December 16th, 2011

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Post-Mortem for an RFID Enabled Smart Fridge

Dear Dr. Rawicz:

Our team at Cyber-Flux Innovations has worked very hard during the past 4 months in the development of an RFID enabled Smart Fridge. The document attached provides details on the current state of our system, how the current prototype deviates from the system described in previous documentation, the future development for the Smart Fridge and a discussion of the budget and timeline. As well, the document includes a personal reflection from each team member.

Our team is comprised of three talented undergraduate students from Simon Fraser University:
Lead Integration Manager: Damir Jungic (Electronics stream),
Lead Hardware Design: Mitchell Joblin (Biomedical stream), and
Lead Project: Renato Pagliara (Biomedical stream).

I would like to extend my sincere gratitude to you, Professor Sjoerdsma and the teaching assistants for your help and support throughout this process.

If you have any questions or concerns regarding the document attached or the project itself, please don't hesitate to contact us at rpa13@sfu.ca

Sincerely,

Renato Pagliara

Renato Pagliara
Project Lead
Cyber-Flux Innovations

Enclosure: ***RFID Smart Fridge Post-Mortem***

RFID SMART FRIDGE

POST MORTEM

Project Team: Damir Jungic
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Submitted to: Dr. Andrew Rawicz – ENSC 440
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School of Engineering Science
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Issued Date: December 16th, 2011

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Introduction

Cyber-Flux Innovations is comprised of a group of highly motivated engineering students who over the last 4 months have been dedicating their time, effort, sweat and tears to the development of the Smart Fridge project. After considering different ideas during the first week of the semester, we chose the Smart Fridge system due to the simplicity of the idea, the big potential behind it and the demanding software and hardware requirements which would test our engineering skills.

The final prototype was formally demonstrated on December 5th 2011. This document summarizes our learning experiences and outlines the project's evolution over the last 4 months. The Smart Fridge system allows users to keep track of the products they keep in the fridge and learn more about their diet while they do so.

Overview

Cyber-Flux Innovations has been pursuing a prototype system that will bring the refrigerator into the modern, web-connected age. By relying on RFID technology, the system provides convenience and sophisticated nutrition tracking features to the user – all without asking the user to alter their behavior.

A broad view of the system is provided in Figure 1.

