School of Engineering Science
Simon Fraser University
Burnaby, BC V5A 1S6
lifex-ensc440@sfu.ca

December 17, 2007

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

Re: Post Mortem for an Anti-Snore Pillow (ASP)

Dear Dr. Rawicz:

Attached is the post mortems for LifeX Technology's most recent innovation, the *Anti-Snore Pillow*. This document summaries the progression of LifeX's innovation the *Anti-Snore Pillow* which uses active noise cancellation technology to lower the background noise, so that everyone can enjoy peaceful and quality sleep every night, even with a noisy snorer.

The post mortem reviews the current status of our product the Anti-Snore Pillow. This document outlines the steps and struggles to achieve our desired product functionality and our future plans for our product. Additionally, this document will compare our predicted and realistic budget and time constraints.

LifeX Technology is comprised of four highly motivated undergraduate engineering science students from SFU: Camillia Lee, Stanley Yang, Simon Wong and Raymond Lee. If you have any questions or comments, please do not hesitate to contact us by phone at (604) 594-6816, or email me at khl2@sfu.ca.

Sincerely,

Raymond Lee

Chief Executive Officer

Enclosed: Post Mortem for an Anti-Snore Pillow (ASP)

POST MORTEM:
ANTI-SNORE PILLOW (ASP)

PROJECT MEMBERS:

CAMILLIA LEE
STANLEY YANG
SIMON WONG
RAYMOND LEE

CONTACT INFORMATION:

LIFEX-ENSC440@SFU.CA

ISSUED DATE:

DECEMBER 17, 2007

VERSION

1.0

1 Introduction

LifeX started bringing the idea of an anti-snoring device to reality in September of 2007. The concept of suppressing snoring noise brought together four individuals who have all once suffered the pain of sleeping beside a snorer. In the past thirteen weeks, everyone has worked tirelessly developing the “Anti-Snore Pillow”. This report documents all the processes throughout the project as well as the joy and struggles for each members in LifeX.

2 Current State of the Device

The idea behind the Anti-Snore Pillow is to use active noise cancellation to suppress noise ranging from 0 – 500HZ. Active noise cancellation acquires the noise signal through a microphone, process the signal to produce an anti-noise signal and finally drive loudspeakers with the anti-noise signal to cancel the acoustic noise. The main components of the system include an error microphone, a reference microphone, loudspeaker and an ANC controller.

The input signals from the error microphones and the reference microphones are fed into the signal processing stage which is achieved by the Texas Instrument C6713 DSK (DSP Starter Kit). The DSK comes with 3.5mm audio IO, AIC23 audio codec, digital to analog/analog to digital converters and various supplementary circuitries. The AIC samples the audio input at 96 KHz and stores the digitalized data in the memory. Then the DSP chip processes the data with an adaptation algorithm to generate the anti-noise output.

The type of ANC system implemented in our project is an adaptive broadband feedforward control with an acoustic input sensor. The system includes an error microphone, a reference microphone, an output speaker and a noise speaker as shown in figure 2.

Figure 1: Physical arrangement of the system

The black speaker shown is theoretically not part of the design. It is simply there as a noise generator during the development stage. The first microphone on the left is the reference microphone which acquires the reference signal, *x(n)*. The white speaker is the speaker playing the anti noise, *y(n)*. Finally, the speaker on the right is the error microphone which acquires the error signal, *e(n)*.

The signals are then fed to an ANC controller which consists of a digital filter and an adaptation algorithm that updates the digital filter. Both FIR and IIR digital filters have been implemented separately for comparison. In theory, an IIR will be more suitable for this project due to better performances from the IIR. However, the IIR is inherently unstable which makes the system harder to control. For that reason, the digital filter implemented in the current design is a FIR filter with 60 coefficient weights.

Two different adaptation algorithms used to update the filter weight coefficients have been tested: the FXLMS and the URLMS. FXLMS is an algorithm suitable for implementation on a FIR filter while the URLMS was designed for an IIR filter. As mentioned before, the IIR is unstable and, therefore, the current system has implemented the FXLMS algorithm. Shown in figure 3 is the block diagram for the FXLMS algorithm.

