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

May 1st, 2007

Re: ENSC 440 Post Mortem for a Handheld Spectrum Analyzer

Dear Dr. One,

The attached document, *Handheld Spectrum Analyzer Post Mortem*, summarizes the process that SonoSense Technologies Inc. team members went through while designing and implementing the Handheld Spectrum Analyzer, a proof-of-concept device for ENSC 305/440.

The purpose of the enclosed document is to outline the current state of the Handheld Spectrum Analyzer (HSA), after the completion of the first phase of development. We will also review the financial and time constraints as well as personal experiences gained from this project. In addition, this document highlights some of the development plans that will be employed in the future stages in order to further improve the prototype before offering it to the market.

SonoSense Technologies Inc. is composed of four motivated and innovative fourth year engineering students: Sanaz Jahanbakhsh, Johnny Pak, Naureen Sikder, and Kenneth Wong. Should you have any questions or need more information, please feel free to contact me by phone at (604) 722-0473 or our group via e-mail at ensc-440-project@sfu.ca.

Sincerely,

Sanaz Jahanbakhsh

Sanaz Jahanbakhsh
President and CEO
SonoSense Technologies Inc.

Enclosure: *Handheld Spectrum Analyzer Post Mortem*

Handheld Spectrum Analyzer Post Mortem

SonoSense Technologies Inc.

Team: Sanaz Jahanbakhsh
Johnny Pak
Naureen Sikder
Kenneth Wong

Contact: Sanaz Jahanbakhsh
(604) 722-0473
ensc-440-project@sfu.ca

Submitted to: Lucky One
Steve Whitmore
Engineering Science
Simon Fraser University

Revision Date: May 1, 2007

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Table of Contents

List of Figures

List of Tables

Glossary

The following abbreviations are found throughout the entirety of this document. If ever there are terms that may be specific to our product, the acronym or definition is located here.

ADC	Analog to Digital Converter
dB	Decibel
ENSC	Engineering Science
EVC++	Embedded Visual C++
FFT	Fast Fourier Transform
FFTW	Fastest Fourier Transform in the West
GUI	Graphical User Interface
HSA	Handheld Spectrum Analyzer
IDE	Integrated Development Environment
LCD	Liquid Crystal Display
MATLAB	Matrix Laboratory (Mathworks, Inc.)
MX1	M9328MX1ADS/B Freescale Media Extension Development Board
OS	Operating System
PDA	Personal Digital Assistant
SPI	Serial Peripheral Interface
WinCE	Windows Compact Edition

1 Introduction

Four months have passed since the concept of a portable spectrum analyzer was first introduced in one of SonoSense's earliest group meetings. Throughout this document, the current state of the device will be evaluated and the future plans will be outlined. Also, a retrospective analysis of the steps taken and possible improvements will be discussed. In addition, each team members will illustrate their own perspective of the lessons learned while taking this long and rewarding journey of developing the proof-of-concept prototype of HSA.

2 HSA's Current State

As of end of April 2007, the SonoSense HSA is a completed and working proof-of-concept product. Audio frequencies ranging from 0-16 kilohertz can be fed in via a microphone or mic-input to be processed and their respective frequency can be displayed on a dB scale on the device's LCD unit. The accuracy of the HSA is comparable to other products available for personal computer use. Figure 1 is an algorithm that portrays a current overview of the HSA system.

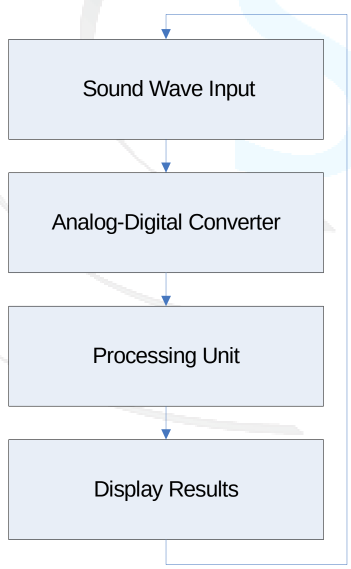

Figure 1: Handheld Spectrum Analyzer's System Overview

HSA's input channel currently is a high-precision microphone or microphone input combined with a voltage amplifier, designed to increase the input signal strength for processing. The amplifier is a single rail circuit that centers the input signal about the ground reference and the rail voltage (chosen as 5 volts).

The high-precision 16-bit Analog-to-Digital Converter (ADC) of the HSA currently samples at a rate of 32 kHz which is a fraction of the maximum rate of 200kHz. It is set as a master device to be used with its SPI compliant transfer method where it continuously sends data to the MX1 Processor.

