs will be discussed further in section 3.3.

The Sharp GP2D12 IR sensor takes continuous readings from 10-80 cm when supplied 5V and gives an analog voltage output at pin Vout. This pin is connected to an Analog to Digital Converter on the Adapt9S12DP256 Microprocessor. This reading is analyzed in Metroworks, a C language program, and used to detect the presence of a user to initiate the case to send a message to the UI to switch ON.

The Parallax PIR Motion Sensor has been used in conjunction with Sharp GP2D12 IR sensor on the fridge UI. The PIR senses motion up to 20 feet away when connected to a 5V supply. It consists of three pins: Vcc, Ground, and a Single Bit Output. The output communicates a High/Low bit to the Adapt9S12DP256 Microprocessor which states if there is motion (High) or no motion (Low). This is paired with the code established in Metroworks for the IR sensor and UI interface and will be discussed more in chapter 3.3. The PIR is encased in a Fresnel lens which allows it to achieve a sensing “dome” up to 20 feet away from the device.

The Whirlpool R&E Relay Board with Adapt9S12DP256 Microprocessor, provided by the Whirlpool Corporation, is utilized to send WIDE communications to the UIs. It is supplied by a 15V AC adapter and connected to the PC via a USB Multilink connector.

The High End Graphical Interface utilizes an ultrasonic sensor with a serial output, this makes the design concept for this structure very straightforward and it is illustrated below:
The design concept for the MaxSonar Ultrasonic Sensor utilizes three pins: 5V, Ground, and TX. TX delivers a serial output with an RS232 format. The output is an ASCII capital “R” followed by three ASCII character representing the distance in inches and a carriage return (ASCII 13). The MaxSonar detects objects from 0-inches to 254-inches with 1-inch resolution. The MaxSonar was chosen because of its excellent distance sensing, small size, and low current draw, typically ~2mA. The serial data outputted from the MaxSonar is translated in MATLAB and utilized to form an interactive information density display, this will be discussed further in chapter 3.3.

3.2. **Hardware Implementation**
The physical layout of each device is illustrated below:
Figures 3.2a. and 3.2b. show the washer and fridge UIs connected to the Whirlpool R&E Harpoon Relay board and the Adapt9S12DP256 Microprocessor. The ground line on the UIs is connected to a pin labeled TP2 GND on the Harpoon Relay Board. The Wide Communication line on the UIs is connected to a pin labeled TP7 DATA. This line will send data back and forth between the PC and the UI’s EEPROM. As is evident in the photos above the Adapt9S12DP256 Microprocessor is connected atop the Harpoon Relay board. The PC is connected to the Adapt9S12DP256
Microprocessor via a 6 pin connector (BDM In, in figure 3.2c.) on the USB multilink. The layout for the Adapt9S12DP256 Microprocessor is shown below:

[FIGURE OMITTED FOR CONFIDENTIALITY]

Figure 3.2c. The Adapt9S12DP256 Microprocessor

The IR sensor is connected to the Adapt9S12DP256 Microprocessor on the H1 primary side at pin 50 for ground, pin 47 for +5V, and pin 22 for Analog In Channel 0. The PIR can be connected to the Adapt9S12DP256 Microprocessor on the H2 secondary side at pin 49 for ground, pin 50 for +5V, and on the H1 primary side at pin 23 for Analog In Channel 1. In order to maintain proper aesthetics the team has taken great care to make the IR sensing device as imperceptible as possible. To ensure the device is still able to sense object motion a specialized white glass has been installed in on the washer UI for the IR sensor to peer through. On the fridge user interface a specialized black glass has been used to not detract the user from the overall aesthetic design of the interface.
Figure 3.2d. shows the Ultrasonic sensor when connected through a serial to USB adapter controlling an information density display on a computer. The Ultrasonic sensor takes continuous readings and sends the serial data to a MATLAB program which allows a certain amount of information to be viewable to the user depending on the user’s distance from the sensor. The final prototype of the Ultrasonic sensor transmits serial data from the TX pin to the RXD pin (Pin 2) on the COM1 DB9 serial header. This device’s trivial hardware implementation lends to easy integration in future appliances. The complexity lies within the algorithms developed to maintain a flexible system.
3.3. Software and Interface Design
The software algorithms developed for the end design utilize two software programs. For the washer and fridge UI the team used Metrowerks Codewarrior, a C software that is consistent with current Whirlpool applications. For the High-End graphical Interface, the team used MATLAB because of its robust handling of serial data and its straightforward Graphical User Interface (GUI) design.
In order to become familiar with WIDE communications with the UIs, the team’s sponsor Mr. Jeffery provided the team with wide_core_vb, a GUI that allows the user to send and receive data over the WIDE bus as well as monitor the traffic over the WIDE communication bus. This introduction to WIDE communication allowed the team to understand the difference in the messages sent to the fridge and washer UI. A representation of the traffic seen from the wide_core_vb is displayed below.