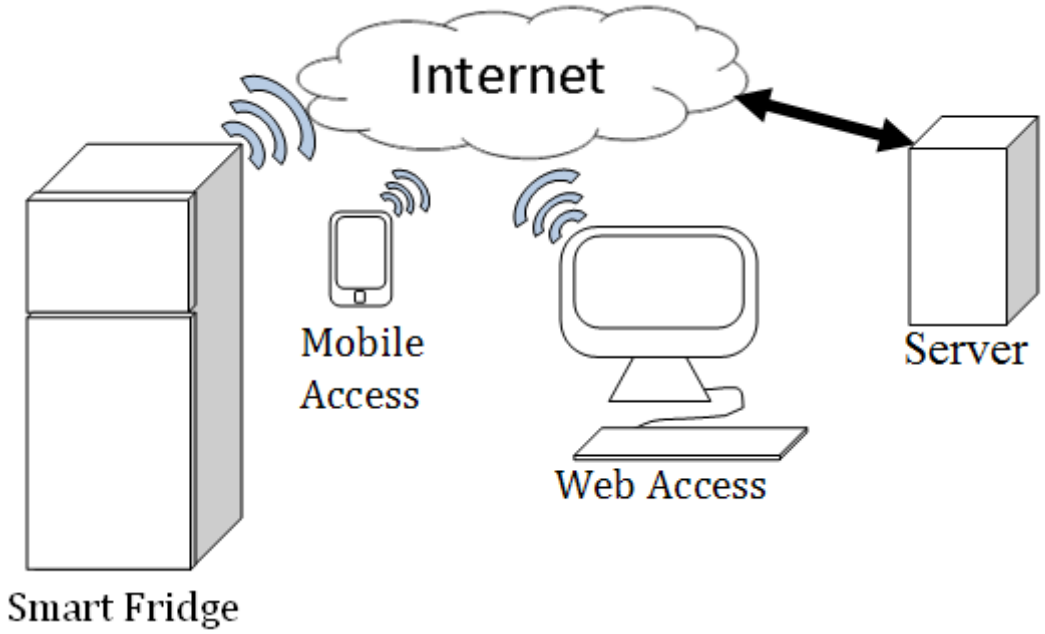


Figure 1: Smart Fridge System Overview

The Smart Fridge reads all of the RFID tags within it each time the door is shut. It then sends all of the information read (including RFID tag numbers, UPCs and expiry dates) to the server over the Internet. The server processes the information received from the In-Fridge Hardware, and dynamically updates the web-content available to users, ensuring that it reflects the current state of the fridge's contents.

The server also interacts with a product catalog in order to obtain more information about the contents of the fridge. The server is able to query the product catalog by UPC in order to obtain item description, brand name, image and nutritional facts.

Beyond just presenting the current and previous contents of the fridge, the web site is able to provide sophisticated nutrition tracking information and convenience features. By leveraging the nutritional facts obtained from the product catalog, the web site provides a caloric breakdown of each item in the fridge. In this way, it is easy to see if a product is mostly fat or mostly protein. The site also provides an automatically generated grocery list, based on the users purchasing history.

Since the delivery of information to the user is a standard website, it is accessible from any internet-capable device. This includes phones running Android, iPhones, tablets and traditional computers.

Status of the Project

A prototype of the Smart Fridge System was designed and implemented.

A bar-fridge was modified in order to include an RFID reader under the shelf. The reader was connected to a microcontroller and a Wi-Fi module located within a plastic case on the top end corner of the fridge. The microcontroller also connected to a temperature and humidity sensor (also placed within a plastic case) located on the bottom left corner of the shelf. A reed switch and a magnet were placed on the ceiling of the fridge and on the fridge door respectively and connected to the microcontroller. Finally different status LEDs were placed is strategic places to signal the power, network connection and scanning status of the system.