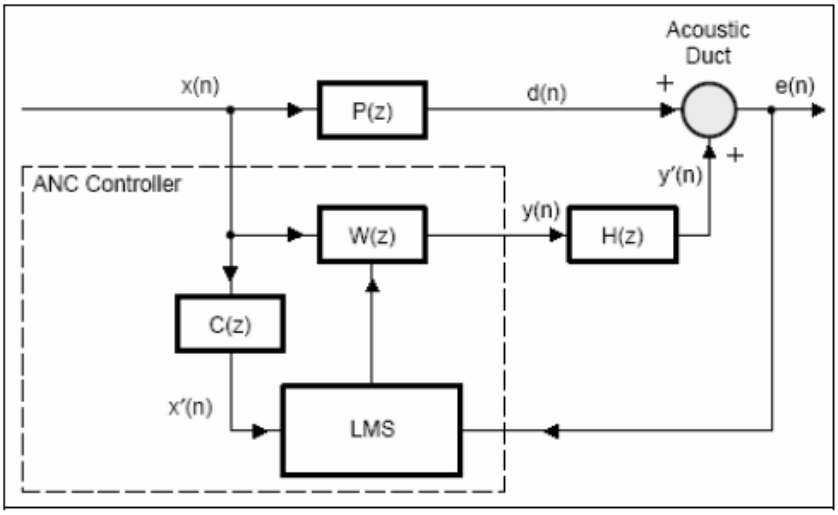

Figure 2: FXLMS algorithm block diagram

In order to implement the FXLMS algorithm, the secondary path H(z) must be modeled to create C(z). This is accomplished in our offline training stage which uses the training algorithm shown in figure 4. The full algorithm can be found on page 22-23 of "*Design of Active Noise Control Systems With the TMS320 Family*".

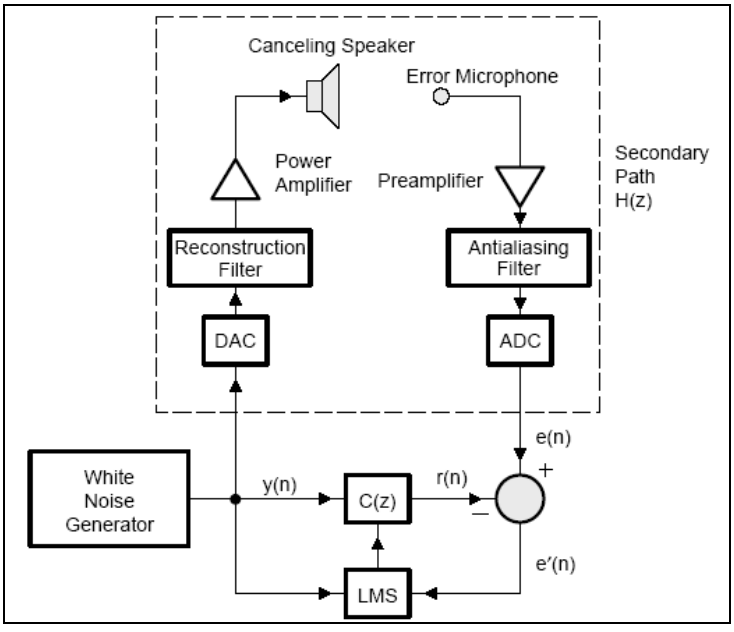

Figure 3: Secondary path estimation algorithm block diagram

The system is currently able to reduce single tone 200-600 Hz sine waves by 10-20 dB depending on the frequency of the input. An obvious difference can be heard with our ears when the system is being turned on and off. However, the system is still incapable of suppressing multi-tone sine waves or more complex signals like snoring. We believe that a number of modifications to the physical system and the software have to be done to suppress broadband noise. These possible modifications will be discussed in the section “Future Plans”.

3 Deviation of the Device

3.1 Overall system

The overall system is capable of performing active noise cancellation on single tone sine waves. Due to time constraints, we were not able to further develop the system to suppress more complex noises such as multi-tone sine waves or snoring noises.

The current prototype is a proof-of-concept model and the system is not integrated into a pillow. In addition, the speakers and microphones used in the prototype are not suitable for the final product.

