WINNOVATIONS
Wireless Innovations For Security

School of Engineering Science ♦ Burnaby, BC
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April 21st, 2005

Lakshman One
School of Engineering Science
Simon Fraser University
8888 University Drive
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Project Post-Mortem for a Wireless Home Security System

Dear Mr. One,

The enclosed document, Post-Mortem for a Wireless Home Security System, outlines a discussion of the results of our capstone project for ENSC 440. Our goal was to design a wireless home security solution that notifies the home owners through their computer or a cell phone, in case of fire, flood, or break-ins.

The purpose of the post-mortem is to recollect and discuss the project management and budgetary and time constraints encountered throughout this project. It outlines the current state of the system, any deviations from the proposed design and functionality, possible future enhancements, budgetary and time constraints and finally the experiences gained from each of the team members.

Our company, WInnovations, is comprised of four 5th year SFU engineering students: Jason Fong, Alex Hsiao, Gavin Lee, and Gaurav Magoon. If you have any questions please feel free to contact us at ensc440-security@sfu.ca.

Sincerely,

Gavin Lee
CEO
WInnovations

Enclosure: Post-Mortem for a Wireless Home Security System

Post-Mortem for a Wireless Home Security System

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Issued date:

April 21st, 2005

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1. Introduction

Through the collaborative efforts among the four members of WInnovations, we are pleased to report that the team successfully developed a working prototype of the Wireless Home Security System, and gave a professional demonstration at Simon Fraser University on Wednesday, 2005 April 13.

This document summarizes the work done towards the prototype in the past 13 weeks, and any significant differences from what we presented in the proposal. In addition we discuss groundwork for potential future enhancements, compare the actual schedule of events with the original, the actual budget with the original, as well as personal interviews with each of the four team members.

2. Current State of the System

Initially the wireless home security system was designed such that sensors could be placed in various settings in a home. Their status would be constantly monitored and if the sensor had gone off or had detected a state of danger (such as smoke detector, flood detector, home security, etc), a wireless signal would be sent to a PC that is located in a different location for urgent notification. Figure 1 illustrates this idea [4].

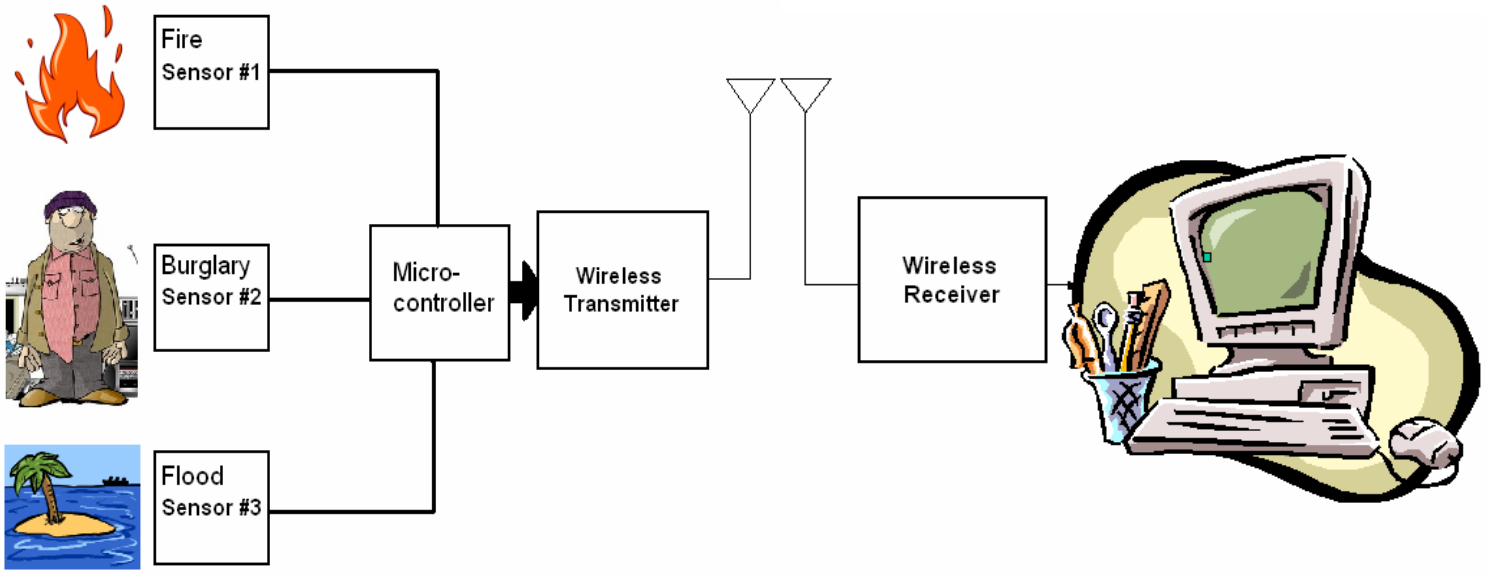


Figure 1: Conceptual Overview

Figure 2 shows a flow chart of the behaviour of the system setup as in Figure 1 but at a slightly more detailed level.

