holla
home solutions

School of Engineering Science
Simon Fraser University
Burnaby, BC V5A 1S6
holla@hollahome.com

April 23, 2005

Lakshman One
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

RE: ENSC 440 – Post-Mortem Report for a Remotely Accessible Temperature Control System

Dear Mr. One,

Please find attached the document; *Post-Mortem Report for a Remotely Accessible Temperature Control System*, Holla Home Solutions' post-mortem report for ENSC 440: Capstone Engineering Project.

This document gives an outline of our project, explains some of the deviations made from the original design plan, proposes some plans for the future, and discusses some of the problems encountered. A revised budget and timelines are also included, as well as a personal account of each group member's experiences.

Holla Home Solutions is comprised of four determined, talented, and attractive senior engineering students: Jennifer Fong, Steve Judd, Wojtek Piaseczny, and Chris Richardson. The Holla Home team is dedicated to bringing innovative solutions in our never ending search to efficiently and ecologically manage our homes and workplaces.

If you have any questions or concerns regarding our design specifications, contact me by e-mail at holla@hollahome.com or by phone at (604) 298-1885.

Sincerely,

Jennifer Fong

Jennifer Fong
President & CEO
Holla Home Solutions

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Post-Mortem Report for a
Remotely Accessible Temperature Control System

Project Team: Jennifer Fong
Stephen Judd
Wojtek Piaseczny
Chris Richardson

Contact Person: Jennifer Fong
holla@hollahome.com

Submitted to: Lucky One - ENSC 440
Mike Sjoerdsma - ENSC 305
Scott Logie - ENSC 305/440 TA
Tony Ottaviani - ENSC 305 TA
Amir Masoud Niroumand - ENSC 440 TA
Steve Whitmore
School of Engineering Science
Simon Fraser University

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Executive Summary

Since its inception, the Internet has revolutionized the communications world and has provided a powerful means of transferring information. Access to the Internet is available now more than ever, which is why the team at Holla Home Solutions envisions using the Internet to offer peace of mind and comfort, as well as decreased energy consumption in the home and office space.

Holla Home Solutions will develop a *Remotely Accessible Temperature Control System* as a first step in achieving their vision. The system allows the user to control their home's current heat settings, as well as to set a pre-programmed temperature schedule, from any Internet connection. Unexpected changes in schedule or simple bouts of absent-mindedness can be conveniently managed while on the road or even out of the country. Still remaining is the ability to make changes to settings manually in the home.

As part of the first phase of development, the Holla Home Solutions team will construct the basis of a remotely accessible smart appliance control system. There will be a potential to integrate the control of multiple appliances remotely from a single user interface. Additional controllers for these devices will follow in later development phases. The system will work in conjunction with existing home heating systems and wireless Internet connections.

As proof of concept, a prototype of the remotely accessible temperature control module was completed in early April of 2005.

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1 Introduction

The Remotely Accessible Temperature Control System allows access and control to a user's home or office heating system from any Internet connection. This is the first phase in the development of a remotely accessible smart appliance control system, which would allow remote control to a network of integrated appliances. Working in conjunction with a home's existing heating system and wireless Internet connection, the temperature control module was completed in early April of 2005.

2 Current State

As specified in the design and functional specifications documents, the RATCS acts as a typical wall mounted thermostat, the kind you would find in a home. However, the RATCS extends the capabilities of a wall-mounted thermostat by connecting to a wireless home network in order to allow remote accessibility to the functionality of the device. A system diagram is shown below in Figure 1.