3.2 Signal Acquisition

Instead of small sensitive microphones, the prototype is currently using karaoke microphones as input microphones. The microphones have to run through a preamplifier in order for the signal to be strong enough for the DSP. This was not mentioned in the design specification. The karaoke microphones are not sensitive enough at low frequencies such as 0 – 100 Hz. Microphones with better low frequency sensitivity should be used.

3.3 Signal Processing

In the design specification, we stated that the IIR and the URLMS will be the digital filter and adaptation algorithm used. However, the IIR and the URLMS was extremely unstable during our testing stages. Time constraints restricted us from optimizing and stabilizing the system using the IIR and URLMS. The FIR

digital filter and FXLMS algorithm was implemented instead. Using this combination, we were still able to achieve the goal of suppressing single tone sine waves but with much more stability in the system.

3.4 Physical Arrangement of the System

In the functional specification, we proposed a multi-channel system which had two error microphone and two output speakers. A multi-channel ANC system will be much more effective for broadband noise such as snoring. Unfortunately, multi-channel system is extremely complicated and beyond our reach for a four months project. Furthermore, the TI C6713DSK does not have enough I/O ports to support a multi-channel system. The system is currently a single-channel system with one output speaker and one error microphone.

4 Future Plans

LifeX plans to further research and understand the ANC technology, in order to fully maximize the quality of the Anti-Snoring Pillow. After the Anti-Snoring Pillow has been perfected, LifeX plans to expand their market into the biomedical field, in order to ensure a higher living standard for all of our customers.

4.1 Overall System

- *Better Equipment for System Testing*

  Higher quality speakers and microphones are required to fully detect any flaws in our system. We are currently unable to test low frequency noise, since we do not have access to compact low frequency speakers to act as source noise. Also, the microphones we are currently using only transmit signals more than 100Hz. As mentioned earlier, all power within a snoring sample is less than 300Hz.

- *Controlled Environment for System Testing*

  Currently, we do not have a controlled environment to properly test our system. Factors such as temperature, background noise and room arrangement interfere with our test results.

- *Package the Device*

  The prototype if our product has not yet been modified to be compact and portable. On our next release, the canceling speaker and the DSP chip will be embedded inside the pillow, and not add any dimensions to our currently proposed pillow size.

- Memory for recording user's default mode

  Due to the adaptive nature of our product, a different system environment will yield a different set of filter coefficients for our secondary path. Currently, the 10 seconds offline training will occur every time the device is switched off and back on in order to calculate these coefficients. Our next goal includes storing these parameters within the DSP's read-only memory, allowing the user to recover the previous mode (if system environment had been consistent, which is usually the case) and bypass the 10 seconds of offline training.

4.2 Signal Processing

- *Automatic Gain Control to increase stability*

  In order to increase the stability of our system, an AGC is required to ensure the input and outputs are at the same level. This is largely due to the IIR algorithm requiring both a feedback and a feedforward system. In our code, when the input and the output are summed together, often the feedback system loses effect since the amplitude in our output is much smaller than the input.

- *Optimization*

  In the IIR design of our system, there are many parameters to be altered in order to yield the best results. Convergence rate of our filters, filter size and sampling rate strongly affect the computing time and quality of our anti-noise. Although a bigger filter size increases the accuracy of the anti-noise, it also increases the computation time.

When the lag time is significant compared to the period of our source, the anti-noise starts to lag behind the source noise.

- *On-board LCD*

  In the future, LifeX plans to further expand the user-friendliness of the anti-snoring pillow. A 3 inch monitor will be placed on top of the DSP, in order for the device to successfully communicate with the user. The device will come with additional functions such as alarm clock and games.

- *Low-pass filtering*

  Since ANC works best at low frequency, we will low-pass filter the snoring sampling with a cutoff frequency of 500 Hz to ensure only low frequencies are being processed. Without the contamination of high frequency signal, the stability and convergence rate will increase.