The MX1 200 MHz Processor is set as an SPI slave device, which continuously receives serial data from the ADC in order to process the incoming data. This data is received via a custom-built driver under the Windows CE operating system for the specific purpose of accepting sample input.

In order to process our data, we have a real integer Fast Fourier Transform algorithm. Our device uses a 1024-point FFT implementing the Butterfly algorithm and symmetrical properties of real signals to increase the speed of the processing. Because this is an integer based algorithm, look-up tables are used for computation. The input of the module is 1024 real data values while the output is 512 power data points due to symmetry. These 512 data points are then divided into 10 power data bar values for use in the graphical user interface (GUI).

Finally, the GUI of our device currently supports a refresh rate of approximately 100 ms. Our device is able to capture a single set of data and show it on ten display bars that are setup to match standard equalizer divisions. Alternatively, the HSA can be set to a continuous mode, which constantly displays the spectrum of the current surroundings. The device is also able to invert the colours of the display graphics (currently black and white) and can save single sets of captured data to a formatted HTML file for viewing and transfer.

3 HSA's State Compared to Functional and Design Specifications

Comparing HSA's current functionality to those outlined in the functional specifications [1], the SonoSense team has implemented all the features listed under "proof-of-concept" phase and achieved the set goals planned of the first development stage. The main goal of the device was realized with a device that amplifies the sound input, utilizes an accurate frequency processing algorithm and displays the results on a LCD unit. Please see the following sections regarding a more detailed comparison between planned and implemented features. For a complete list of all the proof-of-concept features and original design please refer to *Handheld Spectrum Analyzer Functional Specifications* [1] and *Handheld Spectrum Analyzer Design Specifications* [2] respectively.

3.1 Input and Conversion Units

The input channels and amplification implementations have not deviated from the proposed plan. In connecting the ADC to the main processing board, instead of using a PIC microcontroller and a serial interface, a direct approach was taken. The ADC is connected directly to the board through its expansion port as shown in Figure 2. Rather than having the MX1 as the master device, we chose to implement the ADC as the master of the SPI module in order to maintain a very precise timing for sampling and reduce the amount of processing required.

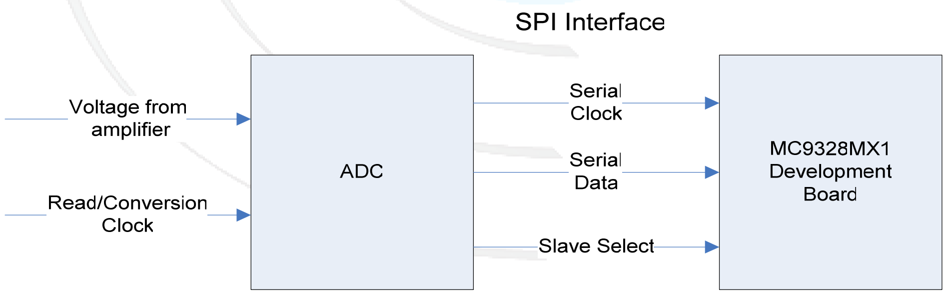

Figure 2: Overall Hardware Module Connections

3.2 Software Modules

All the user interface features that were listed under the "proof-of-concept" phase were implemented. The deviation of the three main software modules from those proposed states in the design specifications are detailed below.

3.2.1 Interfacing Module

In developing features, a major change was introduced when the ADC was connected directly to the development board. In order to initialize data transfer from ADC to the MX1 an SPI stream driver was developed. The implemented driver was then included as part of the device operating system. Creation of a custom built operating system also eliminated the use of a serial and data segmentation module, which were proposed in the design specifications [2], as an interface between PIC microcontroller and the main application. Shown in Figure 3, the display application accesses collected ADC data by sending a driver read request.

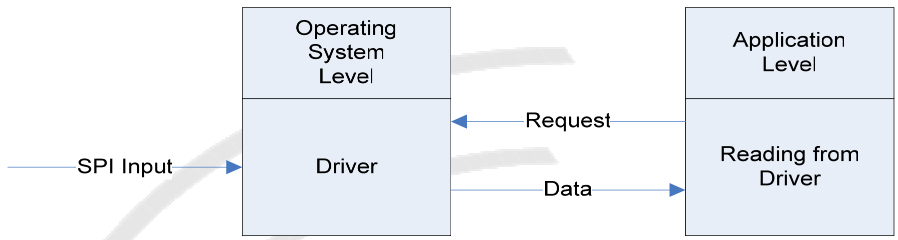

Figure 3: Overall Software Module Connections

3.2.2 Data Processing and Application Module

Comparing the method used for processing the incoming data, the implementation matches the prediction of the earlier stages of development. As mentioned in the design specifications a Fast Fourier Transform algorithm was employed. However, due to the MX1's lack of a floating point unit, an integer FFT was chosen over FFTW because it reduced the amount of time required for calculations. As proposed in the design specifications all the application coding was performed in Embedded Visual C++, but major changes were made in the application's algorithm due to the changes in the data processing unit.

