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December 17, 2007

Dr. Andrew Rawicz
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Re: ENSC 440 Post Mortem for Trans Dental Monitoring Solution

Dear Dr. Rawicz,

Please find attached the *Post Mortem for Trans Dental Monitoring Solution* (TDMS) which outlines the process our team went through in designing and implementing our device. Our project aimed to create a tool that can be used to monitor nerve activity in a tooth, and therefore give the dental an objective approach to measuring the effects of anesthesia.

This document outlines the current state of the device, deviations from the original plans and our future plans. We also outline our budget and time constraints, and compare it to our original plans. This document also explains the inter-personal and technical experience we gained from this project.

Trans Dental Technologies consists of four enthusiastic and innovative final-year engineering science students: Isabella Taba, Petar Ivaz, Bahman Sotoodian and Mohammadali Khorasani. Please feel free to contact me at skhorasa@sfu.ca with any questions or concerns regarding the design specification.

Sincerely,

Mohammadali Khorasani
Chief Executive Officer
Trans Dental Technologies

Enclosure: *Post Mortem for Trans Dental Monitoring Solution*

Post Mortem for

TRANS DENTAL MONITORING SOLUTION

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Submitted to Dr. Andrew Rawicz – ENSC 440
Mike Sjoerdsma – ENSC 305

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1 Introduction

The Trans Dental Monitoring Solution (TDMS) is a device that can be placed on the tooth and monitors the activity of a tooth under anesthesia. A tooth that is "awake" or "waking up" will show nerve activity and the dentist can administer anaesthetic to achieve profound anaesthesia. TDMS sends consecutive pulses at predefined intervals and amplitude which is below the patient's perception threshold. As soon as the amount of the anaesthetic drops the patient will feel the signal and gives the feedback to the dentist. The design specifications are listed in the following document.

2 Current State of the Device

Our device is currently attached by a metal bracket that is glued to the tooth using temporary glue. One end of our device clips to the metal bracket, while the hook is placed in the corner of the mouth. We begin by slowly increasing the intensity of the current until the patient feels a distinct sensation in their tooth. As soon as this is accomplished, the dentist will apply the anesthesia. When it has set in, the patient will stop feeling the sensation produced by our device. To verify that the anesthesia has set in, the dentist will proceed to increase the current by a factor of 3 – 5 μA. If the anesthesia has not set in, the patient will feel this increase. However, if nothing is felt by the patient, the dentist can be certain that the tooth has been properly frozen.

Figure 2.1 presents a high level overview of the TDMS system.