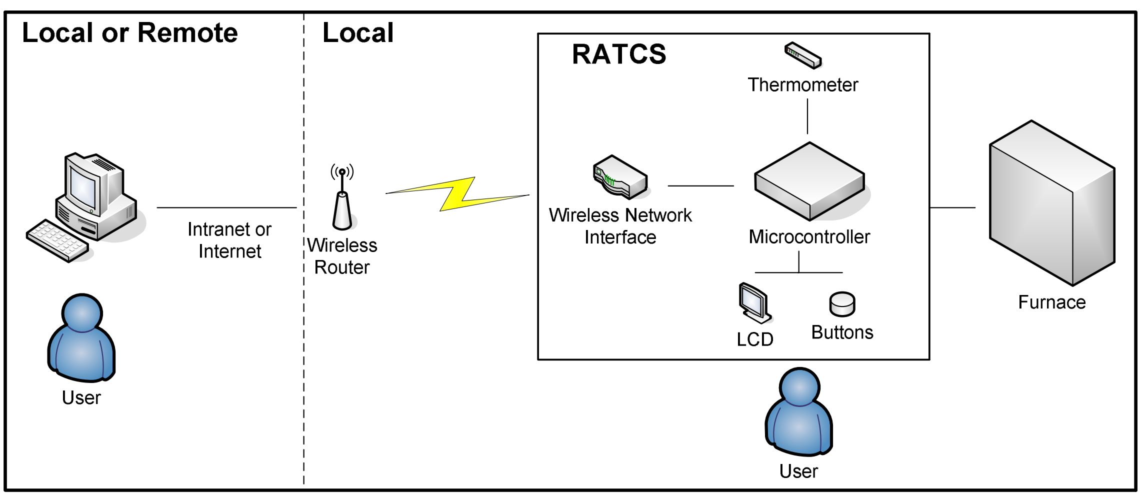

Figure 1: System Overview

Reading the current temperature is triggered by a timer interrupt that initiates serial communication to a digital thermometer chip. The RATCS displays the current temperature, at half a degree Celsius resolution, on the LCD constantly, allowing the user a point of reference for making decisions when changing temperature settings. Temperature settings are changeable via a four-button interface, which are read by the microcontroller using an interrupt detecting level changes on the input port.

The RATCS has two modes of operation, normal mode and schedule mode. Different modes are accessible via the Left and Right arrow buttons; pressing these buttons scrolls through each mode. In normal mode, pressing the up or down button sets the current desired temperature higher or lower by half a degree Celsius. In the schedule mode of operation, the user of the RATCS can scroll through eight different time periods (morning, day, evening, and night for both weekday and weekend) to set the desired temperature for that time period via the up and down buttons.

The temperatures defined in the user programmable schedule are implemented using a clock that was implemented on chip using timer interrupts. However, the user must first set the current time when they power on the device. Setting the clock is done using the four button interface, where the up and down buttons are used to set hours, minutes, seconds, and day of week and the right and left buttons are used to move between hours, minutes, seconds, and day of week.

The RATCS can connect to a network using the Ethernet port or using the wireless PMCIA card, both of which came packaged with our board. The remote functionality of the RATCS is accessible via a webpage that is served from on board the microprocessor. The user must first assign an IP address and any encryption settings to the device using a serial interface, after which the device will be located on the wireless home network. The webpage is only allowed to be 1.5Kb, as specified by the board used, so it uses a style sheet from www.hollahome.com. The webpage offers the same functionality as the physical interface, displaying current temperature and allowing current temperature and scheduled temperatures to be changed.

The RATCS has two wires coming out of its case, one ground and one signal, that are meant to attach to a furnace relay. In this way the RATCS controls a home furnace and regulates home temperature. The temperature control mechanism that we used was a very basic PID method implemented in software. The RATCS would of course turn the furnace on if temperature was too low or turn the furnace off if temperature was too high. In addition, the RATCS looks at how fast temperature is increasing/decreasing when making decisions on whether to turn the furnace on or off. In this manner, the RATCS uses the slope of temperature change to implement derivative control and maintain temperature within a certain range. The graph of temperature verses time under RATCS control is shown below in Figure 2. Note that time is variable scale because temperature control is dependent on furnace potency and the size of the area to be controlled.