[FIGURE OMITTED FOR CONFIDENTIALITY]

Figure 3.3a. wide_core_vb screenshot for washer UI

Figure 3.3a. displays an example of a communication with the WIDE bus. It is important to note specific aspects of this screenshot. This particular communication is with the washer UI. The washer UI is an arbiter node and can be labeled node 1. Thus when setting up communications with this UI the proper steps are as follows:
Select correct communication port (this is the port on the computer where the USB is connected)
1. [PROCESS OMITTED FOR CONFIDENTIALITY]

Toggling TxWIDE1 will turn the washer on and off. This is because the washer recognizes the command 6.1.1 as a switch between power ON and power OFF. It is important to note that the washer UI is an arbiter node where the fridge UI is a simple node. The wide_core_vb commands for using the fridge UI are as follows:

1. [PROCESS OMITTED FOR CONFIDENTIALITY]
Clicking the TxWIDE1 button will toggle the light switch on the fridge UI. The UI recognizes 6.1.2 as a toggle command for the light interface. At this time it is not possible to turn on and off the fridge UI with the wide_core_vb, but it will be investigated by the Whirlpool Corporation for future appliances.

With the knowledge that each UI requires different node characteristics the team began development of an algorithm through Metrowerks CodeWarrior that could handle an analog to digital input from a sensor and a unique WIDE communication signal as an output. This will be discussed further in chapter 3.4.

For the graphical user interface developed using the ultrasonic sensor the team utilized MATLAB to read in the Ultrasonic serial messages and display the appropriate graphic at the appropriate user distance. The LV-MaxSonar-EZ1 ultrasonic sensor provides a converted ASCII numeration in inches over the serial line as discussed before. To utilize this, the team developed a reading of distance as the following:

```matlab
Dist = str2num(strtok(ReadOut,'R'));
```

This command takes the incoming serial input and removes the front of the string (the “R”) and converts it to a number that can be analyzed throughout the routine.

The team then developed a count to estimate when there is user presence and when there is not. If the ultrasonic does not detect user presence or motion for a modifiable amount of time (in this case about 30 seconds) then it will display a “standby mode” which displays a dark screen. The team then developed code for information display as relative to distance as illustrated by the following:

```matlab
if strcmp(Disp,'STANDBY')
    %if in standby mode do nothing
else
    %else display distance (to be replaced by output of images)
        if Dist <= 18
            IMG = imread('2_UI_Near', 'bmp');
            axes(handles.image);
            image(IMG);
            axis off
            PrevDist = Dist;
        elseif Dist > 18 && Dist < 48
```
IMG = imread('2_UI_Med', 'bmp');
axes(handles.image);
image(IMG);
axis off
PrevDist = Dist;
else
    IMG = imread('2_UI_Far', 'bmp');
    axes(handles.image);
    image(IMG);
    axis off
    PrevDist = Dist;
end

The images displayed—'2_UI_Near', '2_UI_Med', and '2_UI_Far'— as well as the working design will be discussed further in chapter 3.4.

3.4. Software Implementation
Current Whirlpool appliances do not utilize a sensing mode to establish a standby mode. The following software is unique because it establishes a precedent of employing a sensing device to send a message to a UI to toggle between outputs. For the washer UI a low-end solution was utilized with only an IR sensor through the Analog to Digital port of the Adapt9S12DP256 Microprocessor. Both UI functions use an if-else statement develop whether or not there is user presence in the room. If, for the IR, an ADC result is larger than 7, this establishes an object has been detected and sends a message to the washer UI turning it on, if no object has been detected after a modifiable amount of time the UI again a message will be sent turning the washer UI off. The ADC result returns a value up to 254— when the user is right next to the sensor—and usually signifies object detection when greater than 5—at it’s greatest reading distance. This is displayed for the fridge below.

[FIGURE OMITTED FOR CONFIDENTIALITY]

Figure 3.4a. Mertowerks CodeWarrior code for Fridge UI
Figure 3.4a. illustrates the code for an IR sensor to toggle the light switch on the fridge UI. It is important to note that the Reveal_SendExternalMessage has a 0X02 character in its protocol. This represents the fridge UI as it is identifiable as node 2 in this case. For the washer UI the character is changed to 0X03 as the washer is identifiable as node 3. To further signify the difference in the code being sent to the
different UIs, the washer code must have a declaration as an arbiter node, whereas the fridge code does not need this declaration. Further to take from Figure 3.4a. is the case OPCODE_INTEGRA_MSU, this case transmits the data over the WIDE communication bus. As discussed earlier, to toggle on and off on the washer UI a message of 6.1.1 must be sent and to toggle the light switch on the fridge UI a message of 6.1.2 must be sent. Thus, these messages are taken into account in the case OPCODE_INTEGRA_MSU found in a source file known as RVAppSpecific.c. 