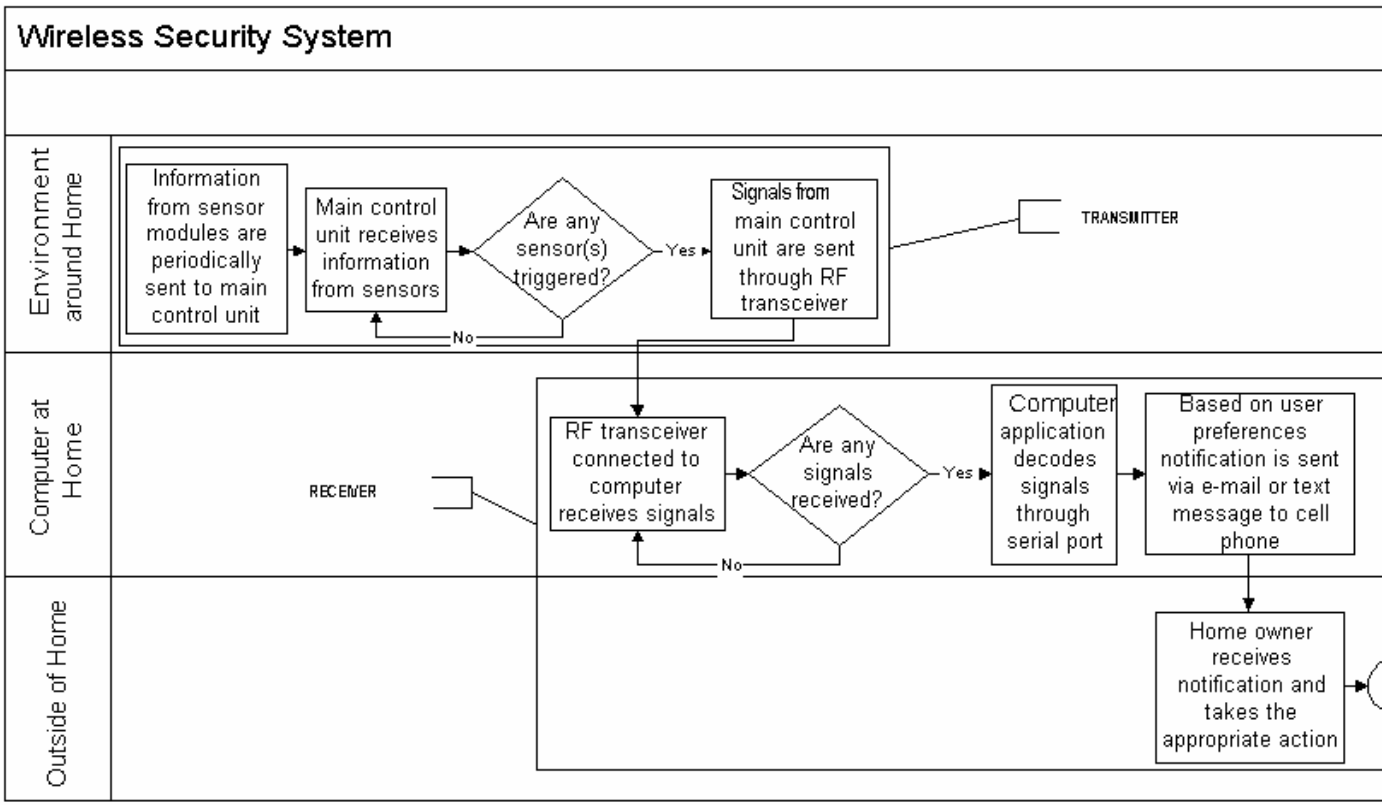


Figure 2: System Overview Flowchart

Figure 2 illustrates the process overview on the receiver and transmitter side of the home security system. This flowchart illustrates the intended process flow of the transmitter and receiver behaviour.

At this current stage of the project, we were able to meet our intended requirements successfully except for the two way wireless communications link and several other issues which will be discussed later in this document. Below in Figure 3 we have shown a screenshot of the GUI for the WHSS that shows the current state of the software portion of the project.

