Solumspect

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April 23, 2010

Dr. Andrew Rawicz
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Burnaby, BC V5A 1S6

Re: ENSC 440 Post-Mortem for Solumspect's Landmine Detection System

Dear Dr. Rawicz,

Solumspect has successfully produced and demonstrated a landmine detection system as our project for ENSC 305W/440W. The system caters to the needs of humanitarian organizations by being both low-cost and robust using off-the-shelf components.

The attached document, *Post-Mortem for Solumspect's Landmine Detection System*, details the current state of our device, describes the changes from our initial design specifications, and outlines improvements for the future production version. Also included in the document is an updated budget and schedule report, along with self-reflections on the project from each team member.

Solumspect is a dedicated team of fifth-year engineering students: Michael Ages, John Berring, Graeme Cowan, and Jeremy Yoo. Should you have any questions about our project or the attached post-mortem report, please do not hesitate to contact us by e-mail at ensc440-cyab@sfu.ca.

Sincerely,

Michael Ages	*John Berring*	*Graeme Cowan*	*Jeremy Yoo*
Michael Ages	John Berring	Graeme Cowan	Jeremy Yoo

Enclosure: *Post-Mortem for Solumspect's Landmine Detection System*

Solumspect

Post-Mortem for Solumspect's Landmine Detection System

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1 Introduction

Over the course of this semester, the Solumspect team has been working hard to build a fully functional ground penetrating radar (GPR) system for detecting buried landmines in an effort to aid humanitarian demining efforts. The resulting GPR device was successful in meeting our goals and adheres to our functional and design specifications with only a few modifications. In all, everyone in the group had a very positive experience working hard, getting along, and sharing knowledge.

2 Current State of the Device

2.1 Overview

At the present, Solumspect has successfully produced and demonstrated a model version of our GPR device designed for landmine detection. Having hand-guided operation, the device produces a 3D map of the ground being observed. It can accurately and consistently detect metal objects buried up to 50 cm deep in both sand and soil, as well as plastic objects buried up to 50 cm deep in sand. A picture of the device is shown in Figure 1.

Figure 1: Fully functional model version of Solumspect's GPR device

As shown in Figure 2, the GPR device can be broken down into three main modules: radio frequency (RF) electronics, low frequency electronics, and processing software that runs on the user's laptop.

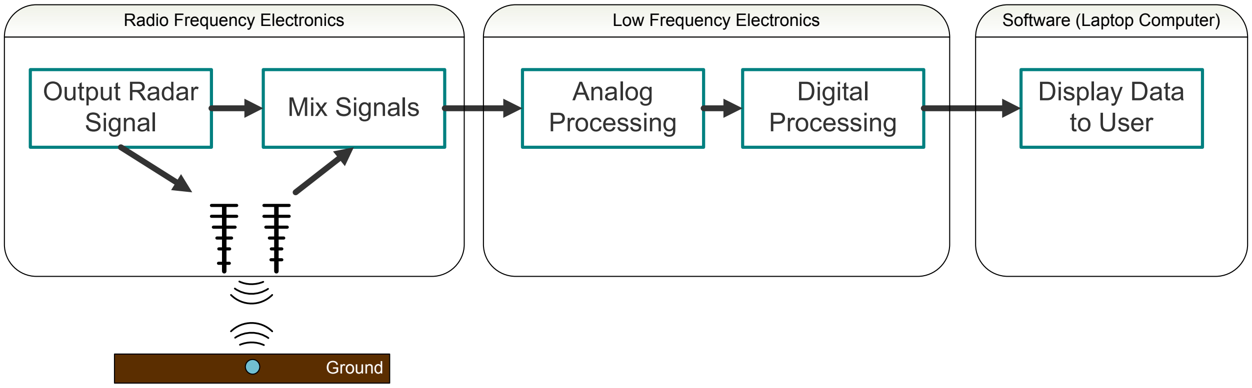

Figure 2: System overview block diagram

The RF module, housed within the scanning head along with the low frequency electronics, transmits a sine wave with a linearly varying frequency (i.e. radar signal) into the ground through one of the antennas. The reflected radar signal is captured by the second antenna and is mixed with the currently transmitting signal to determine the frequency difference which is proportional to the distance travelled by the signal.

After the high frequency components of the mixed signal are filtered, the signal is amplified, sampled by a microcontroller, and transferred along with the capture position to the user's laptop.

The software transforms the sampled time domain signal into the frequency domain and uses it along with the position information to generate a 3D representation of the ground. Slices of the data can be taken to obtain overhead and cross-sectional views. Additionally, the data can be used to generate a 3D contour map to better visualize the structure of the ground.

The device is powered by four 6V lantern batteries, which is rated for about 25 to 27 hours of continuous operation.

2.2 Operation

The user operates the device by first suspending the frame over an area of land to investigate. The base of the structure is placed in a safe area (known to be free of landmines) and weighed down with sandbags as shown in Figure 1.

To initialize a scan, the user turns on the power to the device then launches the device's control window in MATLAB, as shown in Figure 3.

