Pivit Technologies Inc

School of Engineering Science ♦ Burnaby, BC ♦ V5A 1S6 Project
malajube@googlegroups.com

April 18th, 2007

Mr. Lakshman One
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

Re: ENSC440 Post Mortem for a Tactile Hearing Aid

Dear Mr. One:

Hearing loss is a growing concern for many Canadians. Hearing aids are ineffective for individuals with severe inner ear damage and methods utilizing sight are limited by the necessity to observe everything that one wishes to hear. At Pivit Technologies Inc., we aim to deliver acoustic information using the sense of touch to assist the hearing impaired with daily activities requiring an awareness of noise. We believe the ability to interact and "feel" the sounds of their environment will result in an improved standard of living for the hearing impaired.

Our goal was to design and build a PC controlled tactile hearing pad capable of stimulating the skin through vibrations to determine the viability of delivering acoustic information through the sense of touch. Having completed the prototyping phase of the design cycle, we discuss the current state of the device and detail the modifications to the design specifications that were necessary to produce our proof-of-concept device in the attached document, *Post Mortem for a Tactile Hearing Aid*.

Pivit Technologies Inc. is comprised of four dedicated, hard-working individuals: Ryan Dickie, David Dickin, Mehran Eghtesad, and Merle Kinkade. Please feel free to send any questions, comments, or concerns via email to malajube@googlegroups.com.

Sincerely,

David Dickin

David Dickin
CEO Pivit Technologies Inc.

Enclosure: *Post Mortem for a Tactile Hearing Aid*

Pivit Technologies Inc

Post Mortem for a

Tactile Hearing Aid

Project Team: *Ryan Dickie*
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Submitted to: Lakshman One – ENSC 440
Steve Whitmore – ENSC 305
School of Engineering Science
Simon Fraser University

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Acroynms

DLL	Dynamic Link Library
FFT	Fast Fourier Transform
IBM	International Business Machines
IC	Integrated Circuit
PC	Personal Computer
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
SPP	Standard Parallel Port
THA	Tactile Hearing Aid
TTL	Transistor-Transistor Logic
USB	Universal Serial Bus
I/O	Input/Output
DIP	Dual Inline Package
IDE	Integrated Development Environment
DC	Direct Current
API	Application Program Interface

1 Introduction

For the last four months, we have worked towards our primary goal of designing and developing a prototype capable of mapping audio input frequency information to an array of vibrotactile transducers. We conducted various experiments with the intent of determining whether basic sounds can be interpreted using this prototype. In the sections to follow, we will discuss the state of the current design and indicate any modifications to the details of our design specification that were necessary to produce our proof-of-concept device. We will also discuss any future considerations necessary to determine the practical applications of our device. Lastly, we will compare the projected budget with our current budget and any scheduling issues we encountered along the way.

2 Current State of the Device

2.1 System Hardware

2.1.1 I/O Control Board

The I/O Control Board was fabricated as a two sided PCB with top and bottom copper layers. A picture of the board is shown in Figure 2-1.

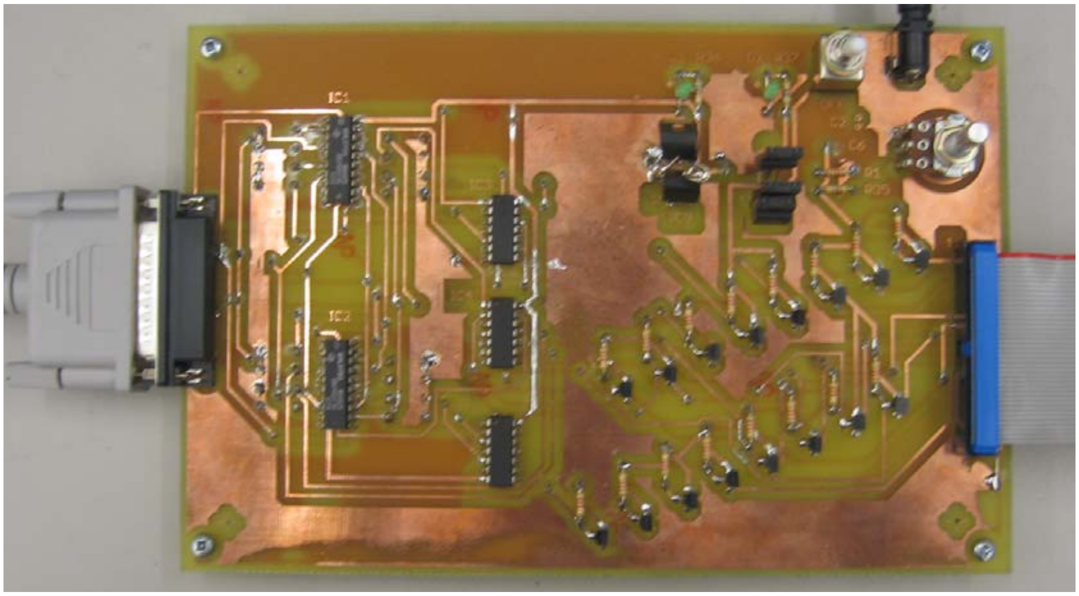

Figure 2-1: I/O Control Board top view

Signals generated by the software are connected to the board via the parallel port connector shown to the left of Figure 2-1. These signals are then routed to the two leftmost chips, which are 8-bit latches. The outputs of these latches are then directed to the three DIP package chips in the center of the board which are hex open-collector buffers. The outputs are then routed to the array of 16 discrete transistors, whose outputs go to the vibrators through the 40 pin IDE cable on the right side of the board. At the top right corner of the board is the power section and user interface. The DC jack is located in the top right corner and the on/off switch is just to its left. The voltage regulators and associated circuitry is just down and to the left of the switch. Finally, the potentiomer controlling the intensity of the vibrations is to the right of these regulators.