5 Budget and Timeline

5.1 Budget

Item	Predicted Cost	Actual Cost	Difference
Texas Instrument TMS320C6713 DSK	150	$480	$330
Audio Accessories (Cables, Adaptors, etc)	150	$126	-$24
Pillow	100	$0	-$100
Miscellaneous (Book, Interface, etc)	100	$40	-$60
Total	**500**	**$646**	**$146**

Table 1: Budget Comparison

In Table 1 , is our cost difference from our predicted cost to our actual cost. As seen in Table 1, we underestimated the cost of our product by $146. During the development stages of product we experienced many unexpected costs which the main cause to our cost underestimation of our product.

Even though we included the prediction of unexpected cost in our budget, there still were numerous unforeseen costs. The majority of the funds in the development of our product were allocated towards our DSP chip. This cost was unforeseen because we thought that we could have borrowed the engineering ‘s DSP. But since the un-availability of the DSP was not taken into account our cost of our product significantly increased.

An additional cost which was not taken into account was a book which clearly outlines some important aspects about ANC. This cost was not taken into account because most of our sources of research came from the library.

After researching numerous audio products we realize that for an optimal system our system would total to over $1000. Therefore, during our development process we recycled many of our own audio components which cut down some of our cost. Also we predicted that our pillow would cost approximately $100 but since our product is still in its development phase we just used our own pillow.

5.2 Timeline

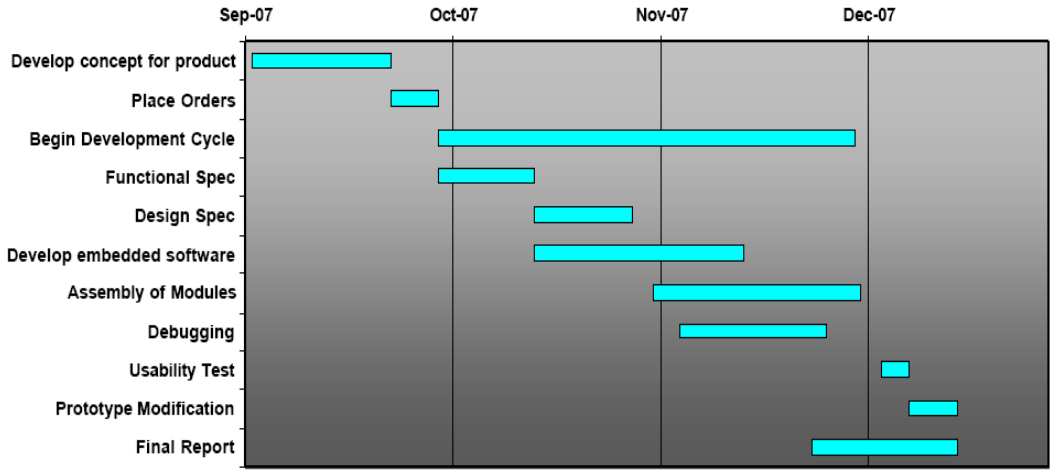

Figure 4: Proposed Timeline

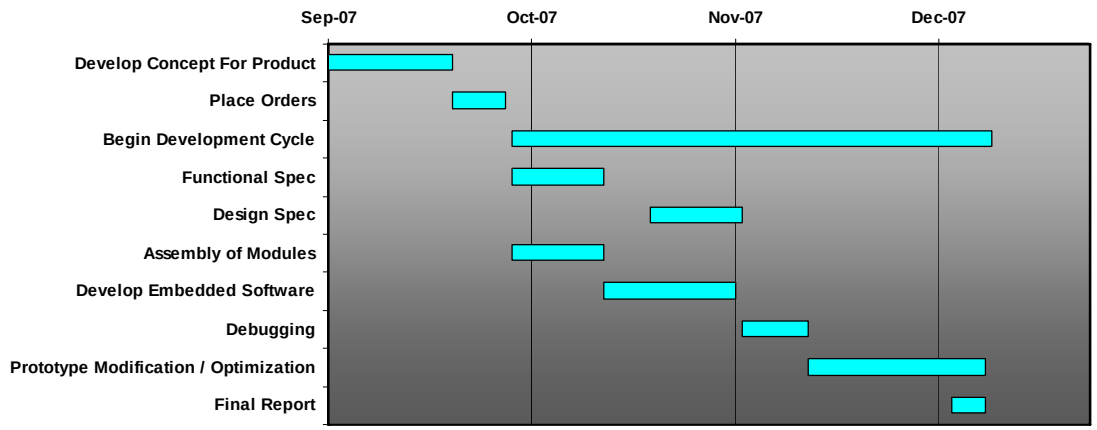

Figure 5: Actual Timeline

Shown in Figure 4 and 5 is the grant charts, in Figure 4 is our estimated time to complete our project and in Figure 5 is our actual time spent. When comparing the two graphs, we can see that most of our time was allocated to the development phase of our project.