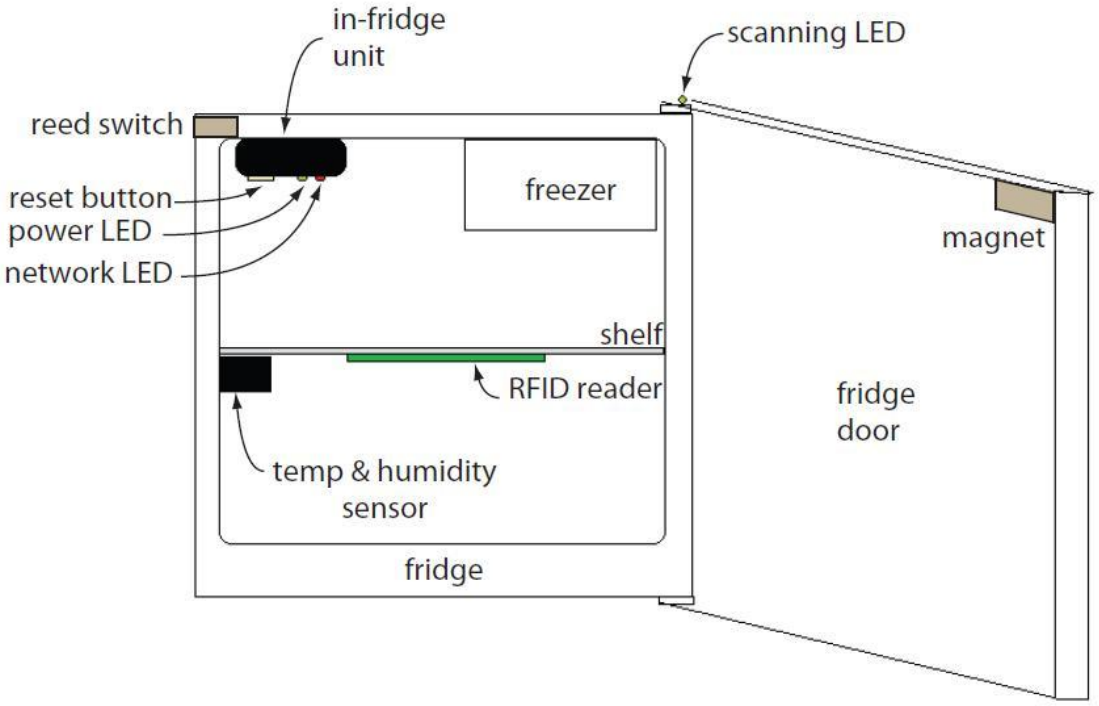


Figure 2: Smart Fridge Hardware

The power LED signals the user that the in-fridge unit is being powered. When the WiFi modules connects to the network, the network LED light up and when the door shuts, the RFID scanner reads all RFID tags within the range and the scanning LED blinks giving visual feedback to the user that the system is working correctly.

A software backend, which was responsible for tracking the contents of the fridge and providing web-accessible features, was also created. A fully functional, user-friendly website that focused on neatness and simplicity was developed. A screenshot of the "In Your Fridge" page is presented in Figure 3.

The web features of the system included access automatically generated grocery lists. Further, users could specify if they wanted particular items to always appear on their grocery list. Another software feature was the presentation of the nutritional facts of the products currently (and previously) in their fridge. Graphically presented caloric breakdowns were also provided. The system is capable of handling items that were RFID tagged "manually" by the user. Through the web site, users would specify a product or container that was tagged manually, and the system would handle the item accordingly.