The I/O Control Board draws about 350mA while idling with no vibrators turned on. When all vibrators are active at maximum intensity the board draws 1200mA or 1.2A, thus turning on 1 vibrator results in about 53mA of extra current consumption.

This board deviates from the schematic detailed in the design specification in a number of ways. A summary of these modifications is provided in Table 2-1.

Table 2-1: Board modifications

Relevant Component (s)	Modification	Consequences
Pull Down Resistors between Latches and Buffers	Removed. They were drawing too much current from the 5V regulator	If the board is turned on without the software program running all the vibrators turn on because the parallel port floats.
Pull Up Resistors between Transistors base and Regualtor	Changed from 100Ω to 1.2kΩ. Buffers couldn't pull transistor input low to turn off vibrators.	Maximum intensity of vibrators reduced. Significant power savings
Extra Voltage Regulators	Added 1 extra 5V regulator and 2 extra variable regulators.	Regulators were shutting off due to overheating. Extra regulators split the work. A heat sink would also have worked
Poor Copper Traces	Some traces didn't come out well when board was developed. Extra wiring along some traces.	Makes the board work.
Capacitors	Removed	Several capacitors in the power section were suspected of causing problems. Later we found out they probably weren't a problem but they were never added back in.

2.1.2 VibraPad

2.1.2.1 Belt Design

The belt component of the VibraPad functions to secure an array of 16 vibrators in a finalized pattern around the waist of the user. It is designed to ensure that all vibrators maintain proper skin-to-surface contact while the device is in use. The schematic for the VibraPad is illustrated in Figure 2-2 and conforms to the details outlined in our design specification.

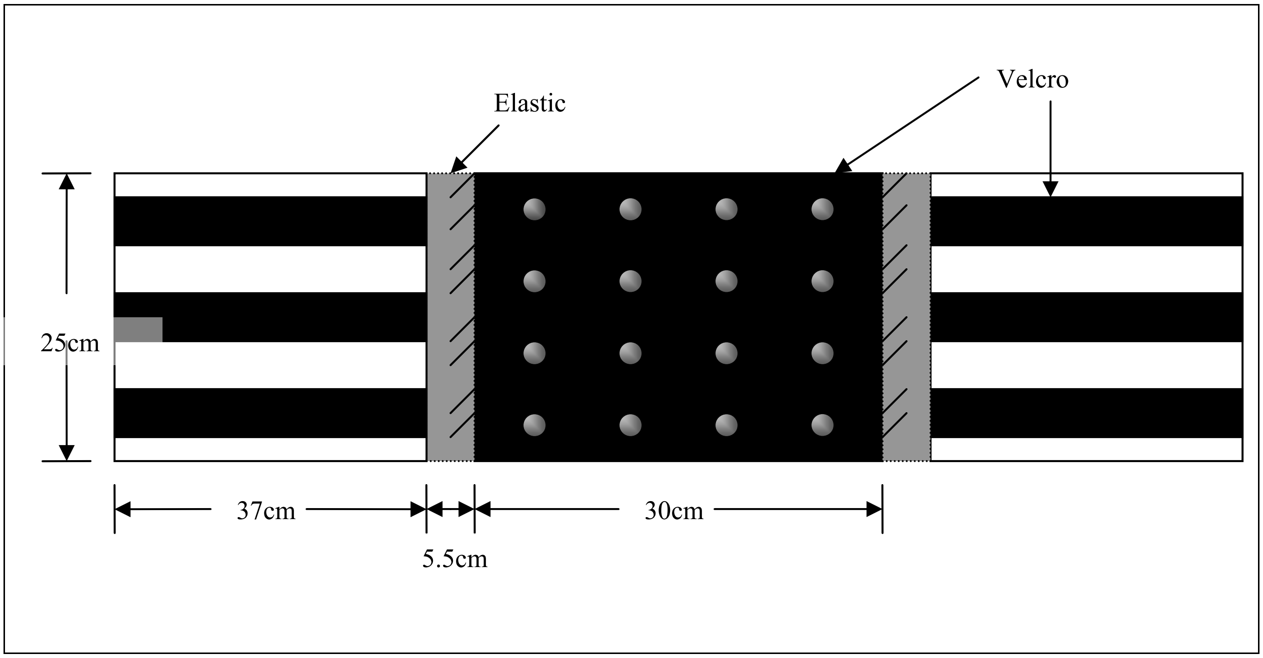

Figure 2-2: VibraPad Belt Design

2.1.2.2 Vibrator Array Layout

The array pattern implemented for initial testing purposes is shown in Figure 2-3 and is as detailed in our design specification.