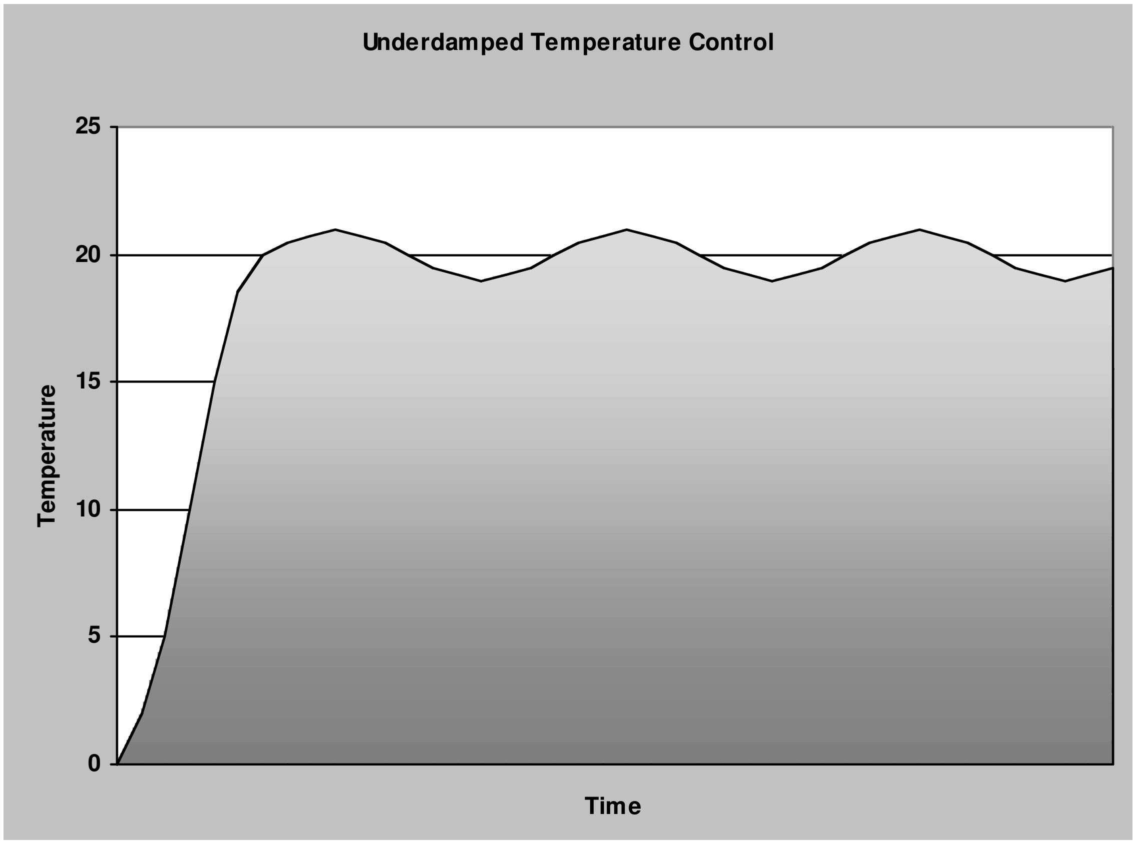

Figure 2: Underdamped Temperature Control

3 Deviations

The goal for this project was to create a smart appliance that was remotely accessible through the internet. This goal did not change, and we successfully created a remotely accessible thermostat, but some of our design decisions did change along the way. This section will briefly explain these deviations, as well as a future plan for this project.

The only significant design change has to do with how we implemented the communication between the thermostat and the internet. We initially planned on writing a PC application to communicate with the thermostat by a protocol we would define, and have all internet communication pass through this PC application. While this solution would have sufficed in reaching the end goal, we were unhappy with the need for this PC application, and the extra work our customers would have to put in to make this system accessible through the internet. We wanted more of a plug-and-play solution. We came up with using the HTTP protocol to communicate between the thermostat and client application. In doing this, we allowed generic internet browsers, such as Internet Explorer and FireFox, to serve as the link between users and the thermostat. Using this design, the installation of our thermostat became trivial: customers must connect the thermostat to the furnace (like with all thermostats), and specify any wireless encryption keys their home network requires.

The other changes in our project were insignificant, and completely transparent from the users' point of view. For example, we decided to increase the reaction time of the web server by polling for requests rather than by waiting for an interrupt. Another change was to add a software module representing the temperature control loop. This was actually an omission from our original design specification rather than a change. Any other changes we made were strictly based on implementational issues/optimizations, and did not change the "big picture" of our project.

The design specification laid out a few requirements that would be required in a commercial release of our project. We had the chance to implement some of these, but not all. The future work on this project would begin by completing these requirements.