4 Financial and Time Budgets

The following two sections compare the deviations between the money spent on acquiring needed components and the time spent developing the product to those predicted in our functional specifications.

4.1 Budget Deviations

Table 1 lists the original proposed budget for the SonoSense HSA prototype. The first phase is built on the MX1 development board supplied free of charge by Lucky One which has not been included in the budget below. The incurred costs for the final development of the proof-of-concept HSA totaled $96.76, which is approximately 27% of the proposed costs. The cost of the remaining two stages of development would be significantly higher, since the device has to be portable and a lot more stable.

The total income for this stage was $115, funded by the ESSEF, which would have covered 32% of the total proposed development costs. However, this income was more than adequate for the proof-of-concept prototype costs used for the ENSC 305/440 courses.

Table 1: Proposed and Actual Development Costs

Module	**Income (CDN$)**	**Proposed Costs (CDN$)**	**Actual Costs (CDN$)**
ESSEF Fund	$115		
Input Module (Microphone circuitry, Line-in Circuitry, Switch Circuitry)		$25	$30.22
ADC Module (Interfacing Circuitry, Analog to Digital Conversion Circuitry)		$55	$62.00
Software Development Cost		$40	$0
Processing Unit (ARM processor- $20 per unit onboard chip (RAM/ROM))		$50	$0
Display Unit (LCD Unit)		$120	$0
Memory Unit (SD Card)		$30	$0
Power Module (Battery Requirement)		$15	$0
Packaging		$20	$4.52
Total	**$115**	**$355**	**$96.76**

Table 2 confirms that the total cost of the first phase of development was less than the ESSEF income by $18.24. It should be noted that the total amount spent during development was greater than the final components utilized in the proof of concept device.

Table 3 shows that the total product cost was $25.70 (27% the total cost of development). The cost of development is greater due to numerous changes in hardware design, errors in purchasing due to incorrect packaging (SOIC instead of DIP), and purchase of excess and unused parts.

Table 2: Differences in Development Costs

Difference between Proposed and Actual Costs	$258.24
Actual under-Budget Amount	$18.24

Table 3: Actual Cost of Prototype Development*

Module	Component	Estimated Cost (CDN$)
Input Module		
	Switch	$1.86
	Line-in Jack	$1.13
	Microphone	$3.12
	3.5mm Male to Male Cable	$1.13
	Capacitors	$1.42
ADC Module		
	Oscillator	$6.20
	DIN-48 connector	$3.94
	Flip Flops	$1.78
	Capacitors	$0.60
Casing		
	Packaging	$4.52
	Total	**$25.70**

*Does not include costs of ADC samples from analog devices or loaned components such as the MX1 development board provided by Lucky One.

4.2 Timeline Deviations

The January 2007 proposed milestones and GANTT chart for the HSA development are shown in Figure 4 and Figure 5, respectively. Tasks include both the documentation and the technical development of the HSA which can be compared against the actual schedules as shown in Figures 6 and 7. The documentation schedules were all followed because of the "hard" deadlines required for ENSC305, except for the design specifications document when the three day delay was used.

Comparing the two GANTT charts, it can be observed that implementation of many of the technical tasks were delayed. A major portion of integration development occurred at the end of the semester.