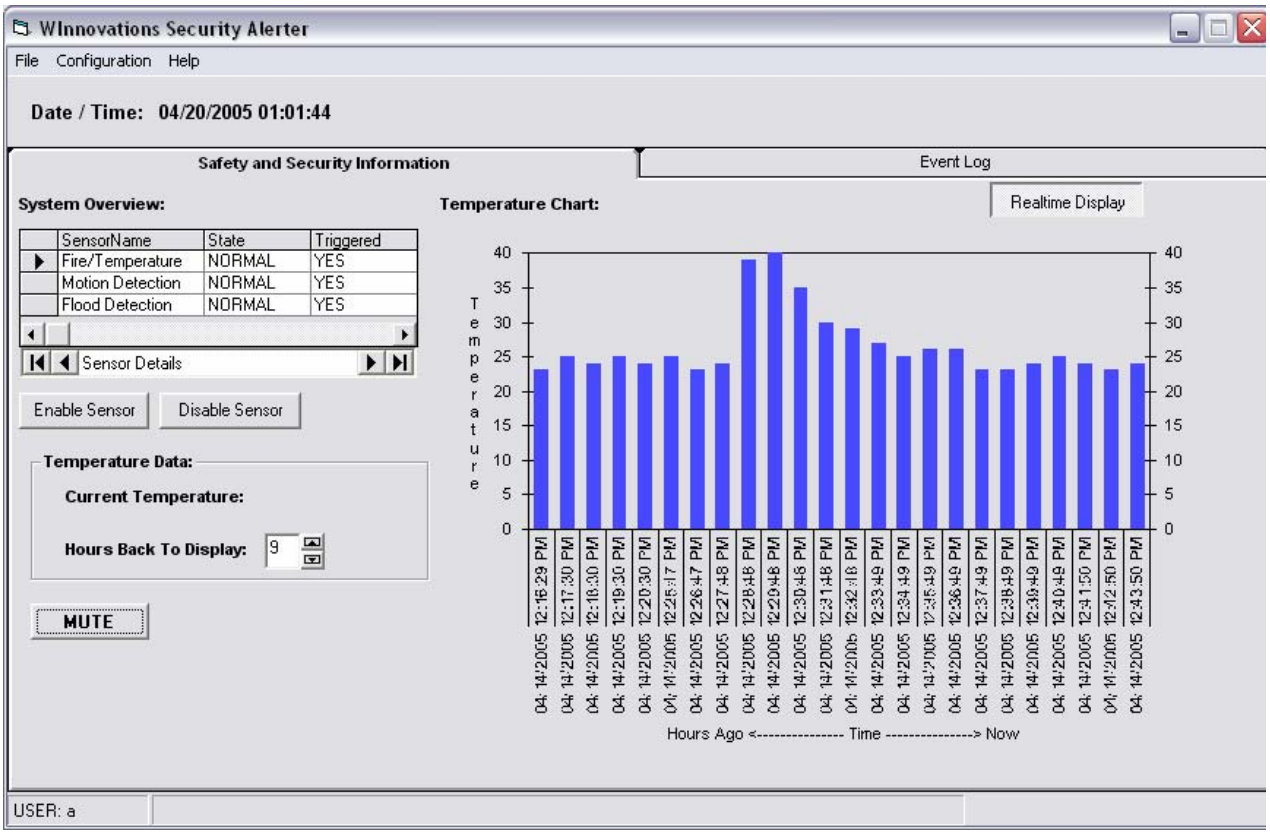


Figure 3: A screenshot of the GUI program for the host computer

3. Deviation from proposed project

3.1 Communication Protocol

In our design specification, we had proposed the presence of a two way wireless communication link such that the host pc would have been given the ability to reset the wireless security system or be able to disable each sensor remotely. This was not possible in the final product and our final product ended up having just a one way wireless link. The security system transmits continuous sensor readings to the host personal computer. Individually the wireless link both ways worked but due to problems in switching the modes between receive and transmit on the two transceivers and other technical difficulties, we were unable to implement the two way wireless link.

3.2 Email functionality using SMTP server

In our design specification, it was stated that e-mail functionality would be enabled via an SMTP server using Winsock. However, Winsock can only be used in a trusted domain and ISP (Internet Service Provider), which means that e-mail cannot be sent in the ENSC labs since port 25 is restricted only to authorized users. As an alternative, MS Outlook was used with authentication using the SFU POP3 and SMTP servers.

3.3 Flood sensor design

In our design specification, we intended to directly amplify the output of the photo-detector device. However, due to the limitation in the performance of the amplifier opamp, we ended up using a comparator instead to generate the output logic-high for the external interrupt pin of the PIC microcontroller.

3.4 Motion sensor design

In our design specification, we intended on using an amplifier to amplify the output of the PIR sensor for the input of the A/D converter of the PIC microcontroller. Instead, we opted to utilize a difference amplifier to compare the output of the PIR sensor to a variable reference voltage level and to amplify the difference.

3.5 Temperature sensor accuracy

In our design specification and functional specification, the temperature sensor was noted to be able to provide 1 degree of accuracy in readings. However, in the final project, the temperature sensor was unable to provide us this accuracy; instead we were able to only gain 4 degrees of accuracy in readings. The source of this problem is determined to be the temperature sensor IC. The IC could have been switched to confirm our speculations.

4. Future Enhancements

In our design solution, we provide a solution to the problem of a single device that can provide features to monitor home security, fire, floods, etc. The information from the sensor modules are sent wirelessly to a receiver on the computer and interpreted with the software application. The software application allows the user to choose whether to notify him/her when a sensor is triggered via email or SMS. Possible enhancements with this product could include:

Communications:

- Calling the user using a phone line, through a modem or via Voice over IP (VoIP) with an automated message.
- Notifying the authorities directly via telephone.
- Include a two-way communications link by which the user has more control over the operation of the security system wirelessly.
- Modify the communication protocol such that time is separated into two components: transmitting and receiving. This is the method utilized in cordless phone systems to date and is quite an efficient method. By splitting the time into reception and transmission modes, both sides of the wireless link get a chance to exchange data instead of having to worry about message collision.

Computer / Data storage:

- Use flash memory or other non-volatile storage solutions to store information rather than having the hard disk continually spin-up upon receipt of data (to prolong the life of the hard disk).
- Have a built in battery backup to prevent failure of the device due to power outages.
- Produce a more audible alert (possibly with the use of a siren).

Main module / Sensor modules:

- Allow for easy and flexible expansion of the entire security system by adding or removing sensors as needed.
- Notifying the authorities directly via telephone in the event of an emergency.
- Monitor voltage levels if using batteries as a source of power.
- Use multiple sensors of the same kind for better performance. For example, use multiple motion sensors and develop an algorithm based on the status of each sensor to determine if an individual truly has breached the security of the home.

Software:

- Update the software to implement a more efficient means of displaying the data. The user should be able to select whether to view a graphical form of the data or just a textual form of data in presentation.
- Update the software such that it is more robust in the detection of the cause of the breach, whether it is a security breach, flood or a fire in the home.

- Develop different mental models for the different kinds of situations that might rise when a user is in the home and when not. For example, if a user is in the home, the audible alert should automatically be turned on if a user is logged in (into the program). If a user is not logged into the GUI, the audible alerts can be turned off and remote alerts (SMS, telephone call, etc) can be activated. If the user is logged in, the audible alerts can also be turned on.

5. Funding and Budget

For the wireless link of the project, we were fortunate enough to receive permission from Mr. Sarkis Tegharian from VTech Engineering Canada to use his RF Evaluation Kit for the duration of the semester. In total, these wireless modules saved our team about $700 for the development of the project.

The preliminary budget for the project, estimated at January 2005, is shown in Table 1.

Table 1: Estimated Budget for the Project

Equipment and Parts	Estimated Cost
Wireless Transceiver Evaluation Kit (includes receiver and transmitter)	$0
Sensors • Fire (temperature/smoke detector can be accomplished with a DIP chip) • Burglary (motion detector) • Flood (level sensor)	$300 (~$10 – may order samples, ~$10 for shipping) [6]
PIC chip	$20
Other lab tools & misc. (e.g. DMM, tweezers, prototype board)	$70
Total	**$390**

The actual cost of parts, updated April 2005, is shown in table 2.

Table 2: Actual Expenses Chart for the Project

Equipment and Parts	Confirmed Cost
Wireless Transceiver Evaluation Kit (includes receiver and transmitter)	$0
• Crystal Oscillators • Protoboards • Woodcasing • Microchip PIC chips • Project Folder • Cables	$212.00

• etc	
Total	**$212.00**

As you can see the total cost was $212.00. This saves us about $178.00 from the originally projected costs.

6. Schedule and Milestones

Figure 4 shows the initial Gantt chart of the estimated time that will be spent on each task during the project period. The figure also shows the expected completion dates as milestones for each of the major tasks.