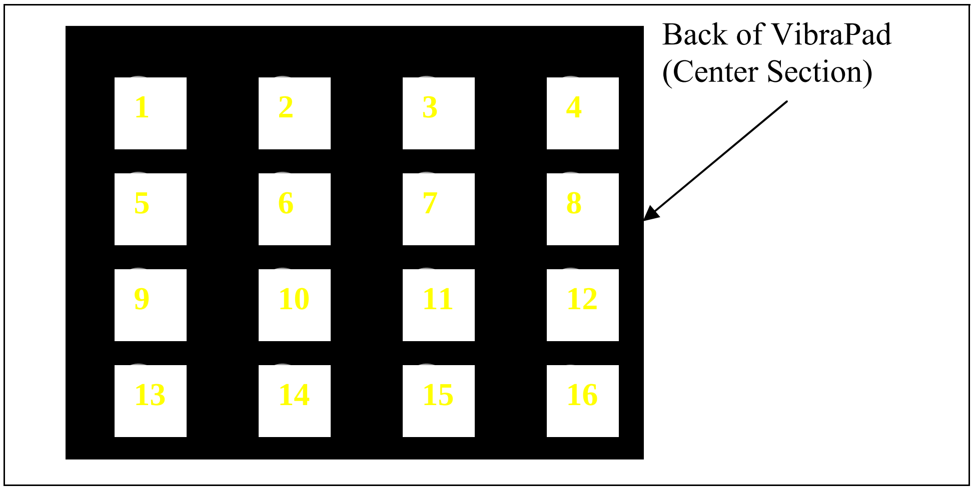

Figure 2-3: Uniform Vibrator Array

After several tests with various layouts, we decided upon the finalized array shown in Figure 2-4.

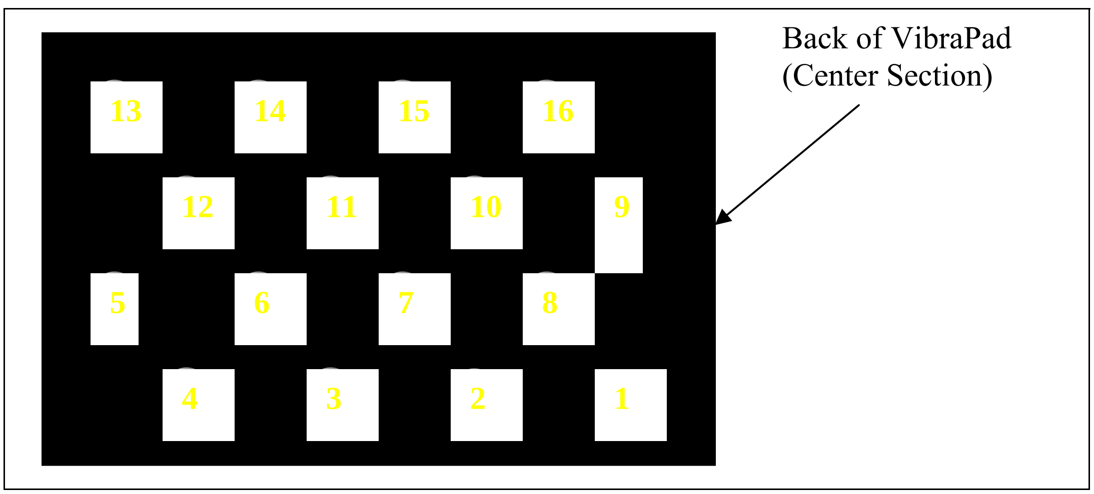

Figure 2-4: Offset Vibrator Array with Snaking and Natural Mapping

The layout in Figure 2-4 incorporates an offset of 3.5cm for the second and fourth rows of the array. It accommodates any desensitization that may occur with certain individuals after repeated or continuous stimulation of a given area of skin. We implemented a "snaking" pattern that places vibrators (namely vibrators 4 and 5, and 12 and 13 in Figure 2-3) mapped with adjacent frequencies close together on their respective rows so that the user can more intuitively associate them with similar frequencies. Additionally, the layout includes a natural mapping whereby the highest frequencies are associated with the vibrators on the top row and the lowest frequencies are mapped to the vibrators on the bottom row.

According to our design specification, to implement the offset pattern required the removal of two vibrators; in particular, those associated with the highest and lowest frequency bands. From our test results we found that removal of any vibrators would significantly impact our mapping and reduce the success of our experiments. By compressing the overall design and minimizing the borders, we were able to incorporate all 16 vibrators into the design without a loss of the original concept.

2.1.2.3 Wiring Pattern

The wiring pattern detailed in our design specification indicated that after testing, the wires associated with each vibrator would be passed through the front of the VibraPad at intervals designated by the finalized array. Having spent countless hours wiring the vibrators for testing, we realized it would be unrealistic to disconnect all connections so as to pass the wires through the pad; only to spend hours reconnecting them in the hopes that everything would function properly. Our solution was to arrange all wiring for the vibrators between rows and securing them in place with Velcro. The layout and wires were then covered with the overlay as outlined in our design specification.

2.2 System Software

2.2.1 GUI

The graphical user interface includes the features specified in the design and functional specifications documents. It is completely capable of displaying the real-time FFT spectrum, displaying an oscilloscope, dynamically changing between the two transforms, pausing microphone and transform, clearing the buffers, loading a wave file, showing the buzzer status, and making a recording to a wave file. A modification to the design specification includes an additional feature that allows the user to view the bins of the selected transform in place of the FFT figure. This added element was useful in debugging and designing the transforms.

The GUI met the design goals and served its purpose for our experimentation and testing phase. It was modified during this initial testing phase based on user and operator feedback and in the second phase of experimentations there no complaints about the software. There are also no known bugs or leaks in the user interface.