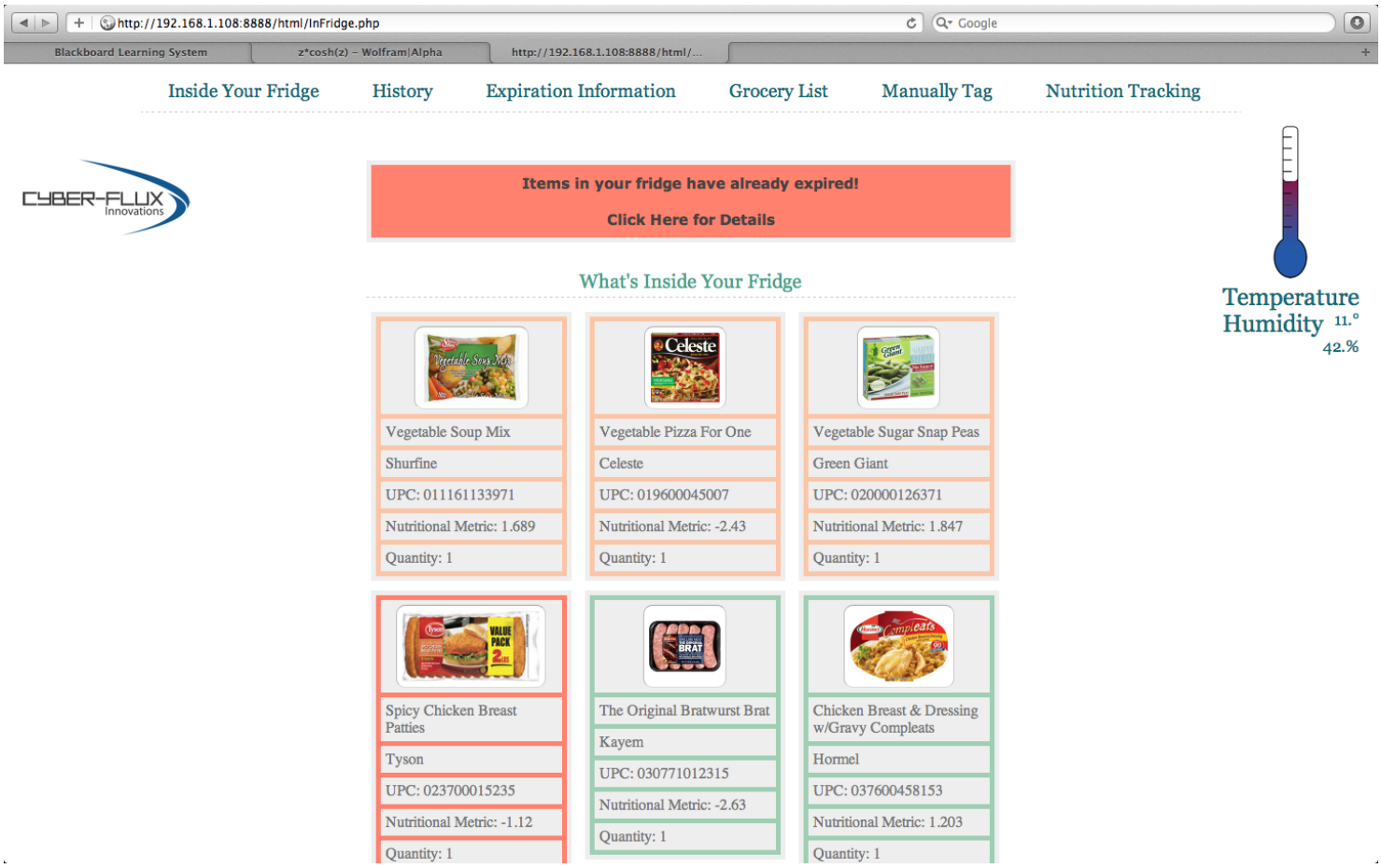


Figure 3: In Your Fridge Webpage

The Backend Server does have some bugs which were not addressed due to time constraints. In particular, when the server fails to connect to the product catalog (a service called SimpleUPC) in a very particular way causes HTML of incoming items to not render properly. Another issue exists in special cases of communication between the server and the in-fridge hardware unit. Specifically, the in-fridge hardware sends a UPC of all zeros when an item without a UPC enters the fridge. When the Backend Server receives this message, it incorrectly interprets this as an item with a UPC of value having all zeroes. The issues mentioned here are easily fixed, should development on the prototype continue. Of course, as with any software project of significant scope, there are likely many unknown bugs that could only be discovered through more testing.

The targeted prototype system was successfully created. Though we do not claim to have capitalized on the full potential of a web-connected fridge, we are proud of what we were able to accomplish in a mere three months.

Deviation From Specification

Specification was largely adhered to in the final prototype. The largest failure to meet specification was the absence of an iPhone application. This deviation was caused by personnel issues, in particular the loss of a team member.

On the hardware side, the original documentation outlined the creation of a in-fridge unit were all pieces of hardware would be contained within a plastic case. In the final stages of development it was realized in order to minimize the space occupied by the hardware within the fridge and to appear as if the final fridge had not been modified, we had to split the hardware location around the insides of the fridge. For this, it was decided to place the microcontroller and Wi-Fi module in a central in-fridge unit at the back of the fridge. The location of the RFID reader remained unchanged (below the shelf). For the temperature and humidity sensor it was decided that to obtain accurate readings, the sensor had to be away from other electronics that might have emitted heat and changed the temperature reading. Status LEDs were added to the final prototype as it was realized that it was necessary to provide feedback to the user. Finally, a USB cable connecting the microcontroller to the outside of the fridge was added to design. This cable allowed us to monitor the serial output of the microcontroller during the demo.