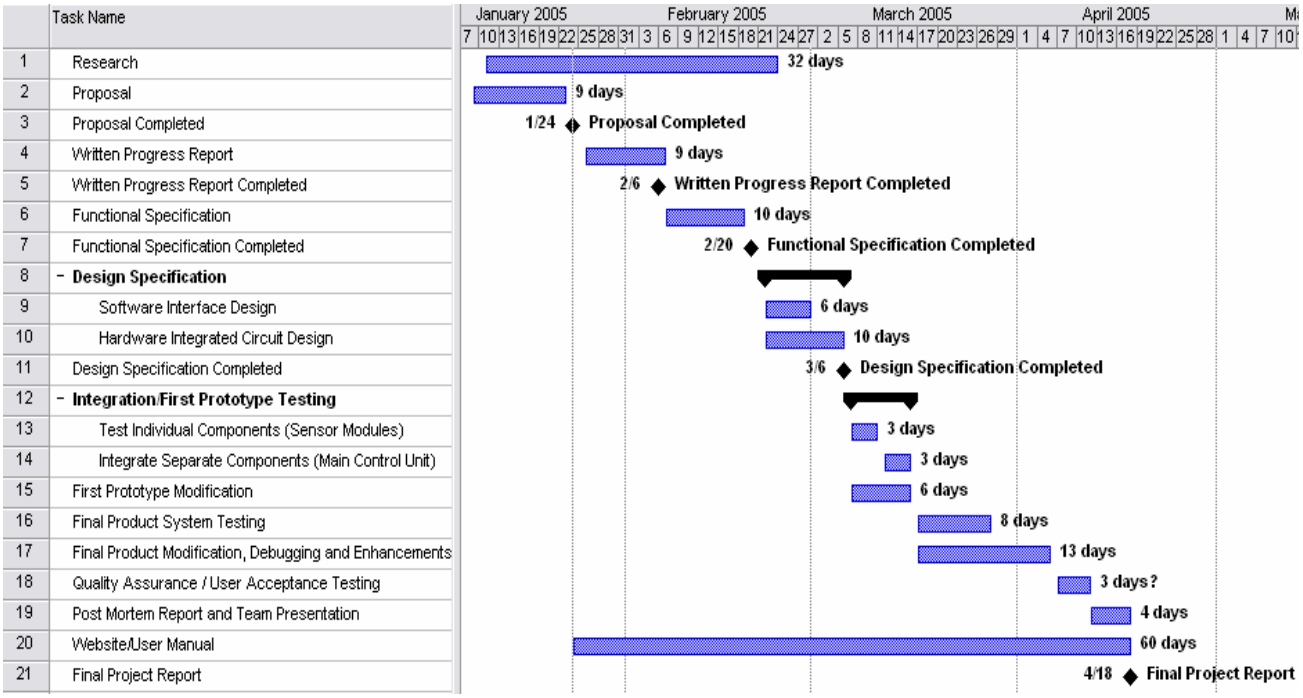
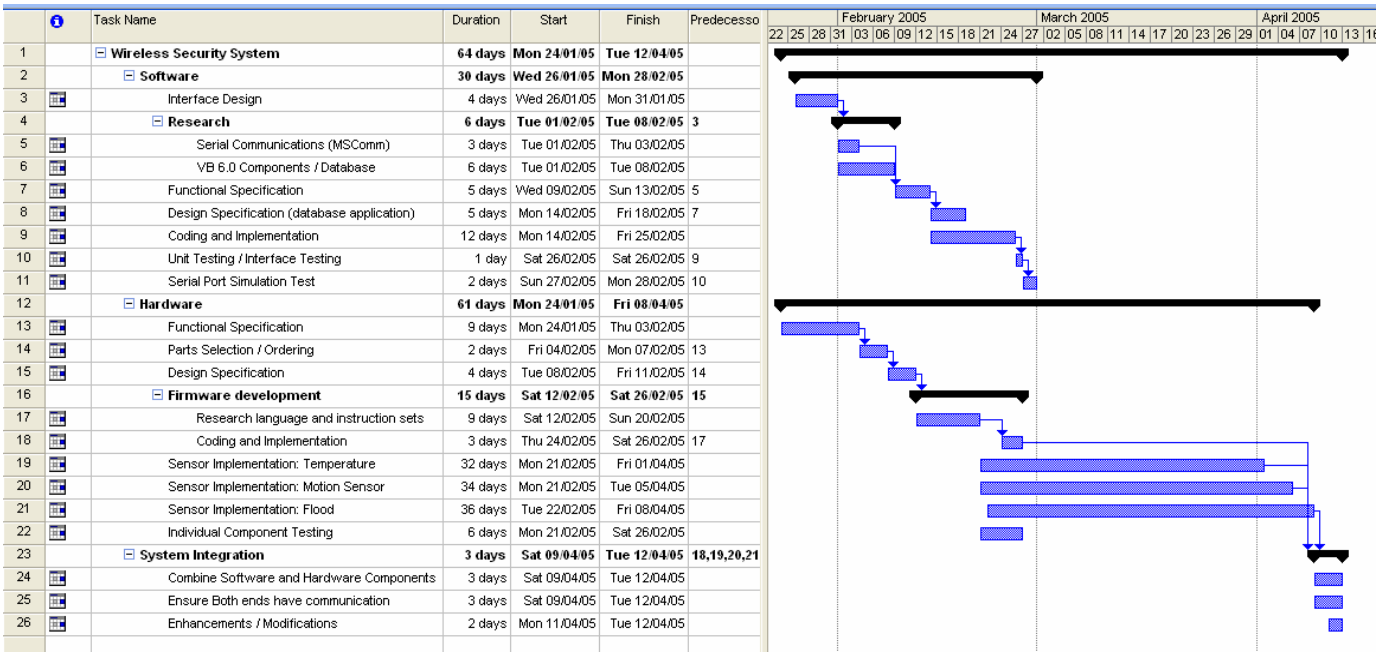