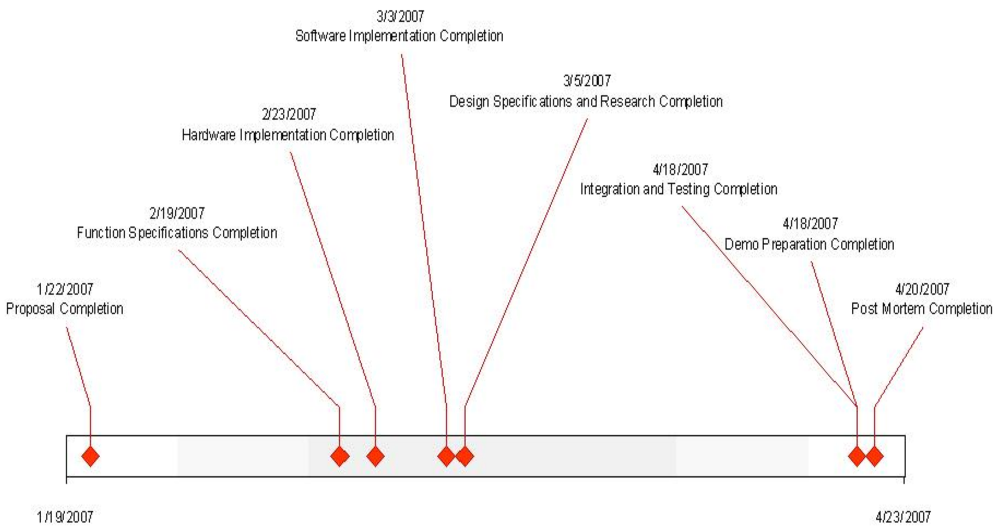

Figure 4: Project Schedule Proposed in January 2007

ID		Task Name	Duration
1		Proposal	6 days?
2		Initial Project Idea	9 days?
3		**Research**	**45 days?**
4		Preliminary Research	13 days?
5		Technical Research	37 days?
6		**Hardware Implementation**	**22 days?**
7		Input Device Design	18 days?
8		Analog to Digital Conversion	17 days?
9		Hardware Interface	22 days?
10		**Software Implementation**	**28 days?**
11		FFT Module	17 days?
12		Display Module	21 days?
13		Software Interface	22 days?
14		Storage Module	12 days?
15		Component Integration	40 days?
16		**Testing**	**61 days?**
17		Component Testing & Debugg	33 days?
18		Integration Testing and Debug	45 days?
19		**Specifications Documentation**	**31 days?**
20		Functional Specs	20 days?
21		Design Specs	23 days?
22		Project Documentation	72 days?
23		Preparation for Demo	5 days?
24		Post Mortem	4 days?