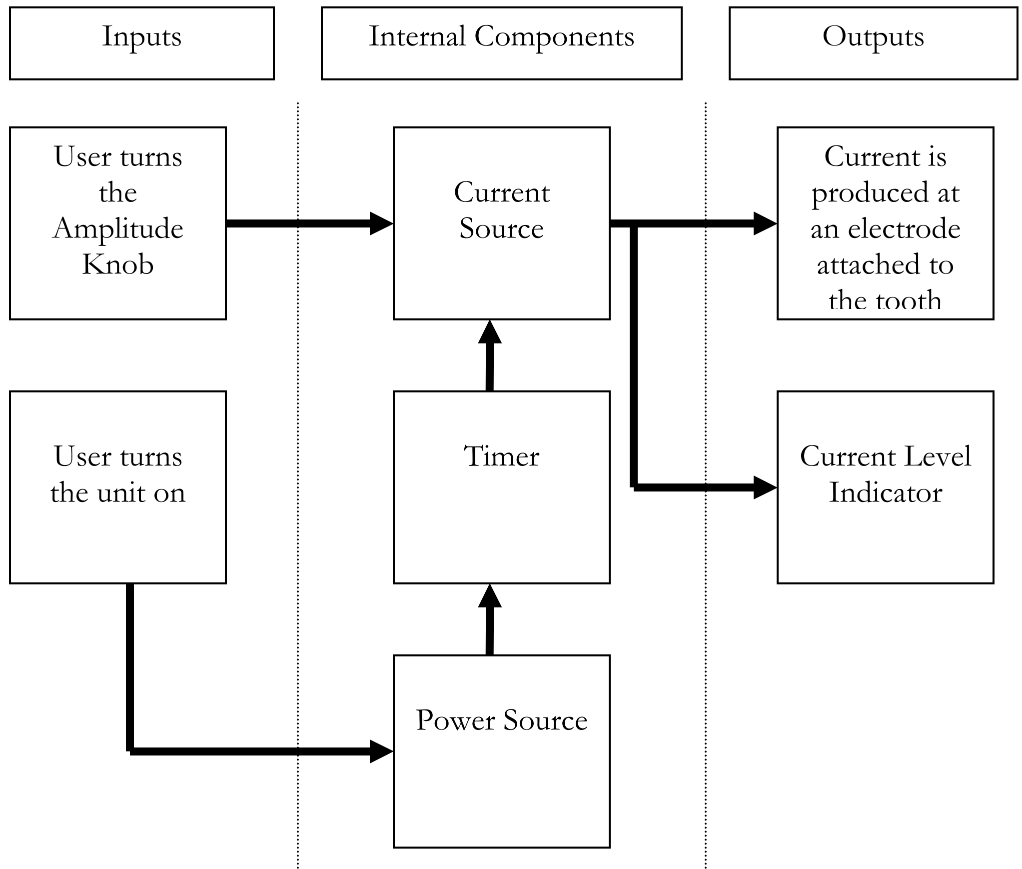

Figure 2.1 – Current TDMS High Level Overview

By sending a series of pulses to the tooth, we are able to produce a tingling feeling in the tooth. This feeling is not painful, but can alert the patient and the dentist if the anesthesia is wearing off/setting in. The constant current is created by placing the tooth in the collector stage of an NPN transistor.

2.1 User Controls

The device consists of very simple controls. We have the Power switch, as well as two knobs to control the amplitude of the current (one knob creates very small changes in amplitutude).

2.2 Power Supply

Due to the large resistance of teeth, in the range of mega ohms, the device must be powered by a supply of 300 volts. The 300 volts is produced by a single 1.5 V AA battery. In order to up the voltage, we have taken a disposable camera circuit and converted it to produce a constant voltage of 300 volts.

2.3 Timer

For a tenth of a second, a 50 Hz square wave is applied to the tooth. There is a 1 second period of OFF time, which is again repeated by a tenth of a second of a 50 Hz pulse. This is accomplished by two stages of LM555 timers. One stage produces a 50 Hz pulse, while the other stage controls when the 50 Hz pulse is turned on/off.

2.4 Ammeter

We have placed a track and hold device across the emitter stage of the NPN transistor. Because the pulses are 1 second between, the controls are not as responsive. Therefore if we turn up the amplitude of the current, we will not see our changes reflected until 1 second later.

3 Deviation of Device

We have been able to properly prove the concept that we initiated our project based on it. Our device functions perfectly and we have been able to test it on various people. Due to time constrains, we were not able to achieve some of the preliminary goals that we had.

We originally intended to use clamp to properly mount the electrode on the tooth. However, we realized that due to conductivity of clamp, we would not able to use it for our device. Hence, we used alternative methods. With the assistance of expert in this field, Dr. Kevin Aminzadeh, we were able to use special brackets for our device. We glued the brackets to the tooth and mounted our electrode to it. This alternative design has some advantage and disadvantage. Due to resistance of brackets, the patients would perceive the current pulses at higher amplitude. However, the brackets can be placed on tooth very quickly and can be removed in a matter of seconds.

Using a digital output on our control panel was intended at the beginning of semester. However, due to time constrain we did not have sufficient time to programme a microcontroller chip and feed its output to a LCD display to present the value of our output current. We simplified our design and used an analog ammeter to present the amplitude of output current. Although the ammeter would not show high accuracy however for our purpose of proving the concept of our device it satisfied our design requirements.

Packaging our device in a fashion that would be very easy accessible for users was desired. However, the battery holders were placed inside our package and the users have to unscrew the package in order to change the batteries. We originally intended to provide a user friendly device, placing the batteries outside the package, but we preferred to save time and locate the batteries inside our packaging box.