4 Future Plans

The idea of hosting a fully-featured web server on a microcontroller is unrealistic, naïve, and/or just stupid. We created a very limited web server that was capable of serving HTML content. This is a reasonable solution for a thermostat that resides in a family home, but becomes problematic in a "busier" environment, such as in an apartment complex, where a single user (i.e. the landlord) might want to control all of the thermostats. Under the current implementation, that user would have to access each web server individually using a web browser, and perform the desired functionality. A better solution for this use-case would be to provide a programmable interface to the thermostat. The obvious design choice would be to make it a *Web Service* that communicates using the Simple Object Access Protocol (SOAP). This protocol works on top of the HTTP protocol. There are two types of requests that the SOAP interface would have to service: first, to provide data when requested, similar to the functionality of a static web-page, and second, to accept data representing requests for a specific action, such as to increase the temperature. We implemented the first of these two, providing a programmable way to read the current settings on the thermostat.

Another key in taking this product to the market would be to re-design the hardware. We purchased a development kit that connected a microcontroller with a generic wireless card. The kit also provided features that we just did not need, such as a modem and an Ethernet port. These features would be eliminated as a part of the final product.

We packaged the thermostat into a plastic box for presenting at our project demonstration. This caused a major problem: inaccurate temperature readings. By putting the project into a box, we isolated the thermometer from the room whose temperature we were actually reading. This caused a long delay in being able to read the correct room temperature, obviously adversely affecting our temperature control loop. The packaging for a market-ready product would have to afford reading the actual room temperature from inside the box without any time delay. We suspect that suitable ventilation around the thermometer would suffice. Also, the box would have to be smaller than our demonstration box, roughly the size of a typical home thermostat.

This project alleviates all technical feasibility issues for developing a market-ready product. There are still many business and marketing studies that would need to be completed before actually creating this product. We feel that this product could be successful on the market, but that is based entirely on a gut-feeling. Reaching out to our core target customer group would provide real data that the continuation of this project could be determined on.

5 Problems Encountered

As we all had imagined, there were numerous problems that stood in the way of completing our design. The first arose when attempting to decide on a particular idea to base our project on. The group was split by two separate ideas. After resolving this issue on the basis of individual interest, parts accessibility, and demand in society, we decided that a wirelessly internet controlled thermostat would be our project.

Finding a microcontroller that had wireless capabilities was our next problem. Faced with further constraints such as the amount of I/O pins and code space available, we were able to find a PIC microcontroller that was suitable for our project. An added bonus in purchasing this particular microcontroller board was the ability to run our Holla Home Solutions web site straight from the board itself. Software purchased with the microcontroller seemed to give us a push into the style of which we finally wrote our software program.

One of the most significant problems we had was finding a PICSTART to use to program our microcontroller with. We did not want to purchase one at great expense and we were aware of many existing in the department. We did not want to share with other groups either. We eventually found a few that the EUSS was in possession of, but after attempting to use them we were made aware that they would not fit our device. We eventually borrowed one from Dr. Rawicz. The process of acquiring a PICSTART took about two weeks and was quite stressful since we wanted to get working quickly.

Once we did find a PICSTART, we found the process of programming our chip quite tedious and even draining. Debugging was a nightmare because we had to reprogram our chip every time something did not work correctly, even small things, which took a few minutes each time. We then had one of our compilers break, so we began compiling on one computer and programming on another, which was also quite tedious. In hindsight, we should have acquired an in-circuit debugger.

At first, before testing the buttons experimentally, we believed that we would have problems with de-bouncing. In reality, the buttons we had purchased were of high quality and the minimal de-bouncing was not noticed by our microcontroller, and therefore we didn't need to handle this problem any further.

The digital thermometer that we choose to use had 3 serial bi-directional data lines that handled its communication PIC. After testing our signals from both devices with the oscilloscope and the multi-meter, we were noticing that we were not retrieving the correct output signal from the thermometer in the PIC as was seen on the oscilloscope. After many hours of consultation between group members and lab T.A's, we were able to solve our problem with a corrected timing algorithm for setting the I/O pins on the PIC accordingly. In similar fashion to this problem, there was an issue with initializing the single serial pin used to communicate with the LCD. For some reason setting this pin to an input initially, as suggested by our lab T.A., and then later defining it as an output pin seemed to hamper the proper communication from the PIC. This problem was solved by setting this particular I/O pin as an output line always.