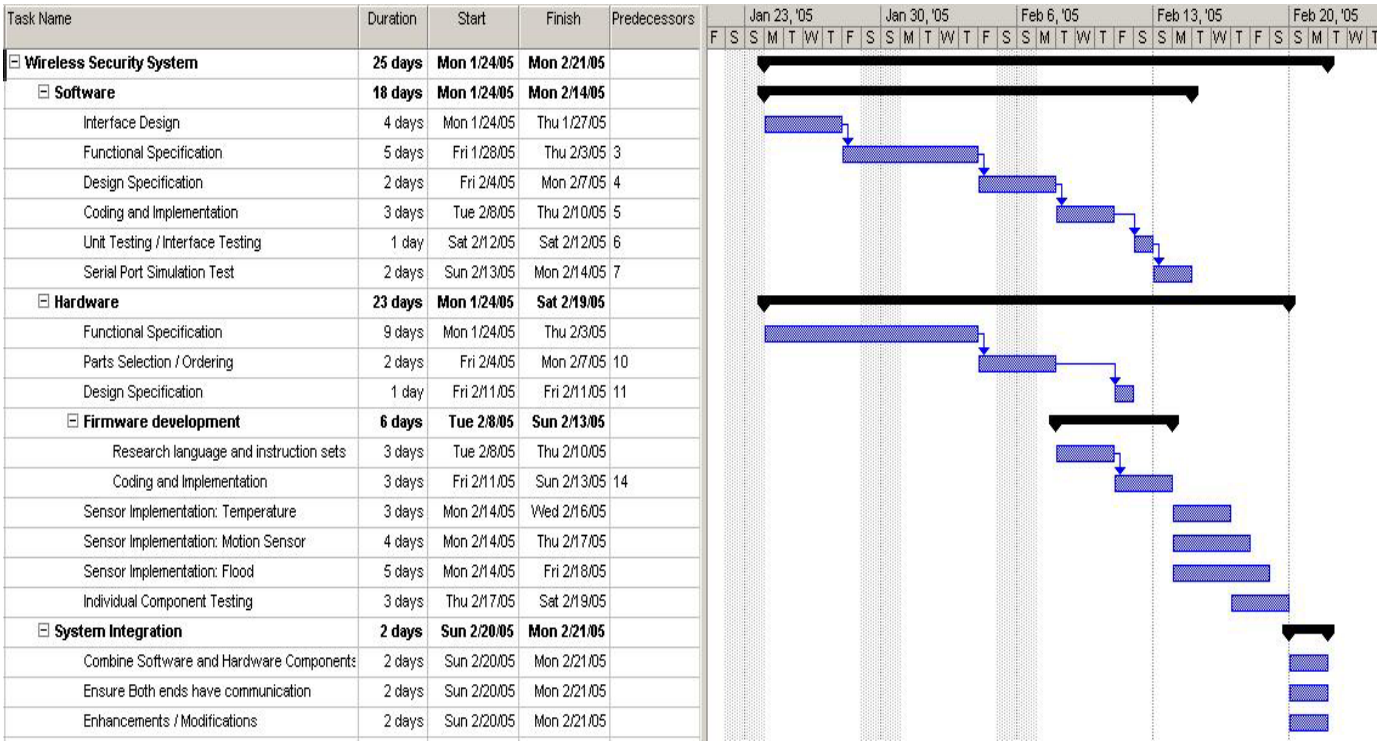
Figure 4: Gantt and Milestone Chart

As with most projects in the real world, the proposed timeline is used as a guide and do not represent the actual timeline of the project. Estimations of the expected time to complete projects do not take into consideration, the possible contingency involved or unexpected delays due to shipment of parts. With so many things to consider, meeting the completion date for the project, the shift in focus for one area of the project to another is evident. For example, a change due to the discovery of some hardware or software conflicts can often result in a changed design which may impact the project in its entirety, thus causing a shift the timeline and a primary focus on the problem at hand. Figures 5 through 8 show Gantt charts that were updated during different stages of our project as it neared completion.



	Task Name	Duration	Start	Finish	Predecesso
1	**Wireless Security System**	**64 days**	**Mon 24/01/05**	**Tue 12/04/05**	
2	**Software**	**30 days**	**Wed 26/01/05**	**Mon 28/02/05**	
3	Interface Design	4 days	Wed 26/01/05	Mon 31/01/05	
4	**Research**	**6 days**	**Tue 01/02/05**	**Tue 08/02/05**	3
5	Serial Communications (MSComm)	3 days	Tue 01/02/05	Thu 03/02/05	
6	VB 6.0 Components / Database	6 days	Tue 01/02/05	Tue 08/02/05	
7	Functional Specification	5 days	Wed 09/02/05	Sun 13/02/05	5
8	Design Specification (database application)	5 days	Mon 14/02/05	Fri 18/02/05	7
9	Coding and Implementation	12 days	Mon 14/02/05	Fri 25/02/05	
10	Unit Testing / Interface Testing	1 day	Sat 26/02/05	Sat 26/02/05	9
11	Serial Port Simulation Test	2 days	Sun 27/02/05	Mon 28/02/05	10
12	**Hardware**	**61 days**	**Mon 24/01/05**	**Fri 08/04/05**	
13	Functional Specification	9 days	Mon 24/01/05	Thu 03/02/05	
14	Parts Selection / Ordering	2 days	Fri 04/02/05	Mon 07/02/05	13
15	Design Specification	4 days	Tue 08/02/05	Fri 11/02/05	14
16	**Firmware development**	**15 days**	**Sat 12/02/05**	**Sat 26/02/05**	**15**
17	Research language and instruction sets	9 days	Sat 12/02/05	Sun 20/02/05	
18	Coding and Implementation	3 days	Thu 24/02/05	Sat 26/02/05	17
19	Sensor Implementation: Temperature	32 days	Mon 21/02/05	Fri 01/04/05	
20	Sensor Implementation: Motion Sensor	34 days	Mon 21/02/05	Tue 05/04/05	
21	Sensor Implementation: Flood	36 days	Tue 22/02/05	Fri 08/04/05	
22	Individual Component Testing	6 days	Mon 21/02/05	Sat 26/02/05	
23	**System Integration**	**3 days**	**Sat 09/04/05**	**Tue 12/04/05**	**18,19,20,21**
24	Combine Software and Hardware Components	3 days	Sat 09/04/05	Tue 12/04/05	
25	Ensure Both ends have communication	3 days	Sat 09/04/05	Tue 12/04/05	
26	Enhancements / Modifications	2 days	Mon 11/04/05	Tue 12/04/05	