As we mentioned in our previous documents, we intended to add safety features to our device to gain the confidence of our consumers regarding the device safety issues. We wanted to build overload and fault detection features for our device. In case where the overload occurred our device would turn a beeper on and indicate to users that an overload had occurred. For the fault detection, we liked to design a circuit that would shut down the entire device when a fault had been detected. However, we realized that testing our device is much more important than adding new features. We allocated much of our time testing the functionality of our innovative device; hence we did not have enough time to add the above features to our device.

4 Future Plans

The Trans Dental Monitoring device has further need for research and improvement. Our device is fully functional and our primary objective to prove the concept of monitoring dental anaesthesia has been met. However, due to time constraints we were not able to implement some ideas which would have resulted in more features and robustness in our system. As we re-examine the development of the device, we have the following suggestions for future development.

4.1 Overall System

Packaging and Device

Although the prototype fits in a small box, the smaller the device the better it is for implementing into a dental office. Dental office space is at a premium. Several devices compete for countertop space. Counter space that is less cluttered will appear more hygienic and less scary to patients. The current analog display needs to be replaced with a digital display as a digital reading allows for faster interpretation of data for the dentist and staff and promotes use of the device.

Safer Controls

Because each pulse has a one second interval, it takes time before the patient feels the pulses. If the pulse has zero amplitude and the dentist increases the current amplitude, the next pulse could be very high which could be higher than pain threshold and could cause pain for the patient. The current amplitude controls should be more controllable and be adjustable with pulse duration. There should be an emergency shut off button as seen in most dental products.

Make sure the device will meet the medical safety standards

In order to be able to use this device legally in Canada and the US (our primary markets), it should meet certain standards. The product should be approved by ANSI and CSA for use in our prospective markets. FDA approval for the use of the device for its specific purpose of anaesthesia monitoring also needs to be obtained

Use rechargeable batteries for power and signal generator

The portability of the device is extremely important. Dentists do not operate from only one room, but usually work between two and three rooms. The device should be portable meaning it should have rechargeable batteries. The batteries should ideally last 2-3 days with each charge. The device should have a battery charge indicator to alert the dental staff that the battery is low. The battery charger should sit outside the device and have the capability of charging a backup battery. When the batteries run low on the device, the dental team member can replace it with the backup battery to minimize downtime for the device and having to wait for charging.

4.2 CURRENT SOURCE AND CONTROLS

Add more Safety features

Our device in the current sate does not have enough safety features for safer use, which are as follow:

- Overload detector, for detecting any disconnection between the parts in the circuitry and the power source
- Fault detector that detects if any parts of the circuit malfunction
- Short Detector for detection of any short between the parts, especially in connection of the power source to the current generator.

4.3 POWER GENERATOR

Add Safety feature to the power generator.

Because the power source generates 350V, we need an additional circuitry connected to the power generator which insures the current flow out of the power generator is always in micro ampere range so that in case of any short in the circuit, higher current does not flow into the patient tooth.
The other safety feature that should be added to the power generator is a circuit that checks whether the capacitor which supplies high voltage to current generator is fully discharged after turning the device off.

4.4 PULSE GENERATOR

In our current design, the pulse generator generates current pulses which are ¼ second in duration in 1 sec intervals, shorter interval pulses would result in short term firing of the nerve and patient would not feel the pulse after 2-3 second. More testing needed to be done to find the pulse with appropriate duration and intervals in which the patient would feel the pulse without any discomfort.

4.5 CLAMP

Make a clamp for our device

Since the rubber dam clamps that are currently used in dentistry are made of stainless steel, they have very high resistivity. To reduce this resistivity the tip of the point that touches the tooth should be made of silver or gold which has lower resistance.