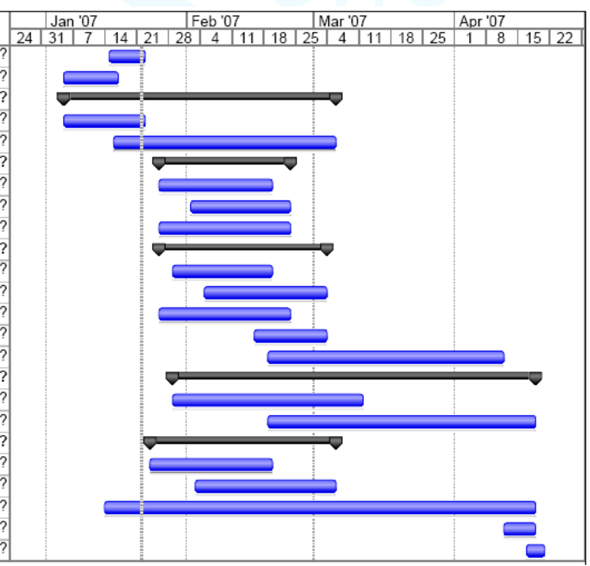

Figure 5: GANTT Chart Proposed in January 2007

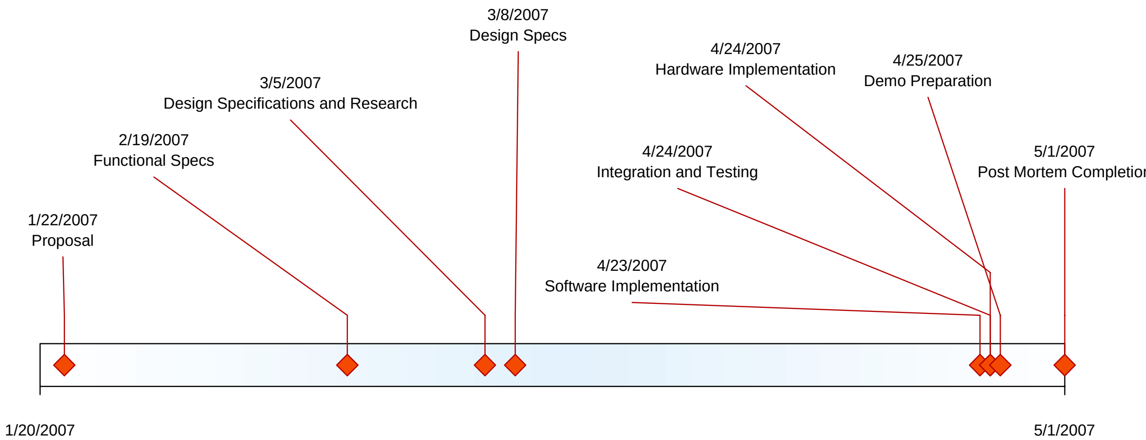

Figure 6: Actual Milestone Completion Timeline

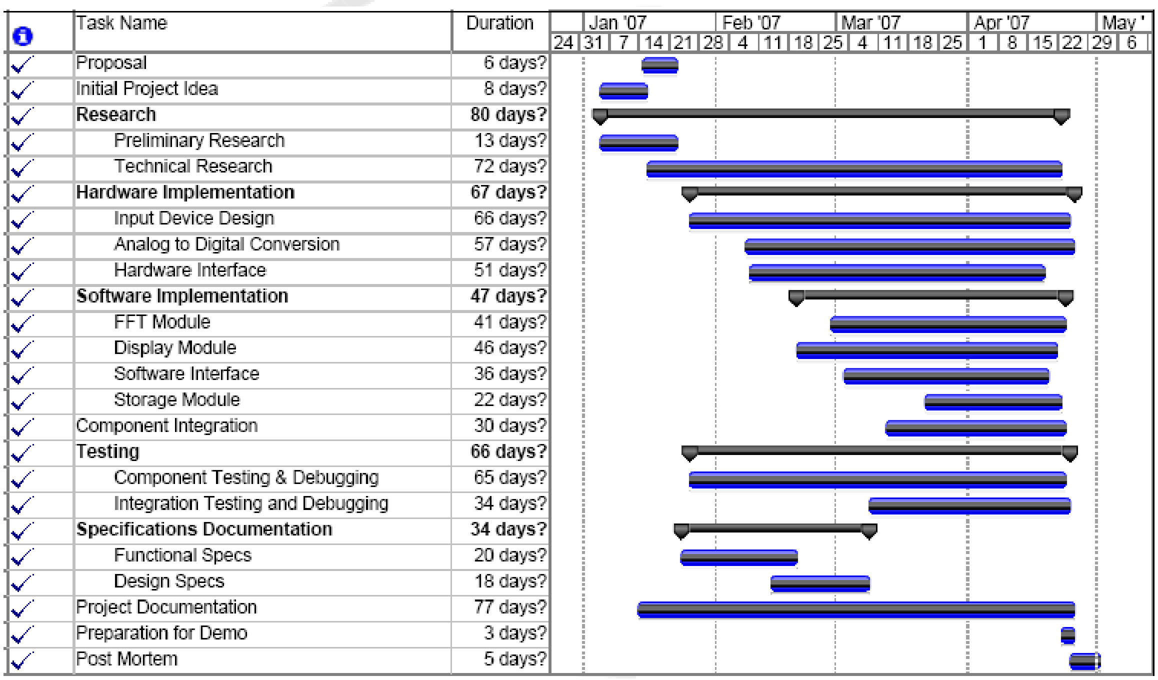

Figure 7: GANTT Chart of Task Completion

Implementation delays were originated due to both internal factors and external factors. Among the few internal factors was the incompleteness of research and unpredictability of possible complications during development which were neglected when forming the initial timeline. For instance, when creating the initial proposal, the timeline had allotted some time for interfacing the hardware components and software components, but it was still unclear as to how those two components would be connected. That area was identified as a critical path, and through many different design changes (using a PIC for SPI, writing inline assembly in the application), the best solution eventually emerged. This solution consisted of writing a driver, but the development tools that were required took longer than expected to acquire, and the development of that area took much longer than expected because each change to the driver required a 30 minute rebuild of the operating system and a 45 minute flashing of the revised operating system to the development board via the serial communications.

Other internal factors that hindered the development of the HSA include the long learning curve required to become familiar with the integrated development environments (IDEs) such as Platform builder (for driver development) and Embedded Visual C++ (for the application development). Although the development team had all previously taken software design courses, this project was much harder because of the lack of experience with embedded development design. In addition, the HSA design was started with minimal guidance and required many code optimizations to obtain maximum performance from the current hardware in order to perform calculations in "real-time". Lastly, many of the tasks were performed sequentially instead of in parallel because it was found that having another person to discuss and go over concepts resulted in a more effective design. However, if tasks were divided up in a more parallel process, it would have made better use of the time available.

The external factors that caused a slow-down in development, included misleading documentation about the development board, leading the team to believe that the provided schematic was correct and the required ADC was already present. Also, there were significant delays when contacting the Freescale technical support, manufacturer of the development board, for obtaining the Board Support Package (BSP) for developing Windows CE drivers because the Motorola MX1 development board has already been discontinued. In addition, since the board is outdated, obtaining references for the driver development and other sample programs were limited. The SonoSense team also encountered numerous Windows CE bugs that were present that resulted in inconsistent results and transfer problems, and understood the reasons why a newer version of the embedded Windows was created.