[FIGURE OMITTED FOR CONFIDENTIALITY]

**Figure 3.4b. Opcode for Fridge UI**

As seen in figure 3.4b. the primary buffer initialization signifies the length of the message sent. The next three buffer initializations signify the outputs. Buf[1] and buf[2] are typically populated with protocol elements so they need not be dealt with here. The important aspect of figure 3.4b. is buf[3] which sends a 2. This will toggle the light switch as stated above. For the washer UI code the team simply changes buf[3] from a 2 to a 1. With a 1 the message sent will turn the washer UI on and off as appropriate according to the code in figure 3.4a..

For the information density display code the ultrasonic sensor reads the distance a user is from the sensor and sends a serial signal to a MATLAB code which gives commands to display mock-ups of Whirlpool LCD displays in varying information densities. These are displayed on the next page.
Figure 3.4c. Oven UI LCD Displays

Figure 3.4c. exhibits four LCD information displays on what would be an oven UI. The top-most display shows a high amount of information and thus is displayed when the user is nearest the sensor, typically less than 18 inches. The second figure in figure 3.4c. illustrates what the user would see from a distance greater than 18 inches but less than say 48 inches. This shows, in this case, the oven’s temperature allowing the user to keep a steady check on the performance of the oven when in close proximity. The third image depicts what a user would see when still detected but of a distance greater than 48 inches from the UI. It displays only the most important aspects of the UI—the time and temperature of the oven. This will ensure the user still has the interface needed while cutting down on extemporaneous power needed to drive the microprocessor’s other unnecessary
functions. The lower-most image in Figure 3.4c. shows the UI in “standby mode”, this occurs after no motion has been detected for a period time, in this case, greater than thirty seconds.

4. Data Testing and Proof of Functional Design
Throughout the design process, three different detection systems were planned, designed, and developed. Design Team 5 researched multiple sensor options and various system configurations. After the team decided on the three specific sensors, all the hardware components were received and the software installed, the first stage of the design was to test the sensors individually. At the second stage, the sensors were tested together as they were going to be implemented in real life applications. The SHARP Infrared (IR) sensor GP2D12 is used in the washing machine user interface (UI), another SHARP IR and a Parallax passive infrared sensor are integrated as a single detection system for the refrigerator UI, and an ultrasonic is used for the virtual LCD display.

4.1. Human Proximity Sensor Detection Ranges
Since the whole system relies on the sensors, Design Team 5’s first task was to test the sensors with a simple circuitry powered up with +5 Volts DC supply, The circuit included a PIC18F4520 microcontroller, a Winford R11 Header connected to the ICD2 microchip, two resistors, and a red light emitting diode (LED) to follow the ON/OFF signals. The software was written in the C programming language to control the sensors’ outputs. The sensor output is high when an object is within the detection range and low when an interruption is not present in the scanning zone. This initial test provided information about how wide and how far the sensor is capable of recognizing the intruder. After over 100 tries, under different light conditions, the detection range results of the sensors are illustrated as the green sections in Figures 4.1a., 4.1b., and 4.1c.. For each sensor, the detection angle is kept 180 degrees, and the maximum distance range was 15 feet. These range readings were completed with regular ambient light, dimmer light, and darkness to
observe if there were no significant changes in the sensor sensing abilities. The results were consistent.

![Figure 4.1a. Infrared Sensor Detection Zone](image1)

![Figure 4.1b. Passive Infrared Sensor Detection Zone](image2)

![Figure 4.1c. Ultrasonic Sensor Detection Zone](image3)

Once, it was seen that the sensors work correctly, the sensors were wired to the appliance UIs to control the appliances’ power consumptions with the user presence detection.

4.2. **Whirlpool Washer User Interface Testing and Results**

The IR sensor is the only sensor used for the washing machine since the washer is the low-to-midrange product, and the goal is to minimize the cost. Mostly, washing machines are hidden in a closed space; therefore, only using an IR sensor is a reasonable choice for this unit. The IR sensor is sensitive when the user stands in front of the sensor with a 90 degree angle. This will make the appliance a very
energy-efficient product. The DC supply voltage that this washing machine UI uses is +5 Volts, which is the same voltage as the supply voltage of the IR sensor. To control the washing machine UI, Design Team 5 used an Adapt9S12DP256 Microprocessor embedded on the Whirlpool R&E Harpoon Relay Board that requires +15 Volts DC, and a smart cable assembly to connect the Harpoon Relay Board to the computer. This setup enabled the WIDE bus to communicate with the washing machine user interface over the supplied software program, wide_core_vb. When the washing machine UI was turned off through the WIDE GUI communication, the washing machine was drawing a small amount of current, and its LEDs were all turned off. When the turn ON command was sent to the UI, then the UI turns back on, which was precisely what Design Team 5 aimed to accomplish. During this procedure, the washing machine UI’s power consumption readings for various washing cycles were recorded to calculate the maximum and minimum power.