One of the last obstacles was to physically show that our device could in fact control the operation of some kind of heating unit in our demonstration environment. The problem was that we had a limited voltage from the board controlling the furnace in our house. With the help of a solid state relay, we were able to connect a space heater to the output of our board exhibiting its operation in accordance with the desired temperature requirements from our device.

One of the greatest challenges we faced was working as a team. We seemed to disagree about almost everything, wasting a lot of time in the process. It seemed that we each had in our minds a different way of accomplishing the same thing and it was very difficult communicating throughout the group those different ideas, especially when the other members already had their own ideas. We wasted a lot of time goofing off too, the downside of working with friends. Although, we probably would not have had as much fun if we were not working among friends.

6 Budget Summary

Table 1, below, shows the budgetary shortfall of $284.48 experienced by Holla Home Solutions relative to the initially proposed budget.

Table 1: Estimated vs. Actual Cost

		Estimate	Actual	Discrepancy
1	**Microcontroller w/ on-board transceiver**	$300.00	$561.14	**-$261.14**
2	**Microcontroller development tools**	$99.00	$151.54	**-$52.54**
3	**Digital Temperature Sensor**	$100.00	$26.70	**$73.30**
4	**Power Supply**	$150.00	$0.00	**$150.00**

			(borrowed)	
5	**Batteries**	$10.00	$11.39	**-$1.39**
6	**Personal and/or Notebook computer**	$0.00	$0.00 (borrowed)	**-**
7	**Wireless router**	$0.00	$0.00 (borrowed)	**-**
8	**Internet Connection**	$0.00	$0.00 (borrowed)	**-**
9	**PICSTART PIC Programmer**	$0.00	$0.00 (borrowed)	**-**
10	**Miscellaneous Hardware** (cables, prototype board, connectors, etc.) *LCD and Serial interface kit* *Buttons*	$35.00	$ 46.13 $ 51.68 $ 43.10 **$140.91**	**-$105.91**
11	**Contingency Fund** *Overhead and Extra/Un-used Items* (project file, printing, long-distance phone calls, executive lunches, PIC18F452 chips, temperature sensor chips, cables, connectors, etc…)	$100.00	$186.80	**-$86.80**
	TOTAL	**$794.00**	**$1078.48**	**-$284.48**

Several factors contributed to the cost overrun in the construction of the Remotely Accessible Temperature Control System prototype. First, our initial estimates did not take into account the costs of taxes, shipping and handling. Also, since some components were purchased from the UK, overseas costs and services were subjected to the credit card company's inflated exchange rates and long-distance phone correspondence was necessary.

Some of the extraneous costs incurred can be avoided in the production stage of the RATCS. These costs were incurred by purchasing components in small quantities and separately, as opposed to all at once, which would decreased shipping and handling charges. In addition, the costs associated with the purchase of extra PIC18F452 and Temperature Sensor chips for contingency purposes will be lessened.

7 Timeline

Figure 1, below, is the proposed timeline to complete the RATCS prototype from January 2005.