5 BUDGET

The initial assessment of the budget was an overestimation, as also indicated in the proposal. We were able to reduce the cost for our project to 60% of what was estimated at the beginning. Table 5-1 is the comparison between the estimated and the actual cost for the project:

Equipment	Estimated Cost	Actual Cost
1. Back up power System	$100.00	$0.00
2. Power Supply	$150.00	$45.00
3. Variable amplitude constant current source	$450.00	$182.00
4. Pulse generator	$50.00	$8.00
5. Cables and tooth clamps	$20.00	$6.00
6. Alerting Beeper	$25.00	$12.00
7. False condition audible alarm	$30.00	$10.00
8. Capacitors, conductors, diodes and op-amps to build the required circuits	$35.00	$22.00
9. Current Display	Not Considered	$50.00
10.Prototyping Packaging	Not Considered	$72.00
11. Others	Not Considered	$80.29
Total Cost	**$810.00**	**$487.29**

Table 5-1 – Initial Budget Estimates VS Actual Cost

The power supply and the constant current generator circuits are accountable for a large portion of this difference. We were able to find and alternative way to supply 330 DC voltage. The Kodak disposable camera flash circuit was modified and used for this purpose. Dr. Rawicz provided us with a few cameras which were enough for testing purposes and we also purchased 3 new disposable cameras for the later stages of the project (each costing only $7). In addition, we were able to build our own Variable Amplitude Constant Current Source as opposed to the initial guess that it needed to be purchased; this possibility was also mentioned in the proposal. Variable resistors, high-voltage transistors and programmable Zener diodes were the major contributors to the cost of the Current Generator circuit. The

Pulse Generator component of the circuit was also made using cheap LM555 timers, resistors and capacitors which helped further reduce our costs.

Some of the costs not considered in the initial estimate were the Current Display Unit and costs associated with preparing the packaging of the prototype. Current display costs were mostly due to the micro-amp analog current meter and that of the prototype packaging were the PCB's and the prototype box purchased.

We have also calculated the cost for producing our system, without including the costs associated with research, back-up parts, or marketing. A break down of the material cost is provided in Table 5-2

Programmable Zener	$50
Box	$40
Variable Resistors	$30
Ammeter	$20
Power Supply	$10
PCB	$5
Battery Holder	$5
Other	$30
Total	$190

Table 5-2 - Material Cost for One Prototype

6 TIMELINE

The initial timeline presented in the proposal is provided below:

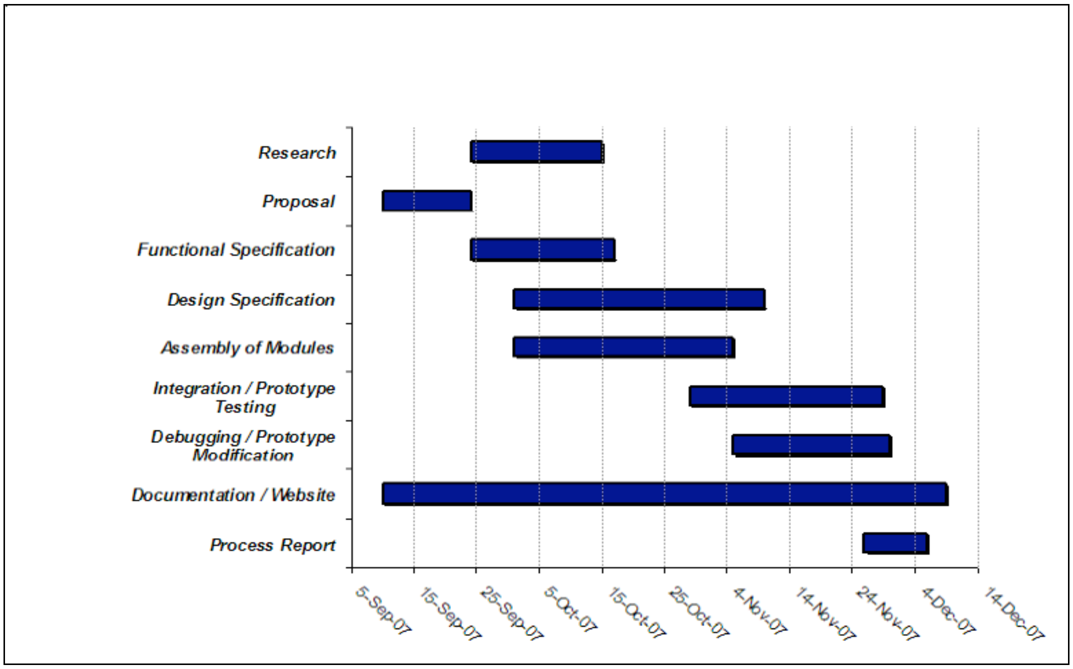

Figure 6.1 - Timeline from Proposal

All the deadlines in the course were met during the semester and the timeline was more or less followed with slight deviations as shortly described next. Various additional deadlines were also set during the project meetings in order to ensure individual parts assigned to various group members would be completed in an order that would realize the timeline proposed and the project progress would proceed in a timely manner.

The research component was continuously taking place throughout the project unlike the short time period allotted to it in the proposed timeline. This was due to the biomedical nature of the device and various safety factors in addition to human interface considerations that needed to be investigated all the way until testing was finished and the device was ready to be packaged. Potentially applying high-voltage to the patients and pattern of the output current applied to them are some of the examples of such considerations. Another deviation from the proposed timeline was the debugging. This took longer than anticipated due to the unexpected defects of the components used in the circuit. The debugging was successfully ended on December 10th allowing us to proceed with finalizing the prototype packaging and final testings a few days left to the demo date. In parallel to debugging, a second working version of the device was prepared as a back-up plan. The rest of the timeline presented in Figure 6.1 was followed as anticipated.

7 INTER-PERSONAL AND TECHNICAL EXPERIENCES

7.1 PETAR IVAZ

Before the start of the semester I had doubts about my future as an engineer. I grew tired of weekly assignments and labs with little room for creative thinking. ENSC 440 changed all that. For the first time I felt like an engineer.

Our goal was clear: build a device to monitor the effects of dental anesthesia. Unlike other courses, we were not given a set of instructions; rather we were left completely on our own.

A large portion of our time was dedicated to research. We had to dig up previous studies pertaining to electrical nerve stimulation. At times I felt very uneasy about the project, it seemed as though we were getting nowhere. However, our research was absolutely critical to the success of the design, and guided us in the right direction.

Electrical resistance of teeth ranges in the mega ohms. To successfully drive current through the tooth, we had to create a 300 volt power source. This was the first time I ever dealt with a voltage higher than 15. This exposed the limitations the oscilloscope and the DMM have when it comes to high voltages. At times, monitoring that the device was working properly proved as challenging as designing it! Though I was involved on every component of the device to some extent, my area of expertise came with the timing circuit. I used the LM555 to create the waveforms required, and was pleasantly surprised at the versatility of this little chip.

Our team was regularly bickering and arguing. Rarely would we agree or have the same approach to a problem. This kind of disagreement was extremely healthy. We constantly challenged each other and in doing so, brought out the best. In order to understand something, you have to be capable of communicating your logic and ideas. This is far more important than being right.

My group members had worked together in many previous courses, and were all close friends before 440. I was more of an acquaintance, and had some concerns about being the odd one out. Nevertheless, I could not have asked for a better group. At no time did I feel left out. What impressed me most about our group was how calm we remained under pressure. A week before our demo, our PCB completely broke down. Nothing was working as it should have; and we had no immediate idea why. The patience and maturity of our group was on full display, we didn't get flustered, we just kept on going.

This was by far the most enjoyable course I have taken at Simon Fraser. The curriculum should have more courses that give students this kind of freedom. The lack of restrictions made me feel like an engineer.

7.2 MOHAMMADALI KHORASANI

Coming into the course, I had an expectation of a miserable semester full of arguments with other group members and many sleepless nights in the lab. Now that the course is complete my perspective of ENSC440 has changed. I have found the course to be one of them most unique and rewarding experiences in my few years in the engineering program.