4.3. Washer Power Consumption Proximity Detection ON/OFF

<table>
<thead>
<tr>
<th>MODE</th>
<th>CURRENT (I in mA)</th>
<th>POWER (P in mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off- Standby</td>
<td>70.315</td>
<td>35.157</td>
</tr>
<tr>
<td>Default Startup</td>
<td>101.5</td>
<td>507.5</td>
</tr>
<tr>
<td>Maximum Load</td>
<td>225.37</td>
<td>1126.85</td>
</tr>
</tbody>
</table>

Table 4.3a. Power Consumption of Washer UI for Selected Modes

When, the WIDE and UI communication flow was running properly; then the next step was to control the UI with IR sensor proximity detection signals. This communication used the software drivers that Design Team 5 was given by Whirlpool. The USB Multilink was added to the system connecting the Harpoon Relay Board to the computer. At this point, the washing machine’s ON/OFF operations were completely controlled by C source files depending on the output signal that is received from the IR sensor. The testing procedure was repeated hundreds of times to ensure the accuracy of the system with continuous readings. By looking at the results of the tests, the IR sensor proximity detection is able to turn the washing machine UI ON/OFF by utilizing the Whirlpool supplied software and
hardware successfully. The power consumption lowering is realized thanks to the human proximity sensing design.

4.4. Whirlpool Refrigerator User Interface Testing and Results

<table>
<thead>
<tr>
<th>MODE</th>
<th>CURRENT (I in mA)</th>
<th>POWER (P in mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backlight OFF</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Light OFF</td>
<td>24.86</td>
<td>348.04</td>
</tr>
<tr>
<td>Light Dim</td>
<td>31.37</td>
<td>439.18</td>
</tr>
<tr>
<td><strong>Light ON</strong></td>
<td><strong>37.47</strong></td>
<td><strong>524.58</strong></td>
</tr>
<tr>
<td>Backlight ON</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Light OFF</td>
<td>61.05</td>
<td>854.7</td>
</tr>
<tr>
<td>Light Dim</td>
<td>67.21</td>
<td>940.94</td>
</tr>
<tr>
<td><strong>Light ON</strong></td>
<td><strong>73.02</strong></td>
<td><strong>1022.28</strong></td>
</tr>
</tbody>
</table>

Table 4.4a. Power Consumption of Refrigerator UI for Selected Modes

The process of developing the communication system for the refrigerator user interface and the selected sensors, Design Team 5 utilized similar methodology as illustrated previously. The Refrigerator UI was considered the high-end appliance, and expected to have a more advanced sensing technology. Therefore, Parallax Passive Infrared (PIR) sensor 555-28027 and Sharp IR sensor GP2D12 were used in tandem. The reason for this strategy was to avoid false detection signals and add functionality. While the PIR sensor monitors the surroundings at a wide angle, the IR sensor will detect only user presence directly in front of the appliance. The system is programmed in a way that the refrigerator system will not be functional until both of the sensors are tripped; the system will stay on until one of the sensors does not detect any presence anymore.

The refrigerator UI testing performed was with the same embedded WIDE programming language that was used for the clothes washing machine UI. For this unit, the software was used with different source files and button commands due to
its hardware architecture. After the PIR and IR sensors were wired to the Whirlpool R&E Harpoon Relay Board and the data flow has started between the sensors and refrigerator UI through the software, the sensors control the usability of the refrigerator UI. However, since the display backlight was hardwired to the physical buttons, the button commands that were used in WIDE protocol would not light up the backlight. The control of the display backlight could not be controlled unless the hardware would be redesigned by Whirlpool. After over 100 performance tests, Team 5 is convinced that the PIR and IR sensors detection system is completed, and all the requirements and expectations are met.

4.5. **High-end Graphical Interface Testing and Results**

The last task to be accomplished was to control a high-end graphical interface using a Parallax Ultrasonic sensor. The sensor is used to control the information density display by monitoring the distance of the user. In the future, the combination of an ultrasonic and PIR sensor will have strong object distance detection and broad screening area capability thanks to the PIR sensor. The role of the PIR sensor in this design would be the same as in the refrigerator UI. The testing of the Ultrasonic sensor was straightforward. Since its output was serial, MATLAB was a suitable choice for the sensor-interface communication. The output signal of the ultrasonic sensor was initially sent to the serial port, where the serial port was then connected to the computer via a USB-to-Serial converter. At this point of the data transfer, MATLAB reads the information signal from the serial port and corresponds the proper information for the data read. Distances at which objects were placed from the ultrasonic sensor were measured with a tape measure. This measurement was done at multiple distances from zero inches to 15 feet. After accuracy was confirmed with the readings, the rest of the program was built to display a GUI that would simulate the information density changing on the LCD. The display of the LCD had four stages of detection: standby mode when the display is dark, far distance for distances greater than five feet, middle distance with a low display information density, and close distance, which is less than two feet distance between the user and the interface with full display information density display.
4.6. Testing Conclusion
This design project has comprised various sensing technologies, including designing a combined detection system with multiple sensors. Design Team 5 has successfully accomplished the tasks that were given to them. Whirlpool’s requirements and ENERGY STAR standard were met. Whirlpool Corporation can implement the standby feature after the Whirlpool’s programmers program the system with advance microcontrollers. This system is capable of providing continuous measurements and remains accurate after multiple testing processes. This design project is feasible to integrate with other developed projects.