Lastly, it is important to note that although the timeline deviated significantly from the proposed version, the team was still able to complete the proof-of-concept prototype on schedule mainly due to the modular design approach that was taken. After each component was completed, they would be individually merged into other existing integrated portions, which required fewer stages of final testing and debugging. This approach allowed identification of problems in specific components and facilitated a more efficient problem solving approach.

5 Group Dynamics Issues

Throughout the course of the project, various group dynamics issues arose due to various external factors. Because of the extensive work requirement of the project, a higher level of communication and understanding was needed in terms of work distribution and group interaction. The main reasons for the group dynamic issues arose due to scheduling conflicts and miscommunication.

A major issue revolved around the ability to schedule group meetings in which all members were present. This was largely due the extreme variation in both class and work scheduling of all group members. From this scheduling issue, communication became a problem as a differentiation of project knowledge occurred as time progressed. Most work for the project was done as a group; however taking this approach, though helpful in brainstorming and solving problems also led to arguments and misunderstandings among the members.

Using the group resolution methods of lecturer Steve Whitmore, group issues were reviewed and resolved. SonoSense team members adapted their work approach to effectively increase the communication among members. Since then members have maintained a stronger level of communication. Also as the semester came to its end, more time was available to resolve the scheduling issues. In the last month of project completion, the group members spent numerous days and nights together focusing on the most important goal – to finish the project before the deadline. The time spend together gave everyone a better understanding of each other's habits. Finally, the group reviewed the previous issues and worked more efficiently as a team to accomplish the goal.

6 Personal and Technical Experiences

Sanaz Jahanbakhsh – Chief Executive Officer

Throughout the past thirteen weeks I have learned very valuable lessons in both the technical and interpersonal sides of managing a project. The most important lesson on the technical side was that one can learn encyclopedically by trying rather than reading or contemplating about trying. Although "learning by trying" is a more time consuming process, it is the only full proof method in eliminating any uncertainties or doubts that one might have about a particular algorithm or process.

Since I was working on a wide range of tasks, from hardware interfacing to application development and then integration of various components, I had the opportunity to upgrade and improve my knowledge of programming as well as the debugging. In addition to coding the GUI in the EVC++ environment, I also learned about Windows CE's message handling process. While helping the other members in driver development and writing the FFT algorithm, I experienced first hand the challenges that all engineers face when limited by certain hardware constraints and how to over come them by "thinking outside the box".

In terms of people management skills, three main issues captured my attention: motivation, time management and communication skills. After going through the course of this semester, I firmly believe that great leaders are the ones that can motivate their colleagues to perform at the best of their abilities. Time management is also another vital factor that can lead to the success of failure of a project. However, from my experience one can only manage others in a timely manner if she or he has enough experience and vision to know what the next steps are.

Another important lesson was finding alternative ways when communicating ideas. Communicating verbally is one of the basic methods of sharing and introducing ideas. However, due to the diverse nature of the engineering profession not everyone has the same level of proficiency in English. Thus alternative methods such as drawing diagrams or flowcharts came in handy when team members had trouble understanding each others suggestions and viewpoints.

Patience, tolerance and respect for others in a team environment are other important factors that can greatly improve the effectiveness of team meetings. By tolerance, I mean learning not to take criticisms personally, always keeping the project goals in mind and respecting personal boundaries when criticizing others.

No sentence can summarize my experience as the team leader of SonoSense Technologies Inc. better than this verse from Robert Frost's The Road Not Taken poem: "Two roads diverged in a wood, and I took the one less traveled by, and that has made all the difference."

Johnny Pak - Chief Operational Officer

The main tasks assigned to me throughout the project ranged greatly, but a major focus of my work came from building and working with the hardware needed for development. Developing the required microphone input, understanding and setting the analog-to-digital converter as well as working with the hardware concepts of the MX1 were my primary contributions. I also aided in the development in the driver by obtaining the files needed to make the driver as well as coding the driver. Though I did not work on the FFT and graphical display as much, I did have an understanding of how they worked as well in order to make sense of the integration of our product.

Throughout the four months of the ENSC 440of this project I confirmed many things related to group projects as well as learned some important aspects about thinking of an idea, following through with it, and working in a group to get the task done. After taking an organizational behaviour course I had foreseen that there would have been various issues relating to group dynamics as well a project decisions even before the courses started. Through this experience however, I have gained a much greater understanding of the way group situations work and project design and implementation.

An important aspect I learned from this course is the unrealism in the design stages for a product and the difficulty in proper scheduling. For any group who has not thought about a project idea before hand and even those who think they have planned their project ahead of time, there are numerous factors that will change and influence the outcomes and effects of the project. Designing a suitable project alone takes half of the process, thus limits the time to design and develop unless the group is supervised by a professor, an outside company, or another group.