During the development our product, we adhered to our timeline until later the later stages. Our timeline was deviated from when we later discovered the complexity and difficulty our system which was unexpected. Additionally, many problematic situations transpired during our optimization stage which was not expected.

Due to a lot for unforeseen problems during our development and optimization stage we did not have time to perform any usability testing and prototype modification. Later in the future we wish to be able to accomplish these final stages of our product.

Throughout the semester our timeline was adhered to but due to the unexpected complexity of our product we strayed away from the final stages of project.

6. Ecological Footprint Assessment

Our system is made up of speakers, microphones, a pillow and a DSP chip.

Even though we have minimal components, all our components consist of numerous materials which contain heavy metals which are can be incredibly hazardous. Many materials such as lead, beryllium, cadmium and mercury are contained in many electronic components. The usage of these materials put many people at risk,

including the workers. The plastic casting used to encase our electronics can be removed in our final product which reduces the waste caused from our product. Additionally, in most of our electronic components we can find a more power efficient alternative.

7. Inter-Personal and Technical Experiences

7.1 Simon Wong

From this project, I have realized that all the courses in 2nd and 3rd year that I thought were useless are not useless at all. In fact, without taking those courses, we would have had a much harder time accomplishing our goal for this project. All the knowledge of programming, signal analysis, electronics and calculus all came to be useful during the development of the system.

Our group started off knowing nothing about active noise cancellation. I thought it would be a simple project before we started, but it turned out to be one of the hardest projects ever. After learning about basic concept of active noise cancellation in the first few weeks, I knew we were going to have many endless nights developing this project. There were so many aspects of ANC to be learned, including digital filters, adaptation algorithms and acoustic cancellation. Each of these topics had no definite procedure and answers. For example, there is no one single way to arrange the system physically that'll perform the best. It was almost like an "art" that requires a lot of personal experience from the engineer in order to achieve good results. Although we were not able to achieve our goal of suppressing snoring noise, I felt that I have become a lot better at this "art" already. In addition, I have become familiar with the TI C6713DSK Code Studio Complier, learning all the hot keys to rebuild, load, run and etc. I have also learned a lot of basic knowledge regarding digital signal processing. It was extremely exciting being able to run the DSP board to produce real time results.

Interpersonally, I have learned that compromise, patience and understanding are very important when working in a group. Everyone has different opinions as to how to solve a problem. It is important to be patient and to listen to what each individual has to say. There might be times where you do not like the idea of others but it is important to compromise and respect the decision of the team.

Finally, I feel very lucky to be able to work with the LifeX members Raymond, Cam and Stan. They were extremely hard-working and dedicated individual. More importantly, they were very fun people to work with and we had tons of fun while working together. We learned a lot more about each other as we spend more and more nights doing the project together. I will definitely miss having them over at my house working on the project on Friday, Saturday and Sunday nights.

7.2 Camillia Lee

I was really looking forward to doing this project. In the start of the project I was really excited to make this active noise pillow. I always had an interest in active noise cancellation and because snoring affects millions of people all over the world, my group and I decided to introduce a non invasive way of obstructing the sound of snoring. I thought it would be a very innovative way to take something already used [the pillow] so that it would not occupy more space and would not be a hassle to use. It seemed like a very affordable product to pursue for long term developments. It interested me because I didn't know as much as I would like to about snoring. I really hoped this project would help.