5. Conclusion
5.1. Summary of Overall Project, Project Cost, Schedule, and Future Work
ECE 480 Design Team 5’s final project design was successful. With the support of Dr. Virginia Ayres, Mr. Randy Jeffery, and other faculty, Design Team 5 has designed and built a proof of concept for both low-end and high-end proximity sensing appliances under budget and nearly on schedule. With the exception of wireless communication between appliances, which was determined with our sponsor to be out of the project scope, all proposed goals have been met. The prototypes built could have a substantial impact on energy savings, user experience, and universal design.

Due to unexpected equipment failure the project was pushed slightly behind schedule. Design Team 5 sponsor, Mr. Jeffery of Whirlpool Corporation, was extremely helpful in making sure progress was not halted significantly by overnighting new parts and giving walkthroughs over the phone. Our schedule, seen in Figure 2.2b., was maintained up until a few weeks ago. Many deadlines hit and other classes had projects as well. Design Team 5 was able to stay on track though, only falling a few days behind schedule. Spending extra time in the ECE 480 lab working has since realigned the project schedule.
Mr. Jeffery and Whirlpool indicated that the given ECE 480 budget of $500 was not of concern; although, this undetermined budget extension was not necessary. The final cost of the project for the semester was $227.73, seen in Figure 2.3b. Most of the items attributed to this cost are not in the final prototypes. Rather the items were used for testing and experimentation to determine the best possible sensors. The sensors implemented in the final designs are low cost, but it is difficult to quantify the price per unit since Whirlpool is a large-scale manufacturer. The IR sensor used for the low-end clothes washing machine UI is extremely basic and cheap; the low to mid-range UI is where cost is of most concern. Whirlpool’s high-end customers are willing to pay more for an improved user experience. Therefore, two sensors were used in the design of the refrigerator UI, PIR and IR. An ultrasonic sensor was used to demonstrate the information density for the virtual LCD display; no wide range detection was implemented because it was outside of the scope of this part of the project.

The final designs showcase the benefits of different sensors. The low to mid-range washing machine UI was fitted with an IR sensor. This allows the UI to activate only when a user is present in front of the machine. When the user leaves the area in front of the washing machine for an extended amount of time, the UI deactivates thereby saving the energy it would take to illuminate the display. This design aesthetically integrates the sensor behind white glass in the UI panel. The refrigerator UI exploits two sensors, a PIR for in-room detection and an IR for detection in front of the UI. The wide sensing range of the PIR sensor is able to determine if a user has entered the kitchen, if a user has not entered the kitchen in an extended amount of time the dispenser lights are turned off or dimmed. The IR sensor determines if a user is directly in front of the refrigerator, if present the dispenser light can turn on as the user approaches the refrigerator. The IR sensor is mounted behind black glass on the washing machine UI; the PIR sensor is free standing because in an end-user appliance it would likely be mounted on the top of
the refrigerator. The virtual LCD display demonstrates the capability of an ultrasonic sensor to actively sense distances. A virtual LCD was used because there were not any refrigerator UIs with a LCD available and the unnecessary complexity of producing images on LCD screen. The virtual LCD is designed to function similar to the prototyped refrigerator UI except with an ultrasonic sensor instead of an IR sensor. This enables the LCD to determine the distance of the user to the LCD. The LCD can then adjust its information density as the user approaches. For example, at five feet away it may show the time in large print, but as the user walks closer the display will change to show more information in smaller print such as internal temperature, amount of ice in the hopper, and time since the last auto-defrost.

In the future, features such as this could be commonplace. Proximity detection in appliances not only improves user experience, it will significantly reduce power consumption and could significantly impact certain people’s lives. Future development could use proximity detection in addition to voice commands and/or audible settings announcements. This would enable blind persons to check the state of their oven timer or spin cycle without having to find any buttons, it would be announced. Voice commands would also allow physically disabled persons to operate their appliance from a distance without the worry of erroneous voice inputs when they are not in the room.

The tested UIs provided by Whirlpool had to be set to their maximum power consumption in order to surpass the impending one Watt ENERGY STAR limit. The UIs would not normally be left in these states for extended amounts of time. Even so, if implemented on current UIs there would be significant energy savings. In addition, an underlying purpose of this project is to make a prototype for future UIs that will consume more than one Watt of power in a normal operating mode. In the coming years LCD screens will become more commonplace and will consume more energy than previous UIs. Whirlpool customers expect an ENERGY STAR certification
on their Whirlpool appliances. In order to maintain a marketable and energy ethical product, appliances with integrated proximity detection have the potential to set Whirlpool appliances ahead of the competition.