Originally, it was intended for the RFID reader to be able to read multiple RFID tags located anywhere inside the fridge. However, due to budget concerns the reader used for the prototype was not powerful enough to cover the entire fridge. Testing revealed that the reading range of the RFID reader was a maximum at the top and bottom centre of the antenna and decreased with distance (similar to a Gaussian). The frequency selected (13.56 MHz) for the reader was found to be susceptible to metals. This also forced our prototype to deviate from previous documentation in which it was claimed any product containing an RFID would be read.

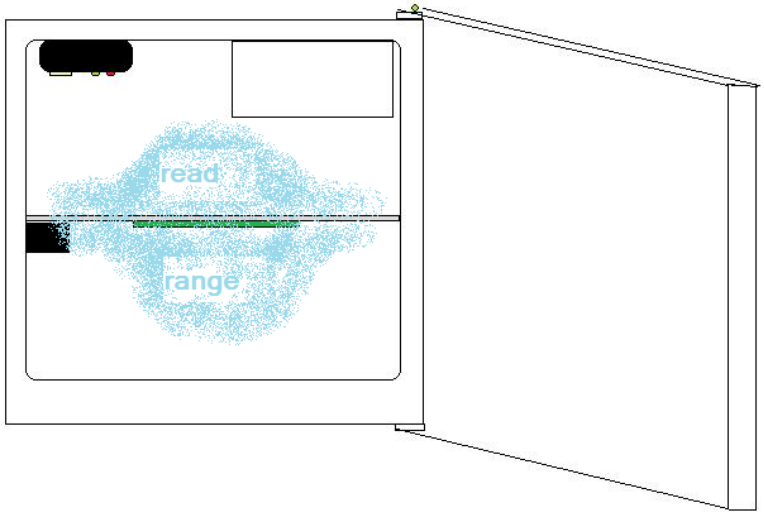


Figure 4: Badly drawn representation of the RFID reader unit´s reading range

The software features closely resemble what had been described in the earlier documents submitted. The most significant deviations occurred in the visualization of the features. The deviations occurred largely due to the last minute change from implementing an IPhone application to implementing a website only. When considering how the information should be presented we determined that pie charts and bar graphs would be most appropriate. We strived to present information in such a way that the user could understand the information with only a quick glance. Figure 5 below illustrates the use of a pie chart for the caloric break down of an item. Unique colors for each piece were used to easily identify what portion of the pie contributes to which nutritional value. The largest piece is "exploded" to emphasize the dominating nutritional component of the item.

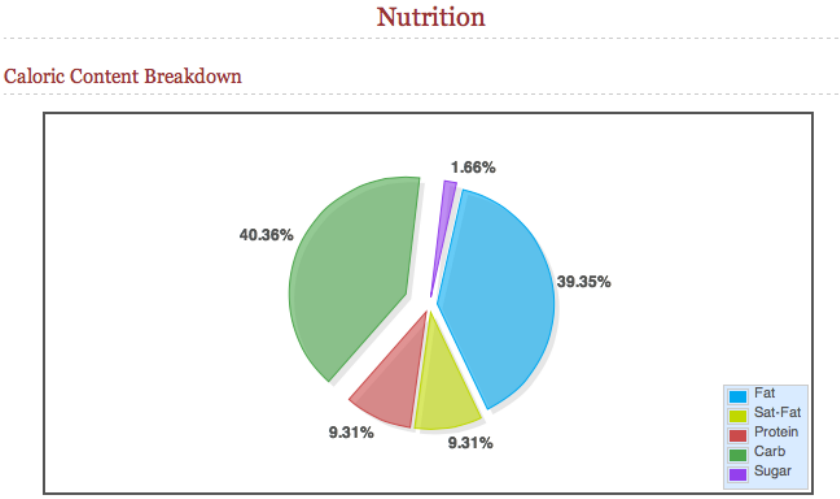


Figure 5: Pie chart example

The nutritional profiling model served a central role in developing a useful set of features for The Smart Fridge. The model would only allow use to quantify the nutritional value of an item yet we still needed a way to clearly illustrate this information. Bar graphs were chosen as the most appropriate style for our needs. Figure 6 below illustrates how we presented the nutritional metric to the user. Heavy emphasis was placed on maximizing the understanding of the nutritional information with only a glance. The bar graph makes it very easy to identify healthy and unhealthy eating periods.