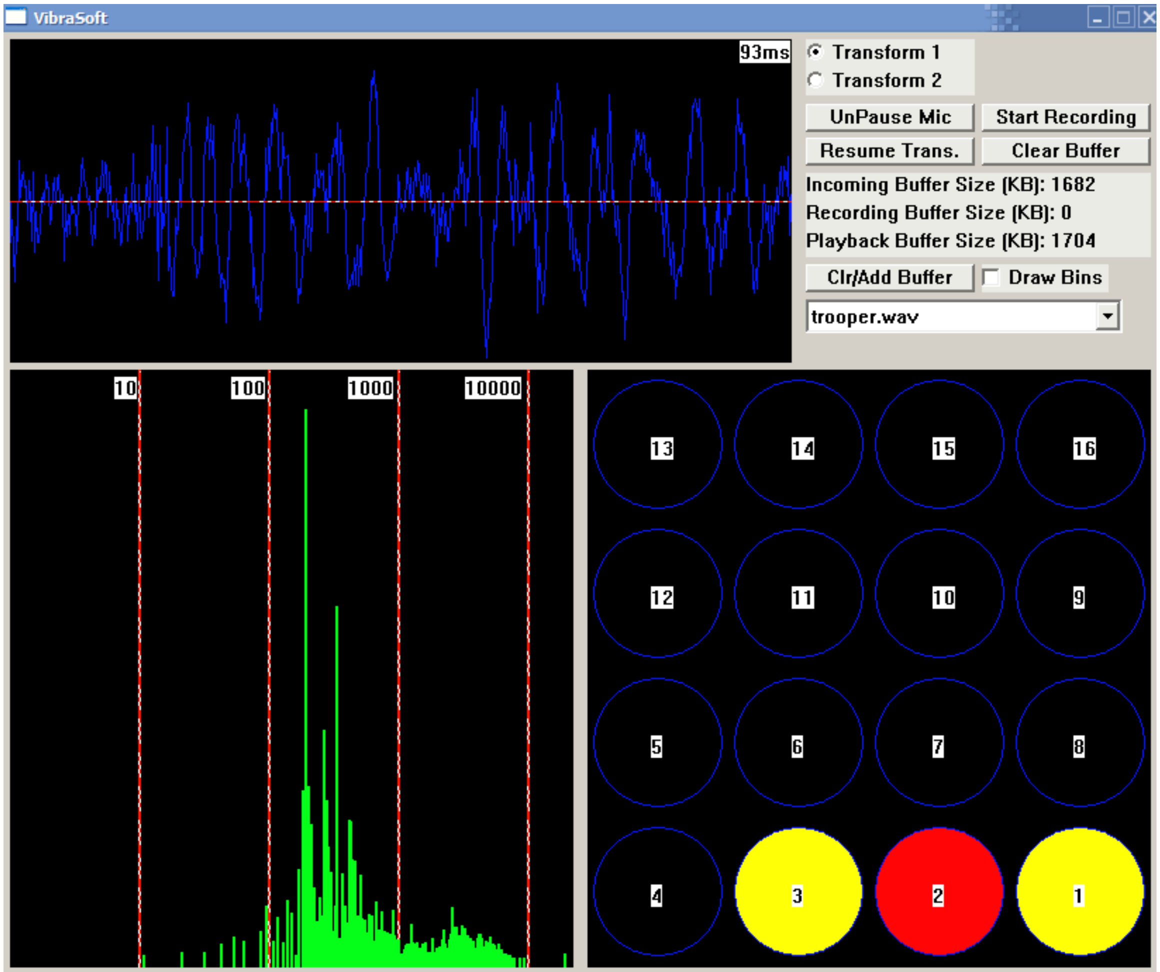

Figure 2-5: GUI Interface

2.2.2 Audio Input/Output

The input audio stream was carefully designed to take audio samples at 44100Hz using 16-bit integer for 1 channel. The system is flexible enough to incorporate 2 channel stereo with minor changes. It will pull data from the principle audio input device set by windows which includes the microphone, line input, and radio/tv-input. The buffering system was carefully designed not to miss any audio frames while maintaining a low-latency retrieval frequency.

The audio output stream outputs audio in the same format as the input system. It is designed as to match the audio which has been processed and sent to the buzzers.

Neither the input nor output systems have shown signs of overflowing, underflowing, or glitching during extensive testing across several makes and models of computers including older laptops.

2.2.3 Critical Band Transform

After several tests, we implemented the current critical band frequency mapping as shown in Table 2-2 to the vibrator array.

Original Frequency Range (Hz)	Current Frequency Range (Hz)	Associated Vibrator
0-200	0-200	1
201-400	201-310	2
401-630	311-490	3
631-770	491-630	4
771-920	631-770	5
921-1080	771-920	6
1081-1270	921-1270	7
1271-1480	1271-1480	8
1481-1720	1481-1720	9
1721-2000	1721-2000	10
2001-2320	2001-2320	11
2321-2700	2321-2700	12
2701-3150	2701-3700	13
3151-3700	3701-5300	14
3701-4400	5301-6400	15
4401-15500	6401 and above	16

Table 2-2: Critical Band-Vibrator Mapping

Because much of the noise encountered on a daily basis falls within the 500Hz – 4kHz range, the current mapping is designed to closely correlate with the frequency bands designated by the Bark scale. In addition, based on our experimental observations, we modified our original mapping to allow for greater resolution at the low and high ends of the frequency spectrum.

2.2.4 Parallel Port

The parallel port I/O module incorporates a third party driver to access the various data and control pins of the parallel port. Simple read and write functions provided by this driver are used to update the parallel port values based on data from the transform software.