6. Appendix 1

6.1. Technical Roles

6.1.1. Berna Saracoglu

Berna Saracoglu is the modular enclosure designer. Ms. Saracoglu was proposed to be responsible for the enclosure design of the sensors and on board microcontrollers that are used in the design process. Along with the development of the design process, Ms. Saracoglu initially worked on the wide bus of the appliance interfaces since the modular enclosure design is a role she would undertake when the project is close to be finished. Ms. Saracoglu helped with the Infrared and passive Infrared sensors testing setups. Mainly, Ms. Saracoglu was responsible for setting up the communication between the Wide bus and the appliance user interface with button commands for specific user interfaces. Ms. Saracoglu helped the team follow the design specifications such as designing energy-efficient products with minimal cost and compact size.
6.1.2. Eric T. Hosey

Mr. Eric Hosey’s technical role on design team 5 was to incorporate any type of software engineering and PC interfacing that was required into the project. Any type of programming that was necessary in order to integrate our sensors into the appliances was assigned to Mr. Hosey. Throughout the semester, design team 5 worked together with different technical aspects of the project, but the majority of the software engineering did fall on Mr. Hosey’s shoulders. The team set different timetables and milestones for the project as a way to monitor the progress of the design along the way. The first milestone was to produce working circuits with the sensors. Mr. Hosey built the circuit and wrote the majority of the code for this milestone that enabled different LEDs to light up depending on whether the sensors were detecting a user. The team collected data indicating the performance of each sensor. As the team moved into working with Whirlpool’s software to control the appliances, Mr. Hosey had to first get accustomed to a new development environment in Metrowerks CodeWarrior. This was necessary to drive the microprocessors that Whirlpool uses in the development of their appliances. Mr. Hosey developed a simple program and tutorial, which is now published as an application note, to start gaining fluency with the environment. After that, Mr. Hosey discussed with our sponsor, Mr. Randy Jeffery, the many different drivers and software libraries that were supplied to the team. The two worked together to ensure that Mr. Hosey would understand which libraries and functions would be necessary to complete the project. At this point, Mr. Hosey was able to turn our washing machine user interface on and off using the Whirlpool supplied software. The team merged
the sensor code from the first milestone with the Whirlpool software to produce a working washing machine with proximity sensing. Mr. Hosey corrected any bugs that were created in the process. The team then tested our design and evaluated power requirements, monitored any false alarms, and Mr. Hosey made any necessary adjustments to our software based on these findings. Design team 5 also had a refrigerator user interface that required slight software-based changes from the washing machine. Mr. Hosey edited functions in the code to change the operating nodes and commands to turn on a light on the refrigerator as well as change brightness levels of the light with a sensor.

6.1.3. **Kevin D. Harrison**

![Figure 6.1c. Kevin D. Harrison](image)

Mr. Kevin Harrison’s technical role as proposed was to work on the wireless integration. In the proposal Design Team 5 recognized that this may not be a part of the project, and added that if wireless communication was eliminated Mr. Harrison would work on the board containing the sensor processor and microcontroller. The wireless aspect of the project was eventually dropped in a decision by Design Team 5 and our sponsor Mr. Jeffery. After Mr. Jeffery visited he provided the Whirlpool Development Board necessary to communicate with the appliance. This meant that there would be minimal hardware to integrate. The challenge would be in learning how to use the board as a medium between a computer and the appliance, and eventually as a medium between a sensor and the appliance. Mr. Harrison began working on controlling the appliances from a computer using custom software provided. This was very troublesome at first, but after plenty of frustrating time spent, he...
was able to establish control of the appliances from a computer. At this point Mr. Harrison began to take power consumption measurements for the two appliances; the control from the laptop was not necessary for this, but the control was more important so it came first.

In the past weeks the appliance UI control has posed serious problems. Mr. Harrison has spent time trying to troubleshoot errors. He helped to decide that two clothes washer user interfaces had broken. He coordinated with Mr. Jeffery and others to get another UI and try to establish the cause of the problems. This was a serious setback, but a realistic constraint of the project.

In addition to the technical aspects that are directly related to the final project, early in the semester Mr. Harrison conducted extensive research on capacitive sensing. This was one part of Design Team 5’s effort to research sensors and decide on the best options. After Mr. Harrison’s research, no further action was taken with respect to capacitive sensing as it was not a good option for the project.