Scheduling also requires a lot of planning and consideration. Many students have other classes and other commitment levels towards this course and making sure everyone puts enough effort into the situation is needed in order to maintain a feel of balance and equity in both work and rewards. Without a good understanding of group dynamics and the interrelationships of group members, group dynamics can severely hinder progress and cause rifts in the process of the project.

Lastly, I learned a great deal about the application of the many courses I have taken throughout engineering course experiences. Because the project we chose was able to integrate many of the courses that we took throughout our engineering degrees, it gave me an excellent understanding of the implementation of the knowledge I have gained.

Naureen Sikder - Head of Research and Development

The main task assigned to me was to deliver a working and efficient Fast Fourier Transform program. The program was tested by comparing its output for the same inputs from other mathematical software, namely MATLAB. Besides the precision of result, time efficiency was also an important factor since we wanted to make a real-time device. From working on this part of the project, I learned in detail about various FFT algorithms, how they enhance the computation efficiency, which algorithm to choose based on the input and other theoretical features of FFT. I have also gained first-hand in detailed experience on optimized programming for embedded systems using C and C++.

While working on the project, I have formed some habits like using paper instead of thinking in my head. I was not used to keeping a lab journal while working on any engineering projects. As the project supervisor Lucky One emphasized on maintaining the lab journal properly, I started to write down my ideas and current state of my work. Since then I found that my thoughts worked in a more organized way, it was easier to explain them to others and it also worked as reminder for things that need to be done. Since in a group project, every idea is examined from various viewpoints by various people, putting them on a paper helps to clarify the main aspects, and results obtained from various examinations.

Among my other observations, I found that communication skills like listening, criticizing carefully, and avoiding laughing at others back play an important role in maintaining the healthy working environment in a group. If we do not listen to all of the members, we miss out some ideas or contributions which might be more efficient or time-saver for the project. It also ensures that everyone feels that his/her opinion is important to the group, and increases their interest in the project. Sometimes we tend to do something in a particular way just because we think that's a better approach, but it is important to learn what others think about that too. While criticizing, we have to be careful about not acting in a way expressing lack of respect for the others. Laughing at someone's back makes the present people the feeling that these members might laugh at his/her back too.

Maintaining record of time spent in project related discussion out of the total time spent in the group meetings can help to keep our offline discussions in control. Talking about other issues unrelated to the project or socializing takes up a lot of precious working time, distract the mind and also interrupt the flow of work. It is important to maintain a healthy balance between forming the social bond among group mates and working towards the project.

This project-based course revealed a new perspective about working in group projects. Besides emphasizing on essential people skills, the project also accentuated the use of all engineering knowledge from courses taken so far in the engineering science studies. Successfully building the proof-of-concept device gives me the faith and confidence that we can make real life devices based on what we have learned in school.

Kenneth Wong - Chief Financial Officer

Over the past semester, I have been working on many areas of the HSA device ranging from hardware design to software development. This project made full use of the courses I have taken throughout the past four years, and has provided a practical stepping stone for creating a product to market. Although writing the documentation for this course was very time-consuming, it further improved our business skills (proposal stage), and also provided us with preparation in writing actual product specifications which would be useful when working in industry.

Throughout the past four months, we have encountered some group dynamic problems, which was not unexpected due to our differing schedules and work habits. However, once we were able to identify and resolve these through better communication, we were able to achieve better results and worked more effectively towards the same goal. Considering the amount of work that was required in the short time we had available, I would say that our team has performed well and throughout this experience we have gained a stronger bond that will last into the future.

In terms of the skills learned, I've increased my understanding of driver development, embedded application development and windows message handling. The limited amount of resources available on an embedded device required more low-level optimization of code, and knowing the exact features of the hardware helped significantly. Having worked on a build and integration team during co-op, this project provided a good experience of the other side of development.

When designing an actual device from scratch, I have found that reading the documentation fully for even sections that may not be used can help a lot in setting up the device correctly which saves time in problem solving. Gaining an understanding of the big picture of the development can also be very valuable because it allows each person to truly understand how and why each component should interact in specific ways.

If I was able to go back in time to change one aspect of our project, I would develop a better researched proposal, which would allow us to create and follow a more realistic timeline. I would have to say that this project course has definitely been one of the most useful in my undergraduate years. ENSC 440 has required a lot of time but the experience we gained through developing this device and documenting it is extremely valuable for the working world we will be entering.

7 Future Plans

To provide the reader with a better understanding of the device features that will be implemented in the upcoming phases of development, improvements to the overall system as well as hardware and software components are discussed.