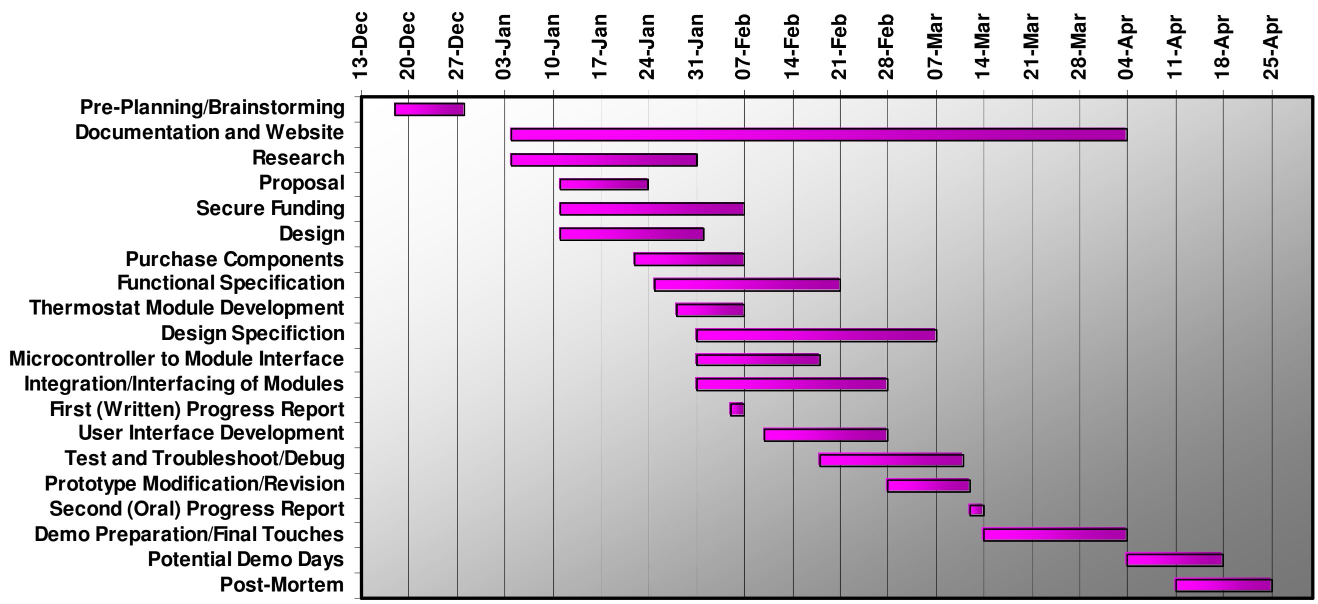

Figure 3: Proposed Timeline from January 2005

We found that the proposed timeline was overly ambitious. While initially, the proposed start dates for stages were observed, we found that the time to complete them had been underestimated. Many phases towards the middle and the end were dependant on previous phases and created a "ripple" effect in the later stages, pushing their start and end times back.

It should also be noted that the stages in the development of the RATCS took on more of a semblance of a cycle as opposed to a linear timeline. This is depicted in Figure 4, and is the reason the Design, Component Purchasing, and Test/Troubleshooting/Debugging times have been extended.

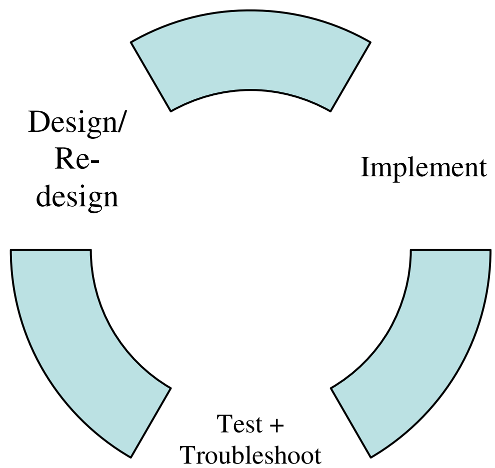

Figure 4: Observed Design Cycle

The realized timeline is shown below in Figure 5.