When I first started, the concept of Active noise cancellation sounded like a simple concept. I later discovered that my notions were wrong and realized that the project was actually very complex. This project has really made me appreciate the complexity of signal processing in complex sounds. I enjoyed learning about and applying what I learnt about using the TI DSP. Although I thought it would be very simple it turned out to be very difficult to completely cancel out something as simple as a single tone. There were many factors that we had to take into consideration in order to achieve a controlled environment to work with. These factors included the equipment we included, gain control, convergence rate, and the surrounding environment. Even small factors such as the temperature of the room would affect the system. We tried our tackled it the best we could and I am pleased with the results.

In the future, I hope to continue to learn and apply other types of ANC algorithms. There are some minor things that I would change for improving the results if I were to do this again. One of the struggles we had was the hardware. Therefore in the future I will start with a more stable system as well as more suitable equipment I will also do research about the hardware I'd be using prior

to the project. After the more stable system is developed I would hope to integrate and experiment with different filters to make it more elaborate. I would be very excited if I get to try out a multi-channel system and apply it to more complex sounds.

I thoroughly enjoyed working with my team. We were able to cooperate well and we each brought different aspects into thought. We each had strengths that added to our project and we supported each other's weaknesses to ensure a good system. During this project I learnt how to problem solve and compromise. I've learnt effective time management and to be more patient. From my teammates I've learned to identify problems and I think that we have really strived off each other.

Through this project, I've learned what it's like to apply my past 4 years of education to something tangible. I really enjoyed working with my teammates on the system and I am really happy with the results. I truly hope that I will be able to be given the opportunity to work with active noise cancellation again.

7.3 Stanley Yang

Although ENSC 440 is a lot of research and work, I really enjoyed taking it. I see this course as crucial in the engineering curriculum because it allowed us to apply all the theories and knowledge that we have acquired throughout our studies. Furthermore, I believe ENSC 440 is a good preparation step for us before entering into the industry, because it allowed us to experience teamwork as well as problem solving. Through ENSC440, I was introduced to a whole new technology, namely active noise cancellation.

In addition to ANC, and DSP programming, another important output that I got was I made three new friends. I believe the most important reason that made my ENSC 440 so enjoyable was the fact that I had wonderful group members. We were able to work to harmoniously together, researching, problem solving, developing prototypes, and testing. I truly enjoyed working with members of LifeX, Simon, Ray, and Camillia. You guys are awesome.

Thanks to Simon for providing us with a place to work on the project, thanks to Ray for inviting me into the group, and thanks to Camillia for carpooling on a snowy day. Take care and keep in touch.

7.4 Raymond Lee

I enjoyed working on a project from scratch, since this allowed us to apply the problem solving skills I acquired at SFU. There are a lot of very technical questions that we had to find the answers on our own. In fact, I felt that the information we attained in school are very entry-level. The school only provided us with the simple concepts of engineering, only for us to discover our interest. In order to synchronize with the industry, we must further research and experiment within that field.

I have significantly improved my C++ programming skills in the past 4 months. Topics such as interrupt driven programs, timers, GEL were all brand new concepts to me at the beginning of the semester. We had to constantly improve the execution time of our code, in order to increase system performance. This was a difficult task, since the “efficiency” of a piece of code was never important to us when doing a C++ assignment.

One thing I regret the most is not starting the project sooner. I felt that we had rushed to a topic too quickly in the beginning of the semester. If we had spent more time researching the topic, we would know the cancellation of a complex sound would mostly likely drag on for more than 4 months. It was very difficult for us to find help on this topic, since ANC was only put into application recently.

Our group had actually developed excellent communication skills throughout the 13 weeks. We learned that team work comes from good scheduling, patience and mutual respect. Even though we assigned roles based on our strengths and weaknesses, we still discussed what we have learned in our weekly meetings.

This project exposed me to a brand new engineering field. Although ANC is currently very under-used, it is definitely a growing industry. Currently, ANC is only appropriate for a continuous source noise that is reasonably close to the canceling speakers. We saw the potential in this technology, and decided to challenges ourselves to something that has not been done before.

Although our project didn’t get to a point of our initial expectations, I am very content with our results. It was satisfactory to put theories into actual practice. To

conclude, I felt that we all appreciated what we learned in this course. We now know what it takes to create an engineering product from scratch, and never again would we make the same mistakes.