7.1 Overall System

In order to make the system truly portable, a compact packaging needs to be designed that would contain the device's main components: 3.5 mm audio input jack, microphone, amplifier circuitry, the processor (MX1) as well as the LCD unit. In addition, to eliminate the occasional application and file transfer glitches, Windows Mobile 6.0 should replace the device's current Operating system Windows CE 4.2 .NET.

7.2 Hardware Plans

The following lists the various expected features and upgrades for the hardware components of the SonoSense HSA.

- Higher Precision/ Increased Sampling ADC
- Processor Upgrade
- Bluetooth Implementation

For a possible increase in accuracy and precision from our current 16-bit ADC, it is possible to utilize either an ADC that has a higher bit precision or our existing ADC at a higher data sampling rate. By using a more powerful ADC it is possible to make the HSA a more accurate device.

Because our proof-of-concept device used an MX1 development board, the processor is much older than current chip technologies. By upgrading our processor we may increase not only sampling rate without issues, but also improve calculation time, utilize different FFT algorithms for even more efficiency, and increase frame rate and refresh rate.

In order to improve data transfer and keep up with current technologies, Bluetooth hardware can be implemented. This will allow for real-time transmission of frequency spectrum data as well as using the most up-to-date method for data transfer.

7.3 Software

In order to make HSA more user friendly the following list of features need to be added and/or improved:

- User Interface Improvements
- Display Algorithm Optimization
- Compatible Driver Development

One of the most influential factors in a successful product is its user interface. Although during the development of the application used for the HSA, standard Windows models were used, the user's experience can be further improved by adding more features. These features include but are not limited to recording sound input in a WAV format and storing saved files onto a removable memory unit.

Currently, a delay exists between change in the input and the results displayed on the LCD unit. To further improve the functionality of the device the delay can be minimized by implementing a more efficient refresh algorithm for the display.

To market the device to a broader market, e.g. licensing the application to existing portable devices such as cellular phones and PDAs, the driver should be modified to support other operating systems such as Symbian and Mac. Alternatively, the Frequency Spectrum Application should be platform independent and able to load onto alternative portable devices such as various Smartphones, and PDAs.

8 Reflections and Improvements

Although all the original goals set out were achieved, looking back at the process, a few steps would have taken differently some of which are listed below.

8.1 Reading Documentations Thoroughly

It is important to understand the functionality of a device before using it. We often started working with a hardware or software component without reviewing the entire associated documentation thoroughly, reading only the related sections, which often resulted in missing important details. Reading the documentation beforehand would have saved us a lot of valuable time.

8.2 Ordering the "Right" Part Type

Special attention should be paid to details and all the attributes of a component should be carefully studied before placing an order. Initially we did not know about the packaging of chips and ordered wrong parts that could not be mounted on a breadboard, which was a wasted of both time and money.

8.3 Allocating More Integration Time

Because of the delays in completing various smaller components, the project integration did not start until the last week of project completion. The process of integration was very time consuming and stressful since many tasks had to be performed in a few hours.
Last minute implementation of circuits soldering and final integration put us at risk of not completing all of the components on time. Excessive stress and last minute panic situations could have been avoided, had we completed smaller sections earlier and started the overall integration sooner.

8.4 Planning a Test Strategy

More time could have been allocated to testing all of the individual components rigorously before starting the integrating process. Due to the inadequacy in testing separate components, we faced a number of issues during integration, which could have been avoided. Instead of trying to test each component as one entity, testing should have been conducted in a step-by-step manner thus ensuring that all the basic modules are properly functioning.

9 Conclusion

Throughout the past four months, the SonoSense team has learned many lessons relating to both the business and technical side of the developing a product. It is now understood why so many engineering entrepreneurs can market a bulletproof business plan, but have difficulty when it comes to executing the technical development. In the time spent developing the proof-of-concept prototype, the SonoSense Team has gained a better understanding of the skills required in embedded development, application of theoretical algorithms, integration of multiple hardware/software components and rigorous testing procedures. The HSA development made full use of the Engineering, Mathematics, Computing, and Business knowledge acquired through previous courses. Although there may have been problems in the original design of the HSA, and some group dynamics issues, the competent and creative team of SonoSense was able to resolve them and deliver the proof-of-concept prototype on schedule. The ENSC 305/440 project has also created a stronger bond between all members that will last into the future.

10 References

[1] SonoSense Technologies Inc. 2007. *Functional Specifications for a Handheld Spectrum Analyzer* Burnaby, British Columbia.

[2] SonoSense Technologies Inc. 2007. *Design Specifications for a Handheld Spectrum Analyzer* Burnaby, British Columbia.