Figure 5: Gantt and Milestone Chart



Task Name	Duration	Start	Finish	Predecessors
Wireless Security System	**25 days**	**Mon 1/24/05**	**Mon 2/21/05**	
Software	**18 days**	**Mon 1/24/05**	**Mon 2/14/05**	
Interface Design	4 days	Mon 1/24/05	Thu 1/27/05	
Functional Specification	5 days	Fri 1/28/05	Thu 2/3/05	3
Design Specification	2 days	Fri 2/4/05	Mon 2/7/05	4
Coding and Implementation	3 days	Tue 2/8/05	Thu 2/10/05	5
Unit Testing / Interface Testing	1 day	Sat 2/12/05	Sat 2/12/05	6
Serial Port Simulation Test	2 days	Sun 2/13/05	Mon 2/14/05	7
Hardware	**23 days**	**Mon 1/24/05**	**Sat 2/19/05**	
Functional Specification	9 days	Mon 1/24/05	Thu 2/3/05	
Parts Selection / Ordering	2 days	Fri 2/4/05	Mon 2/7/05	10
Design Specification	1 day	Fri 2/11/05	Fri 2/11/05	11
Firmware development	**6 days**	**Tue 2/8/05**	**Sun 2/13/05**	
Research language and instruction sets	3 days	Tue 2/8/05	Thu 2/10/05	
Coding and Implementation	3 days	Fri 2/11/05	Sun 2/13/05	14
Sensor Implementation: Temperature	3 days	Mon 2/14/05	Wed 2/16/05	
Sensor Implementation: Motion Sensor	4 days	Mon 2/14/05	Thu 2/17/05	
Sensor Implementation: Flood	5 days	Mon 2/14/05	Fri 2/18/05	
Individual Component Testing	3 days	Thu 2/17/05	Sat 2/19/05	
System Integration	**2 days**	**Sun 2/20/05**	**Mon 2/21/05**	
Combine Software and Hardware Components	2 days	Sun 2/20/05	Mon 2/21/05	
Ensure Both ends have communication	2 days	Sun 2/20/05	Mon 2/21/05	
Enhancements / Modifications	2 days	Sun 2/20/05	Mon 2/21/05	

Figure 6: Gantt and Milestone Chart

Wireless Security System	**32 days**	**Mon 1/24/05**	**Mon 2/28/05**	
Software	**30 days**	**Wed 1/26/05**	**Mon 2/28/05**	
Interface Design	4 days	Wed 1/26/05	Mon 1/31/05	
Research	**6 days**	**Tue 2/1/05**	**Tue 2/8/05**	**3**
Serial Communications (MSComm)	3 days	Tue 2/1/05	Thu 2/3/05	
VB 6.0 Components / Database	6 days	Tue 2/1/05	Tue 2/8/05	
Functional Specification	5 days	Wed 2/9/05	Sun 2/13/05	5
Design Specification (database application)	5 days	Mon 2/14/05	Fri 2/18/05	7
Coding and Implementation	12 days	Mon 2/14/05	Fri 2/25/05	
Unit Testing / Interface Testing	1 day	Sat 2/26/05	Sat 2/26/05	9
Serial Port Simulation Test	2 days	Sun 2/27/05	Mon 2/28/05	10
Hardware	**30 days**	**Mon 1/24/05**	**Sat 2/26/05**	
Functional Specification	9 days	Mon 1/24/05	Thu 2/3/05	
Parts Selection / Ordering	2 days	Fri 2/4/05	Mon 2/7/05	13
Design Specification	4 days	Tue 2/8/05	Fri 2/11/05	14
Firmware development	**15 days**	**Sat 2/12/05**	**Sat 2/26/05**	**15**
Research language and instruction sets	9 days	Sat 2/12/05	Sun 2/20/05	
Coding and Implementation	3 days	Thu 2/24/05	Sat 2/26/05	17
Sensor Implementation: Temperature	6 days	Mon 2/21/05	Sat 2/26/05	
Sensor Implementation: Motion Sensor	6 days	Mon 2/21/05	Sat 2/26/05	
Sensor Implementation: Flood	6 days	Mon 2/21/05	Sat 2/26/05	
Individual Component Testing	6 days	Mon 2/21/05	Sat 2/26/05	
System Integration	**2 days**	**Sun 2/27/05**	**Mon 2/28/05**	**18,19,20,2**
Combine Software and Hardware Components	2 days	Sun 2/27/05	Mon 2/28/05	
Ensure Both ends have communication	2 days	Sun 2/27/05	Mon 2/28/05	
Enhancements / Modifications	2 days	Sun 2/27/05	Mon 2/28/05	