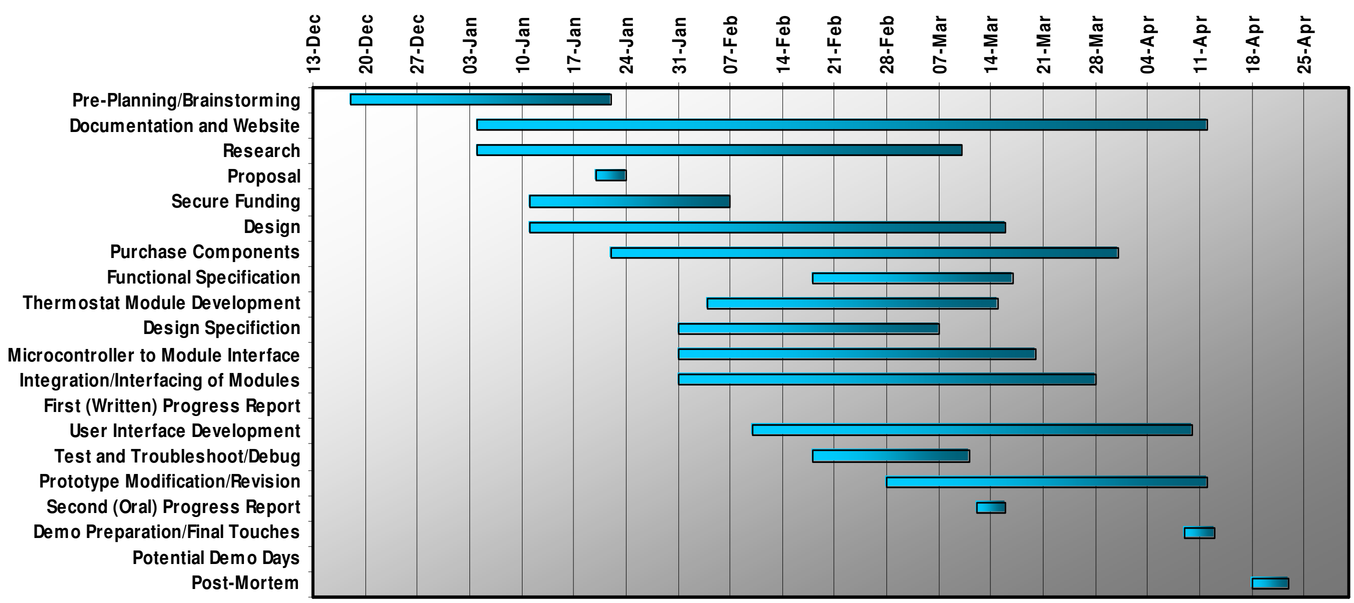

Figure 5: Actual Timeline

Towards the end, with much hard work by all parties, we were able to meet our targeted end date of April 13th, 2005.

8 Personal Experience

Jennifer Fong – President and Chief Executive Officer

If asked four months ago, I would not have even come close to being able to predict the things I have learned and experienced while doing this project. While I have put to use some of the skill set that I have accumulated over the course of my studies at SFU, for the most part, I believe it is my experiences working within and observing a team dynamic that I will take away with me and will prove to be the most useful in the future.

Perhaps not the best strategy, but the Holla Home Solutions team was primarily formed because we were friends. Our titles, for the most part, assigned to make ourselves feel important and because everyone else had them. The difficulties in this arrangement were evident right away when deciding on the project idea we wanted to pursue. Taking a better part of the first month to do so, I would attribute this false start to lack of leadership due to the unwillingness to step on each other's toes. With this approach, we also found that there was an overlap as well as gaps in our combined skill sets relative to those necessary to complete this project. While a better planned group would have avoided this pitfall, this presented opportunities for group members to step up and sacrifice in order to get the job done, despite other commitments and difficult circumstances. I know now that it is this strength of character and perseverance that makes a valuable colleague and a successful group.

I also found that time is not our friend. We had to fight her every step of the way, and she's one tough cookie. I have a new found appreciation for project managers. To know what it takes to stay on top of tasks and make sure everything gets done right… with documentation is quite a feat, especially since we were, for the most part, left to our own devices. Who knew that our instructors and professors would be right in telling us to organize our plans, layout our thoughts and document *everything*. In the end, I learned that sometimes you have to pick your battles in order to get things done.

Technically, I found this project to be challenging and fun. With much of what we've learned in classes not directly applicable, the exercise of researching and finding solutions to our problems proved to be very rewarding. I enjoyed being responsible for a module, independent of others, yet with their continued support throughout. While the higher level software was left to those group members with a more extensive background, I am glad that I was allowed to test my hand at it, no matter how insignificant the task. I also learned quite a bit about web design, which has opened up a path for me that I may want to pursue.

I am proud of our accomplishments, I am proud of our product, but most of all I am proud of the people who came together to make this possible.

Stephen Judd – Chief Financial Officer

This project gave me the opportunity to apply the skills that I have been developing over my past years while at SFU. Beginning with creating an idea for a project that was both interesting to the entire group and desired by society posed problems earlier then I had imagined. After this initial hurdle had been jumped, it became immediately apparent that a timeline with milestones would be crucial to a successful completion of this project. During the last semester I have found new respect for group dynamics and interaction, especially at times where things get stressful and work guidelines become somewhat unclear.

There were many responsibilities throughout the entirety of this project but the main ones that I was accountable for were the interactions of the PIC microcontroller with both the thermometer and LCD. In handling these issues I have been able to further increase my experience writing C code, dealing with hardware interfacing and working with a variety of microcontrollers. Creating a housing model for display purposes may not have been one of the more important parts of this project but it was also a responsibility given to me, and vital in exhibiting the professional nature our project and of our group. One behavior that I believe our group did well was helping one another with their individual parts of the project. This project has reached success partly due to the collective brainstorming and viewpoints of all its members.