Pulse Width Modulation (PWM) is employed to control the intensity of the buzzers. In the original design, the duty cycles for the pulse width modulated signals were set at 30%, 70%, and 100% corresponding to the buzzers being at low, medium, and high intensities, respectively. After some testing and during the redesign cycle, it was determined that duty cycles below 50% are very difficult to detect in terms of the buzzer's vibration intensity. The duty cycles were changed to 50%, 90%, and 100% for the different intensity levels. These values were chosen based on testing and observations to determine the optimum values at which the variation between the different intensity levels was noticeable.

3 Design Challenges

3.1 Overall System and Integration

3.1.1 System Hardware

The major challenges encountered from a hardware perspective were the vibrator driving circuit and laying out the vibrators on the VibraPad.

The original vibrator driving circuit is shown in Figure 3-1. Problems with power consumption arose because the resistor was only 100 Ω. When the vibrator is turned off, the buffer output signal BUF_D# tries to pull the transistor base low. Unfortunately, VDD is about 10 V resulting in a theoretical current of 100mA. This is too much current for the buffer to sink, sine their maximum is 24mA. So the buffers never pulled the base down hard enough to turn the vibrators off, and they wasted a lot of power.

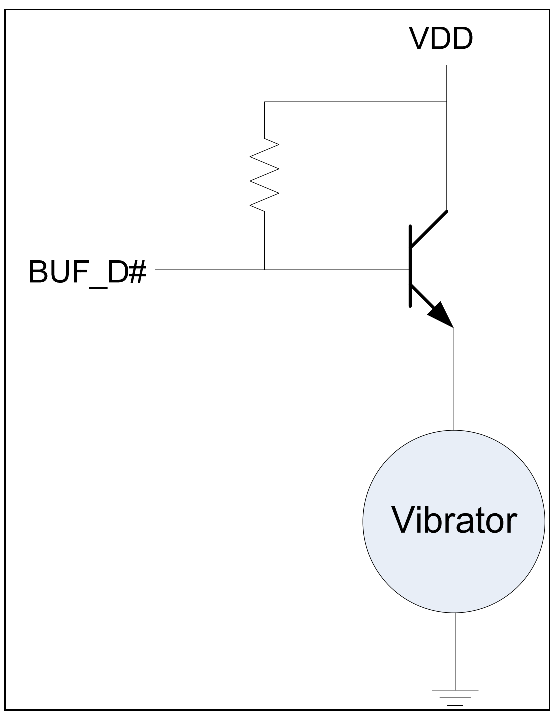

Figure 3-1: Original Vibrator Drive Circuit

Our solution was to replace the 100Ω resistors with 1.2 k Ω resistors. The buffers could now pull down the base, and the power consumption through the resistors was reduced by an order of magnitude. This whole problem could have been avoided if we hadn't used open-collector buffers, which need a pull-up resistor to switch to a high state. This was an oversight, as the open-collector outputs were necessary for an earlier version of the drive circuit and this choice wasn't reconsidered after the design changed. If a normal buffer had been used, no resistor would need to connect to the base, and this whole issue would not have occurred.

The best layout of the vibrators on the VibraPad wasn't a typical hardware issue, and that's what made it so difficult. How do you decide the best way to lay out the vibrators? Trial and error was the only way we could precede. We started with a very simple pattern and as our experience grew we thought of better ways to do the layout. We anticipated this need and used Velcro for positioning the vibrators, allowing for easy adjustability.

3.1.2 System Software

The principle challenges in software design were dealing with buffering and latency of the data retrieval, processing, and output. There were several factors influencing performance including the number and size of input buffers, polling rates, number and size of output buffers, and the FFT frame size. It took much balancing to ensure that scheduling and callbacks were invoked at just the correct rate so as to never skip, lag, overflow, underflow, or present considerable delay to the user. Since each of these factors have independent effects, a stream buffer system for the input was implemented and another for the output was required to isolate the design and ensure the system was more modular.

The stream class was required to be thread-safe, high performance, and with low overhead. There were two streams, one for input and one for output. Input was fetched from the audio device at an independent rate and then sent to the input stream buffer. The main windows API loop would then continuously poll to see if the stream buffer was long enough to pull the required number of samples for the FFT. This FFT sample size of N = 4096 was chosen independently of all other factors to produce the best frequency and time latency results. The input rate was chosen to be in small chunks but triple buffered to ensure that data traveled from the audio device to the stream buffer for processing as soon as possible. Triple buffers on the input device were required because occasionally the buffers would overflow with double buffering even with longer sample lengths due to windows scheduling and audio driver details.

The transformed audio would then be appended to the audio output stream. Several buffers and larger buffers were required here to satisfy the audio drivers to prevent buffer underflows. The timing scheme had to match the audio currently being outputted to the buzzers and the GUI. Anything but the smallest differences in timing were easily discernable and the balance came from extensive trial and error. The audio output remained also highly prone to underflow since it relied upon the continuous transforming of data. In such a case, a stream of 0's were sent out to the audio device.

In addition, pausing transform, gui updating, pausing input, loading wave files, recording, and clearing presented additional difficulties in synchronizing the streams. To resolve these issues, scoped mutex locks were added along with underflow and overflow checks, and state logic was added to the appropriate modules.

In order to maintain accuracy in the playback rate a time elapsed timer was added to ensure that samples were not to be pulsed or transformed from the stream if the total number of samples pulled was greater than the sample rate multiplied by the total time elapsed. This timer was reset under certain conditions including each time the stream was paused and restarted because the time elapsed depends on the time_of_day function the operating system provides.