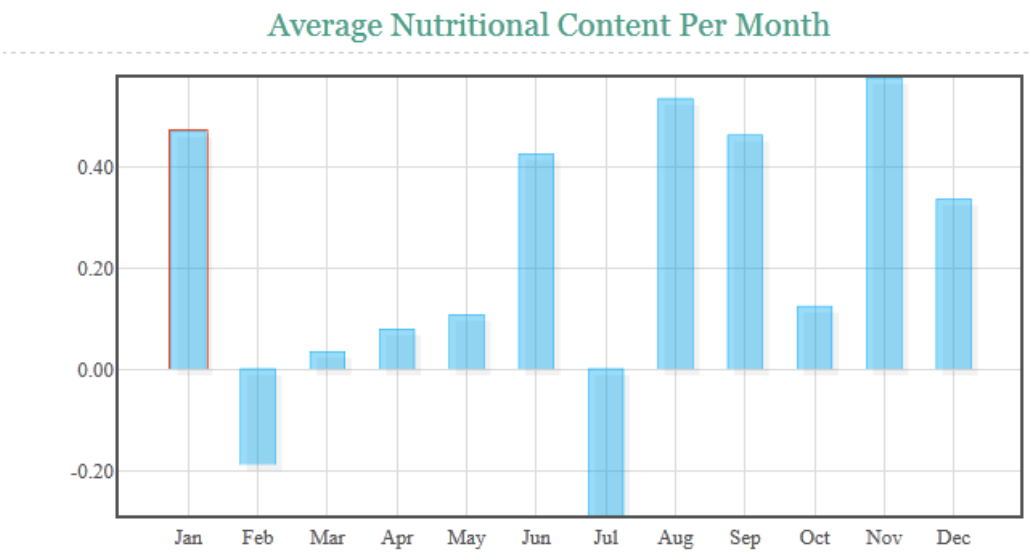
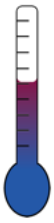


Figure 6: Bar graph example

Most of the features we intended to present were successfully executed with the exception of one. We were forced to drop one feature mentioned in earlier documents due to unforeseen deficiencies in the Simple UPC service. The feature was design to suggest more nutritious alternatives to a specified item. This feature helps to bridge the gap between identifying an unhealthy diet and providing a way to change the diet in a positive way. In order to successfully implement this feature we required a away to search the Simple UPC database for related items. We had initially thought we could use the category field of the item and then search for other items within the same category. Simple UPC does provide a search by category option that we would have used. The problem was that the category field in the Simple UPC database often had seemingly been randomly assigned. It was often the case that the assigned category had no correspondence to the item. The severely inadequate accuracy of the items category field made it useless to try and identify related items. For this reason we made the decision to not go ahead with developing this feature.

In addition to extremely useful nutritional features we also wanted to show that a web connected fridge has the capability to display anything about itself, not just the items that are inside of it. We added a temperature and humidity sensor to illustrate this concept. Continuing with emphasis on visual aids in addition to raw numbers we included an animated thermometer. Figure 7 shows an example of the thermometer at a single point in time. As temperature rises the thermometer fills analogous to a real life thermometer.