To conclude, I would like to thank my group team members for their collective hard work and dedication in completing this project. I greatly value these last four months and believe that they are a vital part of the experience that will help me with my future career. In the beginning we all were a little uncertain of where this project would take us, but in the end, we have been able to develop a product which we believe to be a success.

Wojtek Piaseczny – Chief Software Engineer

This project gave me an entirely new level of respect for project management, starting from the formation of a team, to the division of work, to the accountability for one’s work. Our group was formed of four friends, and with a lot of overlapping skill sets. From a technical point of view, this is probably the worst way to form a team. I imagine that in industry a management figure lays out the requirements for a project, and finds people who are able to fulfill each requirement. We did not have the luxury of knowing our project before forming a group, but this is something I will definitely be aware of before being a part of another team. Dividing tasks among group members is another project management issue that I think we could have done better. I personally like to have tasks that are completely independent of all others, so I can complete my part and know that I have fulfilled the expectations of me. The lines separating duties tended to be grey, rather than black and white, so I found it difficult to know when my contribution was complete.

From a technical aspect, I found this project fun, and somehow similar to building a shed. We were very careful about selecting a project that we would be able to finish, and that would provide some technical challenges. Our project used a lot of off-the-shelf components that we had to put together to make the system work. I probably trivialized this project too much by comparing it to building a shed. What I mean by this comparison is that we knew we would succeed if we followed a certain course of action. We did not invent any new technologies, but the sum of our work did create a product that did not exist before.

This project has the career-altering potential for me. A former employer of mine has approached me in regards to developing embedded components for him. I am undecided about pursuing this opportunity, but it is nice to know that this project can help me beyond whatever school credit I get for it. In my past work experience, I am more accustomed to developing higher-level systems. This project exposed me to the nuts-and-bolts programming that I really have not seen since my first year at school.

Overall, I like that this project was a learning experience for me. I was faced with problems that I really had no experience with before this project, and I was able to work through all of them successfully.

Christopher Richardson, Chief Hardware Engineer

I can honestly say that I learned a lot through completing this project. On the technical side of things, I did not learn so much as I did use what I had already learned. Programming our microcontroller and interfacing simple hardware components did not pose as much of a challenge as the bureaucratic aspects of the project. I did learn some things about hardware integration and low level programming, but it was building on things I had done in first year even. The true challenges of this project were personal, intrapersonal and bureaucratic.

I think that as a group we did a very poor job in planning our project from the start. It took us too long to decide on an idea and because of that I think we rushed into buying our parts. We could have saved time and money by putting more research into part selection. We also did not do a very good job in putting together our group in the first place. Each member of this group should have though of an idea and attempted to put together a team that could build on that idea. Either that or each of us should have looked at the other ideas out there to see if we could have fit into some other group. I do not think that any of us did that; I sure definitely did not.

I did learn a lot about project management through completing 305/440, unfortunately what I learned came from the experience of doing what not to do. Much of the doing what not to do was a result of my own laziness and flawed personality traits. I was often too hard on group members who I thought weren't working as hard as they should have been or accomplishing what they should have done. I haven't changed my mind, but I should have dealt with things differently. I should have also had a better attitude during group discussions and should have had more respect for other people's opinions that conflicted with mine. I definitely learned a lot about myself in terms of what I am good at and what situations I should steer clear of. On a positive note, I feel that my organizational skills stood the test of this project.

I think that our greatest problem was our lack of efficiency. We were a group of friends first and not necessarily a group that works well together. We goofed off a lot and we didn't divide tasks as clearly as we should have. When we did divide up the tasks, there was often a lot of overlap that required other group members to step in. In the end, I am very proud of most of the group because we accomplished our goals. In addition, one of us worked extremely hard through tremendous personal adversity and my respect goes to them.

9 Conclusion

Taking the Remotely Accessible Temperature Control System prototype from concept to conclusion has proven to be an extremely worthwhile exercise. As a group we have put together an original product with market potential as well as social and environmental benefits. Despite any difficulties and frustrations experienced, we have reached a point where we can be proud of what we have accomplished, but also have the opportunity to continue on with the project. Holla!