Windows GDI was used to draw the scope and the FFT and bins widgets. On many systems, these are hardware accelerated functions for speed though software sufficed on the laptops tested. In order to prevent flickering and graphical glitching issues, the technique of double buffering was used. Rather than drawing directly to the screen buffer, an offscreen bitmap was generated. It would be cleared, drawn, and blit to the main screen every time the transform occurred. Windows also handles drawing using a "dirty rectangles" technique, so the entire surface on screen would have to be marked for update.

4 Experiments

There were many variables to consider when designing experiments to be conducted with our prototype. These include the type of frequency transform, the mapping to the vibrators, intensity levels of the vibrators, hearing ability of the test subject, test subject's age, and many others.

Thus far, we have managed to conduct two small scale experiments (4 subjects) and one larger scale experiment (23 subjects). The results of these experiments have been promising but further testing is necessary to determine what the limitations of this product are.

Experiment 1 was conducted using 10 short sound clips and allowed for an extended training time. One objective was to see if there was a significant advantage to using the critical band transform (transform 1) versus the uniform transform (transform 2). This experiment produced an average hit rage of 95% and 100% with an average training time of 20 minutes and 16 minutes when using the critical band transform and the uniform transform, respectively. Due to the small sample size, we cannot determine which transform produced better results.

Experiment 2 was conducted using 30 short sound clips and a limited training time. Again, this experiment was done with both transform 1 and transform 2. The results were an average hit rate of 55% and 53% with an average training time of 43 minutes and 35 minutes, respectively. The significantly reduced hit rates are as expected because we increased the number of sounds significantly. This result also implies that short-term memory plays a large factor in these experiments.

Experiment 3 was conducted using 10 sound clips with a limited training time of only 14 minutes. This experiment was done on a larger scale (23 individuals) most of whom did not have any previous exposure or knowledge about the device. A new transform was designed for this experiment (transform 3) which was a compromise between the critical band transform and the uniform transform and is listed in Table 2-2. The lower frequency divisions in the critical band transform were kept very close to the original mappings while the resolution is increased in some of the higher frequency bands. The result of this experiment was an average hit rate of 68% with an average test time of 17.5 minutes.

5 Future Plans

5.1 Overall System

The initial results obtained from our proof-of-concept device indicate promising, although inconclusive, data to suggest that with practice, a person would be able to recognize sound through the sense of touch. However, to properly analyze and determine the feasibility and applications of our device, much more research is necessary before any conclusions can be made. New tests that incorporate sounds with ambient noise as well as competing dominant sounds similar to those encountered in daily life will need to be developed. These tests would need to be implemented on a large testing pool; the majority of which should be comprised of hearing impaired individuals.

The size and portability of the device are also important factors to consider in the future. The size of the THA renders it relatively useless for practical applications. Therefore it will be necessary to minimize the overall dimensions of the design to allow for portability of the device. It will have to incorporate a portable power supply and be relatively lightweight and designed so as not to obstruct or hinder the ability of the user to perform normal activities.

5.2 System Hardware

The challenge in the future is to shrink the size of the hardware and its power consumption. This is a very difficult task as the current design requires a huge amount of power. One of the main difficulties would be finding vibrators that are incredibly small, incredibly power friendly and yet still quite powerful. This is a challenging but necessary requirement for making the device portable.

5.3 System Software

In the future, this device will be used in portable scenarios. There will need to be a discrete processing unit that can be worn on the user's belt or placed in a pocket. The software for this must be designed to minimize power usage and capable of transforming audio in an outside environment with several noise sources. The software on this unit will need to interact with the personal computer version of this software.

The personal computer version of this software will evolve from the version created for this project thus far. It will be adapted to focus around training and further experimentation. It will be user centered. It will guide users through the process of learning and experimentation and it will be able to track the user's progress. The general maintenance mode of the software will include features to modify device parameters and monitor performance statistics.

6 Budgetary and Time Constraints

6.1 Budget

Table 6-1 provides a summary of our initial budgeted costs in comparison to the actual costs incurred over the course of our project. Because we did not utilize our contingency fund or purchase a high quality microphone, we were able to remain under budget for our final costs.

Table 6-1: Summary of Projected and Final Budget and Funding

Item	Description	Budgeted Cost	Actual Cost
Microphone	Capturing sound for analysis by the tactile hearing aid	$30.00	$0.00
Transducers	Vibrating modules used to transmit the information to the skin	$100.00	$81.99
Pad/Velcro	Used to place transducers on the skin in a specified array	$30.00	$27.10
Wiring	Various wiring and connectors for interfacing pad to the controller (PC)	$20.00	$0.00
Pad Controller Circuitry	Circuitry for I/O interfacing of the pad to the PC	$30.00	$71.82
Controller (PC)	Analyze sound signals and transmit information to the pad	N/A	N/A
Contingency	~20% of total costs	$40.00	$0.00
Total		**$250.00**	**$180.91**
ESSEF Funding			**-$180.00**
Out of pocket			**-$0.91**

We were granted an amount of $250 to cover the cost of our initial budget by the Wighton Fund; however, because our project was completed below cost, we did not require any additional funding aside from the amount awarded to us by the ESSEF.

6.2 Time

The projected timeline for our project is shown in Figure 6-1 with milestones illustrated as the colored diamonds. Because of the careful consideration taken to create this timeline, we were able to adhere to the schedule and meet all designated milestones on time.