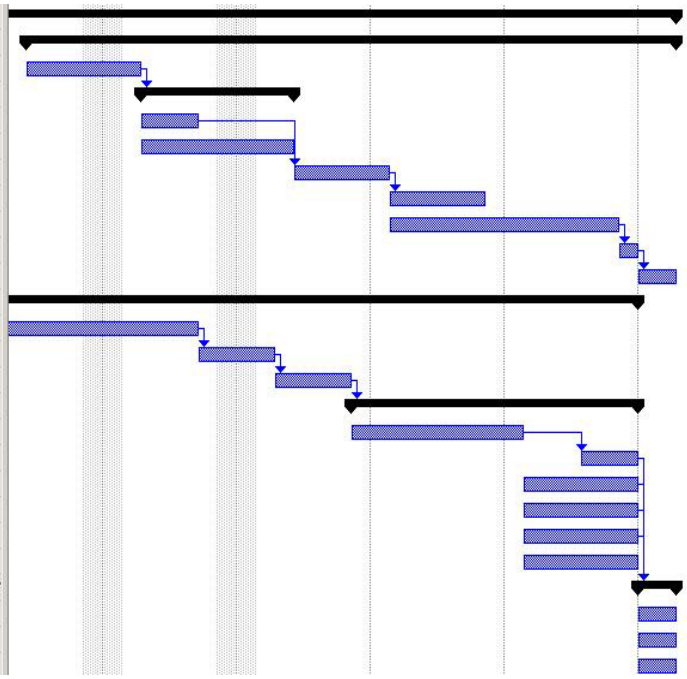


Figure 7: Gantt and Milestone Chart

Wireless Security System	**64 days**	**Mon 1/24/05**	**Tue 4/12/05**	
Software	**30 days**	**Wed 1/26/05**	**Mon 2/28/05**	
Interface Design	4 days	Wed 1/26/05	Mon 1/31/05	
Research	**6 days**	**Tue 2/1/05**	**Tue 2/8/05**	**3**
Serial Communications (MSComm)	3 days	Tue 2/1/05	Thu 2/3/05	
VB 6.0 Components / Database	6 days	Tue 2/1/05	Tue 2/8/05	
Functional Specification	5 days	Wed 2/9/05	Sun 2/13/05	5
Design Specification (database application)	5 days	Mon 2/14/05	Fri 2/18/05	7
Coding and Implementation	12 days	Mon 2/14/05	Fri 2/25/05	
Unit Testing / Interface Testing	1 day	Sat 2/26/05	Sat 2/26/05	9
Serial Port Simulation Test	2 days	Sun 2/27/05	Mon 2/28/05	10
Hardware	**61 days**	**Mon 1/24/05**	**Fri 4/8/05**	
Functional Specification	9 days	Mon 1/24/05	Thu 2/3/05	
Parts Selection / Ordering	2 days	Fri 2/4/05	Mon 2/7/05	13
Design Specification	4 days	Tue 2/8/05	Fri 2/11/05	14
Firmware development	**15 days**	**Sat 2/12/05**	**Sat 2/26/05**	**15**
Research language and instruction sets	9 days	Sat 2/12/05	Sun 2/20/05	
Coding and Implementation	3 days	Thu 2/24/05	Sat 2/26/05	17
Sensor Implementation: Temperature	32 days	Mon 2/21/05	Fri 4/1/05	
Sensor Implementation: Motion Sensor	34 days	Mon 2/21/05	Tue 4/5/05	
Sensor Implementation: Flood	36 days	Tue 2/22/05	Fri 4/8/05	
Individual Component Testing	6 days	Mon 2/21/05	Sat 2/26/05	
System Integration	**3 days**	**Sat 4/9/05**	**Tue 4/12/05**	**18,19,20,21**
Combine Software and Hardware Components	3 days	Sat 4/9/05	Tue 4/12/05	
Ensure Both ends have communication	3 days	Sat 4/9/05	Tue 4/12/05	
Enhancements / Modifications	2 days	Mon 4/11/05	Tue 4/12/05	

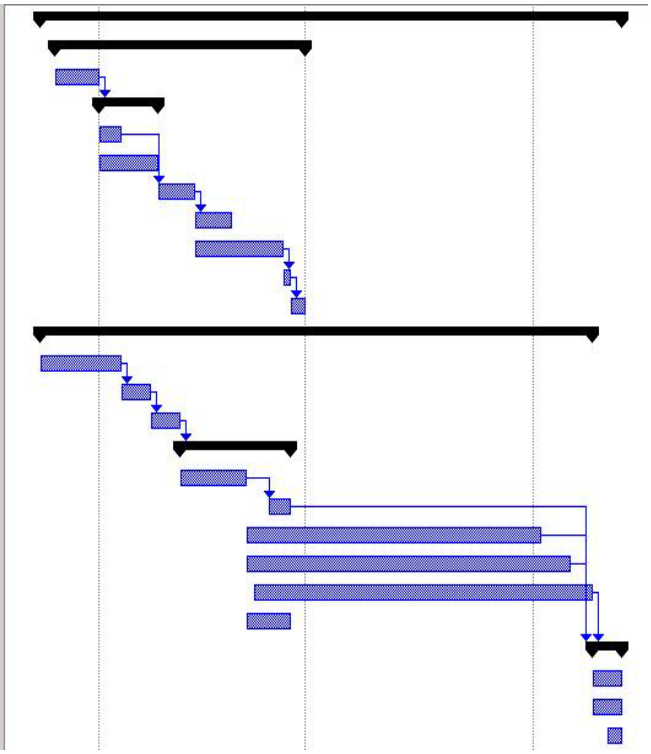


Figure 8: Gantt and Milestone Chart

From Figures 5 to 8, we note that as time progressed through the semester, we ultimately had to update the Gantt charts to reflect our current progress in the project. During the earlier stage of the project, the completion date of the project was underestimated and hence had to be extended to reflect the true completion/integration date. Overall, it was found that using Gantt charts assisted by providing a continuous self reminder of the state of the project compared to the intended progress.

7. Conclusion

Providing feasible, user-friendly solutions in the effort to improve peace of mind is the primary objective of WInnovations. With the Wireless Home Security System from WInnovations, homeowners can leave home knowing that their home is safe from natural disasters and burglaries.

The wireless home security system will notify the homeowner via e-mail, text messaging or by an audible alarm about any security or safety issues that may arise so that the homeowner can take the appropriate action. Other security systems are passive by triggering a siren, require high installation costs to run wiring or require a third party to monitor the system at a monthly cost.

In preparation for undertaking this project as shown in the proposed schedule of milestones, we prepared the Gantt charts which would help WInnovations to stay organized and dedicated to the tasks at hand. Through the whole timeline of this project until the current state of the project, we got a chance to apply all our accumulated knowledge gained from previous co-ops into it. We also followed the strict timing requirement that we had set by the Gantt charts in the initial stages of the project.