It is natural for four engineering students, with strong opinions, to have conflicting ideas with regards to the issues raised in a project, but I learned how these discussions, if carried out maturely and guided appropriately, can lead to the betterment of the outcome at the end of the project. Having someone else continuously challenging your approaches to solving problems and being exposed to various approaches that others take to look at the very same problem teach you new lessons everyday.

In addition, I found out how much of what we don't learn in an academic engineering program is required to take on an engineering project. I realized that even though it is easy not to remember all the overwhelming information that we have been exposed to over the past few years, it is the critical thinking abilities and problem solving techniques that we develop in the engineering program that are the key to one's success in the real-life work situations.

It was repeatedly proven to us during the project that designing a system on paper can be widely different from implementing it. Component imperfections and unexpected interactions between various parts of the system can cause many difficulties. Trouble shooting skills were another valuable lesson we learned when dealing with such problems. Last but definitely not least, was the time management issue over the semester. I believe that the total independence given to students in this course helped us realize the importance of planning, managing time and working together efficiently under pressure in successfully completing challenging projects, like ours, in a timely manner.

As the last remark, I would like to say that I had the privilege to work with three strong engineering students who were enthusiastic about using their skills to solve a problem that leads to making a positive difference. They helped make the challenge both enjoyable and rewarding. I hope that the strong engineering program at SFU would consider including more courses like ENSC440 in the curriculum for future students.

7.3 BAHMAN SOTOODIAN

Capstone Design Project Course provided us with experiences that we have never had during regular engineering science courses. We learned how much time management can be influential in success of any project. Proper time management helped some groups to properly achieve their goals in the intended time period that they had set at the beginning of the semester, while others suffered from a poor time managements and had to postpone their demos for weeks.

During this course, we were able to enhance our teamwork abilities. We realized that sometimes we had to compromise our desires to satisfy other group members, because working together is the most important part of any project.

Being on time and being prepared for meetings also would save lots of time and help the project to keep moving. Performing sufficient research would help the group down the road when they face with deadlock and they would require alternative approach to achieve their desired tasks.

We also realized that obtaining appropriate part is a key factor in success of any project. Not all the components function in a similar manner and choosing the best one would save the hassle that group would face during the testing and debugging stages.

Testing is the most important aspect of any project. During the testing procedures we faced with unexpected problems that we have never thought about them. Testing various features of device is very different than testing the functionality of entire device. When we put different sections of our device together we faced with new issues that we did not encounter during the individual tests.

Having a proper record of our activities is also very crucial in success of any project. Being able to retrieve the previous data and comparing it with new ones can provide deeper insight regarding the functionality of our device.

At the end, I would like to thank our team members for all the effort that they put in designing our innovative device. It was a great semester working with them and I look forward to working with them again in future.

7.4 Isabella Taba

In the past four months the most important lesson I learned was how to be patient and respectful to other's opinions in a group. I have learned how to work in a group effectively and express my ideas clearly. I have also learned to be flexible and appreciate that others may have ideas that may work better than mine. I have learned how to take lessons from failures and not lose my cool if something is not working as expected in the design.

Working on this project gave me a great opportunity to exercise my knowledge in circuit design, analysis and testing. Before this course I had a solid idea about the transistors, current sources and, diodes. Taking this course was an opportunity for me to apply my knowledge in the actual circuit design. I have learned so much about testing and analyzing circuit and troubleshooting. I found that the models and elements in circuitry which we learned in our circuit courses are only true for an ideal case and in actual circuitry you have to consider many other factors which have not been considered in the theory.

In the first month of this course we worked with PSpice for the testing the circuit. Having this opportunity helped me to refresh my knowledge in using the simulator and how the result you get in simulation compares to the actual result you get in the circuit.

One of the most amazing aspect of this course was you are on your own and you will design your own circuit using all the knowledge you accumulate in all of the circuitry courses you took before. I am very proud of my self and my group that we pulled this off very well.

My group members were all hardworking, motivated individuals, who made it a joy to work on this project day and night, weekdays or weekend. Their attitude made our failures bearable and our success more joyful in the designing our device.
I truly enjoyed my partnership with all of them and I believe this course was an opportunity for me to find not only good colleagues, but also lifetime friends.