Temperature

11.4°

Humidity

42.3%

Figure 7: Animated thermometer

Expected-Timeline Validity

Table 1: Development Timeline

Item	Proposed	Implemented
Research	September 20	October 1
Purchasing Hardware	September 18	November 25
Hardware Assembly	October 20	November 28
Account Management System	October 15	Not Implemented
Web Application	October 28	Dec 4
Mobile Application	October 28	Not Implemented
Software Development	November 28	Dec 1

From the beginning the team set a very tight schedule to motivate team members to work hard while allowing for errors and modifications along the development of the project. Thus, it was expected that we would not be able to accomplish most of the milestones on time. Most milestones were implemented throughout the entire semester with the main parts of each milestone completed 2 weeks to a month after the set dates. We underestimated the complexity of interfacing the RFID reader with the microcontroller while relying on bad documentation from the manufacturer and the amount of time involved in performing manual tasks related to the fridge modifications. From the software point of view, the lack of a mobile application signified spending a lot more time on the web application and ensuring that the product information was presented in an elegant and informative manner. In the last 2 weeks before the demo, we spent many sleepless nights ensuring that both the fridge and the web application looked like a finished product.

Budgetary Standing

Our initial estimates were highly variable. The RFID read-writer module that was the centerpiece of our project could have been very costly ($600+) or relatively inexpensive ($130). We also initially expected to buy a new refrigerator; in the case we couldn't find a suitable used one. Our estimate therefore provisioned for the worst case, in which we would buy a more expensive RFID reader. This over-provisioning of funds assisted us later, when we realized we had failed to include costs of the presentation in our initial estimates. Further, we decided to add a temperature and humidity sensor to the final prototype.
A summary comparison of expected to actual expenses is provided in Table 2.

Table 2: Expected and Actual Expenses Summary

COMPONENT	ESTIMATED COST	Final Cost
Refrigerator	$250	$70
Microcontroller WiFi Module	$60	$75
Microcontroller	$35	$70
Barcode Scanner	$100	$0
RFID Reader/Writer	$400	$130
RFID tags	$35	$50
Antenna	$100	$0
Temperature Sensor	$0	$60
Fridge Modification Materials	$0	$85
Presentation	$0	$65
Total Cost	$980	$605

We received a generous sum of $500 from the ESSF to support us in covering these expenses. We also intend to apply to the Wighton Development Fund to cover the remaining expenses.

The Project's Future

There are still many features that could capitalize on a content-aware fridge. For example, if pricing information were accessible to the system, a whole series of money-saving features could be implemented. The functions that our system could perform were in part limited by the information made available by our product catalog service SimpleUPC. With more information, the possibilities of the Smart Fridge System grow dramatically.

Further development of the system is unlikely. Even when beginning, we admitted that such a product relies very heavily on the adoption of RFID technology to replace barcodes. Without this adjustment by manufacturers, the Smart Fridge System becomes cumbersome to users, instead of convenient. However, we nonetheless provided a functional proof-of-concept and valuably explored the possibilities such a product could provide.

There are technical challenges that it would be necessary to address for more realistic implementations of a smart fridge. In particular, the larger-read range afforded by ultra-high frequencies readers is necessary to cover an entire refrigerator by a single antenna. However, EM waves at these higher frequencies cannot penetrate liquids. A different solution is therefore necessary in order for all RFIDs within a fridge to be accessible. Possibilities include wiring the fridge with many lower-frequency antennas.

Individual Experiences

Damir Jungic

Students in the Engineering Department here at SFU spend a lot of time thinking about when they will take ENSC 440, what their project will be and who their teammates will be. It really is a culmination of the academic education, technical experience and social interactions that are afforded by an engineering degree. I will look back on this experience fondly, though there were many late nights and hard lessons learned along the way.

It was my first time implementing a large-scale software application. Often times in classes or on coops, we are only in a position to deal with a portion of a problem. During ENSC 440, it was necessary my colleges and I to design and implement everything – and even to agree upon what the problem precisely was! This was very challenging, and some of our inexperience with early design decision made our lives harder near the end. However, there is only one way to gain experience. The frustration experienced will cause us to learn the necessary lessons more assuredly.