Also, earlier in the semester Mr. Harrison worked on C code used to interpret the input from the IR and PIR sensors. It involved diagnosing the cause of a problem that caused the sensor output, a LED, to blink when nothing was present. Mr. Harrison figured out that adding a counter loop to make sure that an object was present for an extended amount of time (order of milliseconds) was necessary. This was because extraneous input such as moving air and shadows caused the sensor to trip. This was part of the preliminary sensor research.
Ms. Leslie Hodges was responsible for the primary research for both the active and passive infrared sensors. She researched the pros and cons of each sensor type and evaluated them against the design specifications that were provided by the sponsor. After the Design Team agreed that the use of one or both infrared sensors were a possible solution for the final product, she then procured initial samples so that the team could test the actual functionality of the sensors. Ms. Hodges assisted the Design Team in the initial set-up and testing of the infrared sensors. This testing included the measuring of the detection range of the sensors as well as the sensors’ sensitivity to slight versus dramatic motion of the user.

Ms. Hodges also designed the system for the virtual LCD module that used an ultrasonic sensor to simulate the concept of information density in a high-end appliance. Since the sponsor had deemed it unnecessary to attempt to program an actual LCD module, it was suggested that the Design Team simulate the images on a computer instead. To accomplish this, Ms. Hodges chose an ultrasonic sensor that could transmit information about the users proximity to the appliance to a serial port on a computer. In order to get the information from the sensor to the computer, she built a proto-board connecting the appropriate pins of a DB-9 serial cable to ultrasonic sensor unit. She then chose the program MatLAB in order to read the information from the serial port on the computer. In order to insure accuracy, she tested the information read into the serial port using two separate methods. Once accurate readings were being taken, she then
built a graphical user interface (GUI) that would display images from an LCD. This GUI will simulate what a will be seen on an appliance’s LCD as the user approaches it from a distance.

6.1.5. **Nathan C. Kelly**

![Figure 6.1e. Nathan C. Kelly](image)

As designated in the proposal Mr. Nathan Kelly was responsible for identifying and providing conditioned power supply to the team’s microprocessor circuits and IR sensors, as well as maintaining suitable power consumption for appliances in stand-by mode. Mr. Kelly was also responsible for the oversight of project development in the Lab. Mr. Kelly was further in charge of ordering laboratory supplies through either the Whirlpool Corporation or specific manufacturers. The technical portion of this design has smoothly transcended from the suitably trivial to the comfortably complex. The first goal was to ensure the sensors we acquired were appropriate and would react to human presence. Mr. Eric Hosey and Mr. Kelly set up a PIR and an IR sensor on a PIC microprocessor. For each sensor they tested its range and repeatability. To test if it was sensing they set up a simple code that would turn on an LED when the subject it was sensing was in the appropriate range. From those beginnings the team moved to ensuring that the User Interfaces (UI) lent to the team from the Whirlpool Corporation were working and could receive signals over the WIDE communication bus. The goal here was to send a signal through a control board to the UI to turn it on and off with a computer. The sponsor, Mr. Randy Jeffery first showed us how to do this at about the midway point of the project so it was up to each member to be able to do this. This being satisfied the team moved into the final step of the design: getting the sensor to “send” a message to the UI
to turn on. Again, Mr. Hosey and Mr. Kelly, along with Mr. Mr. Harrison Harrison developed an algorithm to turn the UI on using a code written in C supplied by Mr. Jeffery and altered by them. As Mr. Kelly was responsible for power supply to each sensor and UI, he ensured that each UI had the appropriate power (5V for the washer 14V for the fridge) as well as proper connections were made with the sensor and UI.

7. Appendix 2

7.1. References


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8. Appendix 3
8.1. Parts Identification

Figure 8.1a. Refrigerator UI

Figure 8.1b. Washer UI

Figure 8.1c. Whirlpool R&E Harpoon Relay Board with Adapt9S12DP256 Microprocessor, referred to sometime as Development Board

Figure 8.1d. USB Multilink
8.2. **Code Warrior Code** [Confidential]

8.2.1. **Washer UI Code**

[CODE OMITTED FOR CONFIDENTIALITY]

8.2.2. **Refrigerator UI Code**

[CODE OMITTED FOR CONFIDENTIALITY]

8.3. **MATLAB Code for Ultrasonic Serial GUI**

```matlab
function varargout = UltrasonicGUI(varargin)
% ULTRASONICGUI M-file for UltrasonicGUI.fig
% ULTRASONICGUI, by itself, creates a new ULTRASONICGUI or raises the existing
% singleton*.
%  
%  H = ULTRASONICGUI returns the handle to a new ULTRASONICGUI or the handle to
%  the existing singleton*.
```

---

**Figure 8.1e. Sharp GP2D12 Infrared Ranger**

**Figure 8.1f. Parallax Passive Infrared Sensor**

**Figure 8.1g. LV-MaxSonar-EZ1 Ultrasonic Ranger**
% ULTRASONICGUI('CALLBACK',hObject,eventData,handles,...) calls
% the local
% function named CALLBACK in ULTRASONICGUI.M with the given
% input arguments.
% % ULTRASONICGUI('Property','Value',...) creates a new
% ULTRASONICGUI or raises the
% existing singleton*. Starting from the left, property value
% pairs are
% applied to the GUI before UltrasonicGUI_OpeningFcn gets
% called. An
% unrecognized property name or invalid value makes property
% application
% stop. All inputs are passed to UltrasonicGUI_OpeningFcn via
% varargin.
% % *See GUI Options on GUIDE's Tools menu. Choose "GUI allows
% only one
% instance to run (singleton)".
% % See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help UltrasonicGUI