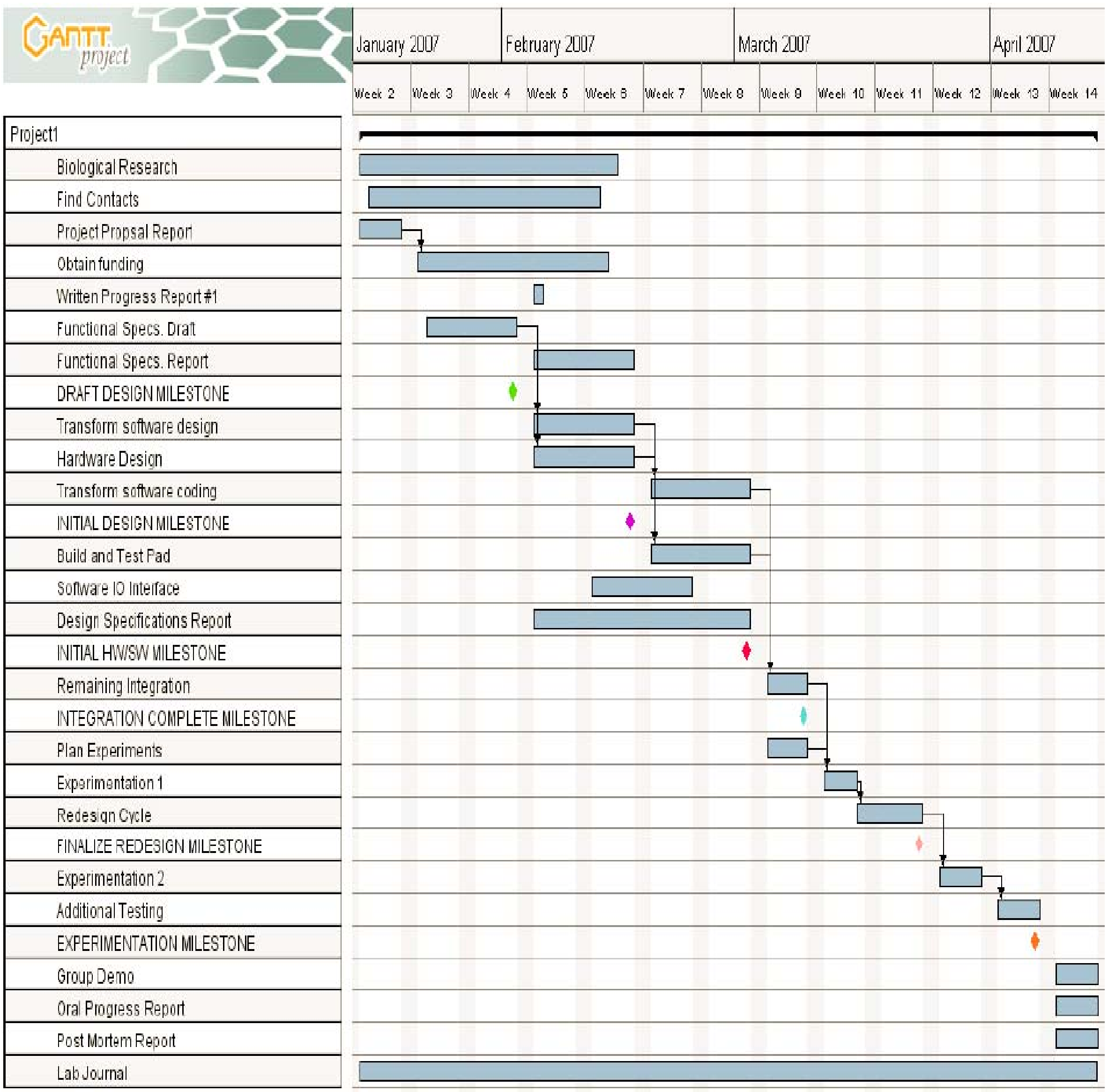

Figure 6-1: Projected Schedule

7 Inter-Personal and Technical Experiences

7.1 David Dickin (Chief Executive Officer)

At the outset of our project, I strapped on the burdensome backpack of leadership, stuffed with books of questions, binders of responsibility, clipboards of hope, and a small tupperware container containing authority and my lunch. As CEO I was determined that come hell or high water this project would be finished on schedule and on budget, or I'd kill several underlings trying. However, I quickly realized that leading our group just meant writing up the meeting agendas, asking questions, and assigning people sections of documents they had to write. The main work of the project, developing the Tactile Hearing Aid, was enthusiastically taken on by all group members. Leadership was displayed by all individuals involved, and now that our work is finished I am happy to call them all friends.

For the most part, work was done independently. However, we held quasi weekly meetings to share our accomplishments and concerns. The meetings combined with email and instant messaging let us communicate freely and effectively throughout the semester. I believe we had a very healthy team dynamic. Mehran, Ryan and I actually know each other from high school and have worked with each other in the past. Merle was new to me, but a pleasant surprise and a talented team member.

My technical area of expertise is hardware, and I was principally responsible for the design and testing of the I/O Control Board as I had previous schematic and PCB layout experience. Other responsibilities included running meetings, being the editor for documents, and assisting my peers with their subsystems. I did not have a lot of experience leading a project group at the beginning of the semester. I had even less experience making budgets and schedules. I believe that these were important skills to become familiar with and am glad they were emphasized in the course lectures.

Of course the heart of the project was actually designing and building the Tactile Hearing Aid, and I learned a good deal from that as well. I had never previously gone through the whole design process for a PCB from start to finish. During co-ops I've designed them, I've tested them, I've even populated the parts on a few of them, but never did I do all of these things for the same circuit board. It was nice to see it through to the end, and learn about my design mistakes using my testing procedures.