The advice given at the beginning of the course – that you can't start soon enough – is probably only best appreciated after the course is complete. There are just too many things that can cause problems as the demo approaches. In our case, we had

very severe software bugs that took hours away from testing the system. Keeping pace throughout the semester is genuinely difficult, since the demo date seems so far away. Further, group members are all enrolled in other classes. In this way, it can be uncomfortable and difficult to apply pressure to teammates when deadlines slip by or expectations aren't met. Despite the challenges posed by team dynamics, there is simply no substitute for starting early and staying on schedule. By the end of ENSC 440, everyone knows it.

Renato Pagliara

For the past 4 months, I have been looking forward to having a physical tangible product resulting from a project that I can proudly say I was involved in. Now I can say that I feel very proud of the final outcome while being very humble and admitting that it takes a lot of hard work for a big project like this to succeed.

One of the biggest challenges I encountered during the development of this project was making the right decision from the beginning based solely on what I had learned while doing some basic research. It is not until now that I have spent many weeks fully immersed into the project that I feel confident in stating what the right design considerations would be. Writing detailed documentation while working long hours on the project and keeping up with other courses proved to be very challenging. From the beginning I took charge of the hardware component of the project since I wanted to have more experience with microcontrollers and serial communication. I feel that the painful experience of dealing with hardware has taught me once again the true value of good documentation from manufacturers, good soldering skills and well thought testing schemes.

Team dynamics are a lot more complicated than I ever thought they could be and I now think that a good leader is not a person who knows what everyone else should be doing but a person who can inspire the rest of the team to work hard and creatively on the project. Despite all the challenges, satisfaction and frustration involved, I feel I have learned very valuable tools while working on this project. If I was to give an advice to future students taking ENSC 440, I would say that quick decision making, communication between team members and sticking to deadlines is your best bet.

Mitchell Joblin

Engineering 440 is undoubtedly the most interdisciplinary course in the engineering curriculum. It forces you to use all the skills gained through course work while also managing issues related to team dynamics. In order to successfully complete a worthy capstone project you must work as a team. Failure to work together and motivate one another will heavily compromise the integrity of the project. Unfortunately, one of our group members dropped out fairly late in the term leaving the team in a difficult situation. The failure of one individual ultimately became a positive experience for the remaining group members. It forced us to support, motivate and encourage one another. It forced us to be more efficient as individuals and as a team. In university we often have the luxury to choose who we

work with. Hand-crafting your team is not authentic to industry situations. Gaining experience to work with previously unknown team members is a valuable skill. When a team member is unknown you must identify their character with only little information and then assign expectations accordingly. The foresight to recognize who is reliable and who is not can make the difference between catastrophic failure and successful completion of the project.

Throughout the engineering curriculum you are exposed to a variety of interesting topics. Most of the courses will focus on a particular topic and then cover that small area of engineering to a great depth. ENSC 440 is different in that it allow you to see a wide range of technologies working together to accomplish a common goal. The hardware is used to gain information from the physical world which then enters the digital domain to be processed then eventually makes its way back into the physical world. It is during the integration phase when all these systems are brought together that you can really see something new and interesting. It became very obvious during the integration phase when bad design decisions had been made. In the small homework projects you complete in a course the consequences of a bad design decision are normally not that detrimental. In a larger system, the consequences of a bad design decision can be catastrophic. I have become more aware that extensive planning before starting development is crucial to getting quality results.

The capstone project was a positive experience that contributed to significant personal and technical development. Though the lessons were not of the formal nature seen in most university courses, they were of immense importance. I am confident that the lessons learned in ENSC 440 will provide a firm foundation for my future engineering endeavors.

Conclusion

The team at Cyber-Flux Innovations set out to design, implement and present a Smart Fridge system which would allow users to make the most out of the information that is provided to them on every product they purchase and keep in the fridge. The final prototype incorporates almost all of the ideas that were discussed in the first brainstorm sessions and more. ENSC 440 has given the members of our team an opportunity to have a firsthand experience at the design and development of a big scale engineering project. Despite the difficulties encountered in the way, this experience has definitively proven to be one of the best educational experiences our team members have gone through while studying at Simon Fraser University.