% Last Modified by GUIDE v2.5 01-Dec-2009 14:22:53

% Begin initialization code - DO NOT EDIT
 gui_Singleton = 1;
 gui_State = struct('gui_Name', mfilename, ...
    'gui_Singleton', gui_Singleton, ...
    'gui_OpeningFcn', @UltrasonicGUI_OpeningFcn, ...
    'gui_OutputFcn', @UltrasonicGUI_OutputFcn, ...
    'gui_LayoutFcn', [] , ... 
    'gui_Callback', []);
 if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
 end

 if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
 else
    gui_mainfcn(gui_State, varargin{:});
 end
% End initialization code - DO NOT EDIT

% --- Executes just before UltrasonicGUI is made visible.
 function UltrasonicGUI_OpeningFcn(hObject, eventdata, handles, varargin)
 % This function has no output args, see OutputFcn.
 % hObject    handle to figure
 % eventdata  reserved - to be defined in a future version of MATLAB
 % handles    structure with handles and user data (see GUIDATA)
 % varargin   command line arguments to UltrasonicGUI (see VARARGIN)
% Choose default command line output for UltrasonicGUI
handles.output = hObject;

s = serial('COM4', 'BaudRate', 9600, 'DataBits', 8, 'InputBufferSize', 5,...
    'Terminator', 13); %initialize serial port
fopen(s); %opens port
s.ReadAsyncMode = 'manual';

IMG = imread('2_Oven_Off', 'bmp');
axes(handles.backimage);
image(IMG);
axis off

PrevDist = 0;
count = 0;
Disp = '0';
handles.stop=0;

while handles.stop == 0
    pause(.05); %max read time is 20Hz/50ms
    readasync(s);
    ReadOut = fgets(s); %reads string from input buffer

    if findstr(ReadOut, 'R') == 1 %error check ReadOut must contain a single R
        Dist = str2num(strtok(ReadOut, 'R')); %takes out R and converts string to number

        if Dist <= (PrevDist+6) && Dist >= (PrevDist-6) %notes no significant change in distance (ie motion)
            count=count+1;
        else
            count = 0; %when significant change occurs, restart count
            Disp = '0'; %when motion reset display variable
        end

        if count >= 30; %enter standby mode
            Disp = 'STANDBY';
            IMG = imread('2_UI_Off', 'bmp');
            axes(handles.image);
            image(IMG);
            axis off
        end

        if strcmp(Disp, 'STANDBY') %if in standby mode do nothing
            else %else display distance (to be replaced by output of images)
                if Dist <= 18
                    IMG = imread('2_UI_Near', 'bmp');
                    axes(handles.image);
                    image(IMG);
                    axis off
                end
            end
        end
    end
end
PrevDist = Dist;

\textbf{elseif} \ \text{Dist} > 18 \ \&\ \& \ \text{Dist} < 48
\begin{align*}
\text{IMG} &= \text{imread('2\_UI\_Med', 'bmp');} \\
\text{axes(handles.image);} \\
\text{image(IMG);} \\
\text{axis} &\ \text{off} \\
\text{PrevDist} &= \text{Dist;}
\end{align*}
else
\begin{align*}
\text{IMG} &= \text{imread('2\_UI\_Far', 'bmp');} \\
\text{axes(handles.image);} \\
\text{image(IMG);} \\
\text{axis} &\ \text{off} \\
\text{PrevDist} &= \text{Dist;}
\end{align*}
\text{end}
\end{align*}
end
\text{end}
\% \ \text{Update handles structure}
guida\text{ta(hObject, handles);}

\% \text{UIWAIT makes UltrasonicGUI wait for user response (see UIRESUME)}
\% \text{uiwait(handles.figure1);}

\% --- Outputs from this function are returned to the command line.
function \text{vargargout} = UltrasonicGUI\_OutputFcn(hObject, eventdata, handles)
\% \text{vargargout} \ \text{cell array for returning output args (see VARARGOUT);}
\% \text{hObject} \ \text{handle to figure}
\% \text{eventdata} \ \text{reserved - to be defined in a future version of MATLAB}
\% \text{handles} \ \text{structure with handles and user data (see GUIDATA)}
\% \text{Get default command line output from handles structure}
\text{vargargout\{1\}} = \text{handles.output;}

\% --- Executes on button press in exit.
function exit\_Callback(hObject, eventdata, handles)
\% \text{hObject} \ \text{handle to exit (see GCBO)}
\% \text{eventdata} \ \text{reserved - to be defined in a future version of MATLAB}
\% \text{handles} \ \text{structure with handles and user data (see GUIDATA)}
\text{handles.stop} = 1;