Overall I am quite pleased with how our project played out, particularly since we didn't spend any sleepless nights in the lab. I enjoyed the success we had, the people I worked with, and the learning experiences the Tactile Hearing Aid project provided me with.

7.2 Merle Kinkade (Chief Financial Officer)

My experience with this project may differ from those of my team members. Initially, I came into this group as a "classmate" rather than a "friend" in comparison to my fellow team mates who were all friends before this experience. However, any initial concerns I may have had were quickly eliminated as I adapted to the amazing team dynamic of this group. Through this experience I have learned the importance of proper scheduling and working together towards a common, realistic, and well-defined goal as well as proper delegation of tasks. I came into this experience with much apprehension; however, I found it was greatly improved because of the organization, communication, and willingness to work as a team to solve problems as they were encountered. Additionally, by taking the time to properly define goals that could realistically be completed within the given time frame, we were able to minimize the amount of frustration that could easily have been encountered during this process.

In the initial research phase of our project, I was surprised at the number of studies that have been conducted into engineering applications for the human auditory system. I was able to learn much about the frequency response of the human ear and how it can be modeled as a filter. I have been able to expand my understanding of the FFT from a concept learned in class to a process with practical applications in real-life settings. I also learned how the various subsystems of a design are integrated and that the testing process can be an ongoing practice - even when there is a working prototype. It was a pleasant surprise that we were able to produce promising results towards our proposed method of sound recognition that with additional testing and research could potentially assist the hearing impaired as originally intended.

I was responsible for the design, construction, and mapping of the VibraPad and vibrator array. These tasks forced me to not only work within my strengths, but to also put aside my reservations and work within my areas of weakness. I learned the importance of asking questions as it is plays an integral part of the learning process. By doing so, I realized that many of my concerns may have been unfounded and was able to not only learn, but also improve my skill-set.

Oftentimes in life it will be necessary to work with people with whom you have no previous experience - which can seem daunting at first. This experience has provided me with insight into the engineering design cycle and greatly increased my confidence in functioning within a team dynamic. I can say with much certainty that this group has been one of the best, if not the best, that I have ever worked with.

7.3 Mehran Eghtesad (Senior Hardware Engineer)

Some of our team members where more skeptical than others about the general theory behind this project, but everyone was on board from the very beginning and willing to work hard and produce a product that we thought someday may help hearing impaired individuals.

The group dynamics were excellent. For the most part, we worked on our respective parts of the project independently. Meetings were held regularly to discuss action items and progress reports. Various design and implementation issues were discussed at meetings or over e-mail and we were able to reach decisions in such a way that everyone was satisfied. Everyone on the team was determined to keep on schedule throughout the semester and we were able to do this with some hard work and determination.

I learned much about the human auditory and sensory system through the initial research we conducted for this project. During the design and implementation phase, I learned about the PC parallel port and how to write software to control the various pins for our application. I also learned about Windows' real time timers and how to use them as a way of creating a pulsing signal on the parallel port. This pulsing signal was necessary in order to have various levels of intensity for each vibrator.

I also helped in the design and debugging of the I/O control board. I personally fabricated this board (including drilling ~300 holes) and soldered all the components onto the board.

Overall this course was a pleasant experience. It was a pleasure working with the other members of my group. I also hope that this project will in some way be continued as I believe there is great potential for research in the field of tactile communication and this is a great starting point for this research.

7.4 Ryan Dickie (Senior Software Engineer)

The way the group got most of the work done was on an independent basis with progress meetings, emails, and quick demos to show progress and mockups for feedback from other group members. Any problems were raised. In general each task had a benign dictator and we were encouraged to get our parts working by the others success. I have really enjoyed being dictator over the code.

We met formally and informally quite often and kept in constant email contact. There were no major disputes though there were some disagreements of course. I suppose we were all more worried about sticking to spec and completing the project than waste time over the petty stuff. It was good that we could keep the big picture in constant focus.

As far as learning goes, I got an increased understanding of audio processing and FFT theory. It is not often that I am able to sit down and actually apply theory to real data. I learn far more doing than simply reading textbooks and ensc380 and ensc327 exercises. I also got to play around with audio input and output devices and learn the quirks of bad drivers and other real-world issues. This device was also developed for windows and I have, over the years, tried to avoid windows development at all costs. I discovered many of those rumours are true and that Windows is a real pain and its libraries are in a state of disarray. Much of the actual functionality is poorly documented.

I have had a lot of project and research based experience for an undergraduate student. Nonetheless, a few unexpected issues and results arose. The experimentation phase unraveled completely different than I had anticipated though. The results of the initial tests were quite unexpected and it was only then that we realize what it was we had actually built. I was rather surprised because we had kept to the schedule within a day or two of the predicted one. For a research-based project this is quite difficult because you cannot schedule discovery.

Overall, this was a rather enjoyable course rather than a sleepless nightmare that I had been hearing about for many years. I suppose the trick is to have very well defined and feasible goals and then produce a realistic schedule. Take the estimated amount of time to do a certain task and double it. Prototyping early and often also helps a great deal because it is not until you can touch and feel device that you truly understand what needs to be done. My group was quite a pleasure to work with.

8 Conclusion

Developing the Tactile Hearing Aid was a fun and exciting learning experience. As we do not intend on taking the product to market at this time we are searching for parties interested in taking up where we left off and continuing our work. It is our hope that one day our work will make a difference and improve the quality of someone's life. We are thankful to the ESSEF and the Wighton Fund for providing the funding necessary to make our project happen. And we would like to thank the ENSC 440/305 professors and TA's for all their time and help.