Keeping in mind that we all have different backgrounds in engineering (software/hardware), we also individually gained further skills in other areas. We produced a product which is marketable to the general public as an alternative to current home security solutions. In the future we anticipate that the product design can be continuously revised and refined. These revisions will help us develop a fully functional and marketable product in the future.

Finally, in this project we learned how to work together in a group environment with times of success and failure, while simulating a real-world company. Through this experience, we learned how critical time management skills and planning skills are for the development of a successful project.

8. Technical Experiences

Chief Executive Officer (CEO)

Gavin Lee

Through this project I have gained valuable technical experience in the areas of software and hardware as well as experienced the pressures evident with project management and budgetary and time constraints.

Software development using Visual Basic, an MS Access database as well as API (application program interface) references to the Outlook Object Library provided me with an opportunity not only to utilize the software to its full potential to achieve the project software requirements, but also allow me to gain the necessary skills in application development. With the use of SQL with Visual Basic's ADO (ActiveX Data Objects), temperature data was queried and displayed on a graph. A demonstration of the power of databases through inserting, deleting, selecting and updating records further provided the functionality to log important events, add users, change program settings, and display critical security and safety information. Using the components adaptable with Visual Basic, e-mail functionality using MS Outlook satisfied the key communication requirement for the project to notify the user in the case of an emergency. The experience gained from my work terms involving database programming and Windows application development was critical in meeting the software requirements and completing the software program in a timely manner.

Hardware research and design were the key areas that were important in the completion of the project. Researching alternatives for motion sensors and looking at the advantages and disadvantages of different types, helped in evaluating the optimal solution for the security system. I proceeded with ordering the necessary parts based on the requirements and the chosen sensor. The flood sensor involved a little creativity by using a mixture of a light source, a photo sensor and the buoyancy of water to block the light source and trigger an output. The knowledge obtained from microelectronics courses and the intended functionality of the sensor modules helped me create a feasible design solution to produce the desired outputs for both the motion sensor and the flood sensor.

In addition, this project allowed me to make use my wood working and machining skills to produce the casings for the flood sensor and for the main unit to be presentable in the final demo.

The experience obtained through researching, learning, and problem solving has provided me with the skills to further my studies as well as to better understand the synergy of software engineering, database development and hardware design. I came to the realization that if I work hard at what I do, I can achieve the desired results.

Chief Technology Officer (CTO)

Gaurav Magoon

Through this ENSC 440 project, I have further acquired valuable lab experience in the area of hardware circuit debugging. Furthermore, I learned how to program PIC microcontrollers from Microchip using assembly language. This was a good first time experience from the usual programming in C++/C and Visual Basic. I also got a chance to see the overall progress of a project from both the software and hardware aspects and learned how critical timing is when it came to project integration. Project integration requires proper planning and a timely approach to integration. Solving integration problems was a very challenging yet valuable learning experience.

I have also learned how to continue to tackle challenging problems as they rise during the project integration phase. The main key is to not give up. Since I was the primary individual responsible for hardware component purchasing and usage, I learned where to acquire hardware components locally and how to pick them in an effective manner based on our technical requirements. I got a chance to apply the experience I gained via my previous coop terms in the development of the main project board and the associated circuitry.

Being there throughout the development of the individual components and during the integration phase, I realized also how critical proper budgetary planning is required before any project is initiated. If extra time is taken to do pre-planning for a project, the workload of the project can be more easily and effectively balanced amongst the group members.

Chief Financial Officer (CFO)

Jason Fong

ENSC 440 has given me an inside eye into the development of a product, from thoughts and ideas in the head, to a working (at least partially!) product in the world. Wireless home security, although a fairly well-developed concept to date, could always use improvements in this early 21st-century era marked by increased crime and terrorism media coverage.

I surveyed all parts of the project, from software to hardware to firmware, but my main focus was on the software and its user interface. With my Delphi experience in China (2nd co-op) under my belt, I didn't encounter too much trouble in adjusting to the event-driven programming environment of Visual Basic 6.0. On my way to developing the application, I finally learned how to use a debugger (it certainly helps!), and learned how to access databases from a VB program, so that settings can be saved even if you shut off the computer. Other interesting things I discovered was the use of tabs, an MSChart object that appears to be rarely used in practice, minimizing to the system tray, serial port settings, and the unorthodox method of automating mouse clicks to send e-mail via Outlook (!). Gavin gave me a hand with that, but it was still neat to know you could do those things.

If there's anything I would do differently, I wish I would have worked more on the hardware side. I was a little too focused on the VB program, which partially led me to spend too little time on the

other material. While my engineering interests lie mainly in software at this point, I understand hardware knowledge would be beneficial. A goal for me in a project of this magnitude in the future is to take 5 minutes on the bus after I'm done and write down what I did that day, and what I'm going to do the next day, and see how I'm progressing toward my goals. For this course, I took the approach as I always have: just put off a block of time to work on the project, without putting in writing what I was going to do.

Nevertheless, I experienced all three entities of what Confucius once said: "I hear and I forget. I see and I understand. I do and I remember."

Chief Operating Officer (COO)

Alex Hsiao

Upon completion of this project, I realized how difficult it is to manage time and stay on schedule for each stage of the product cycle. Aside from the time consuming process of debugging the PIC firmware assembly code, through numerous testing we found problems caused by a faulty breadboard, an inaccurate digital temperature sensor, and an over-sensitive external interrupt pin on the PIC chip.

Being the leading firmware programmer on the WInnovations development team, I learnt the importance of thorough unit testing. Without proper unit testing, it could be extremely difficult to debug or pinpoint the source of error during project integration. In addition, programming the PIC firmware in assembly language helps me gain deeper understanding of the features on the microcontroller such as the timer, UART, and interrupts, message passing, and circular buffer implementation.

It is truly a unique experience to work in a team through each stage - product research, system design, software and hardware implementation and testing, and finally create a prototype of the product!

9. References

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