Figure 3: Device control window in MATLAB

The user then clicks "Initialize" to specify an output directory, followed by "Start" to begin a scan.

The user may now grasp the scanning head's handle and move the head about the square frame in a repeated "S" pattern. When the entire 1m x 1m scan area has been covered, the user clicks "Stop" in the control window and turns off the power to the device.

The software will then process the data to produce the resulting overhead, cross-section, and 3D images, which can be analyzed in the view window, as shown in Figure 4.

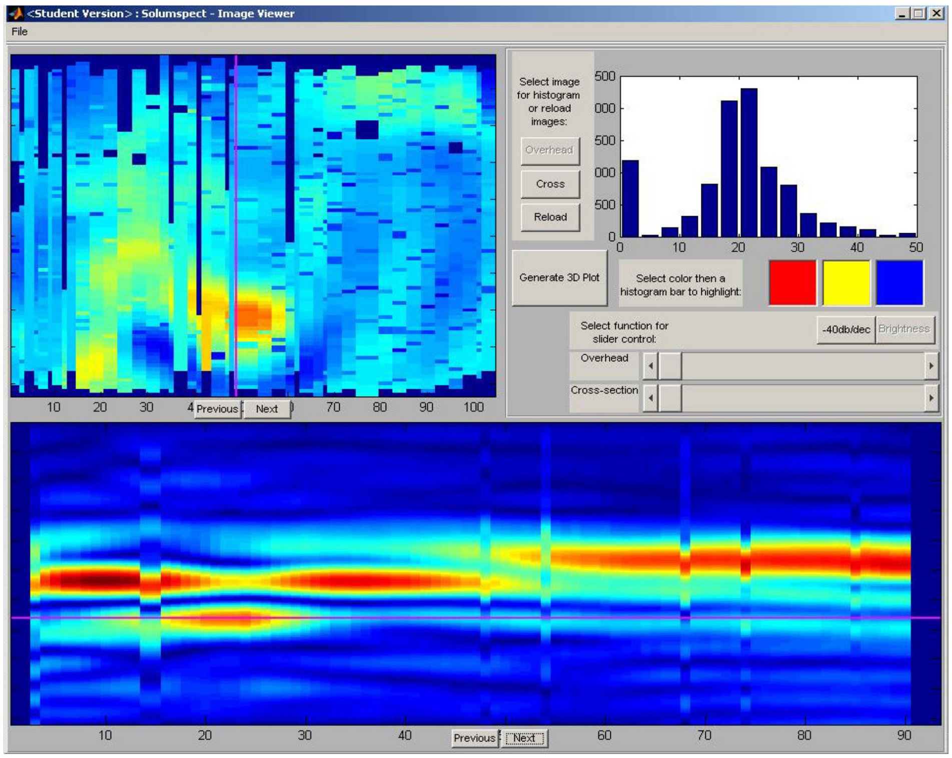

Figure 4: Device window in MATLAB showing results from a sample scan

Sample 3D views of the ground that are generated by the view window are shown below in Figure 5.

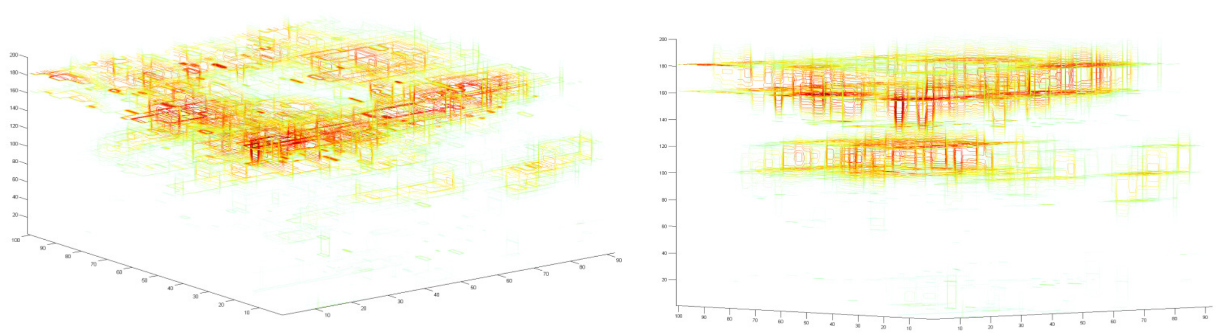

Figure 5: Sample 3D views created by the software

3 Deviations from Design Specifications

3.1 Radio Frequency Amplifier

The only change made to the RF module was with amplifier placement. In the design specification, a single amplifier was placed before the transmitting antenna, as shown in Figure 6. However, we later found that boosting the LO input power to the mixer improved the IF signal strength, so we moved the amplifier to before the power splitter. This change had a small degrading effect on the signal power at the transmitting antenna as the increased power pushed the amplifier output to its limit and slightly reduced its gain; however, the reduced signal power was still well within our requirements. A second amplifier was also added after the receiving amplifier to boost the RF input power to the mixer as we discovered this was too low. An updated RF module diagram is shown in Figure 7.

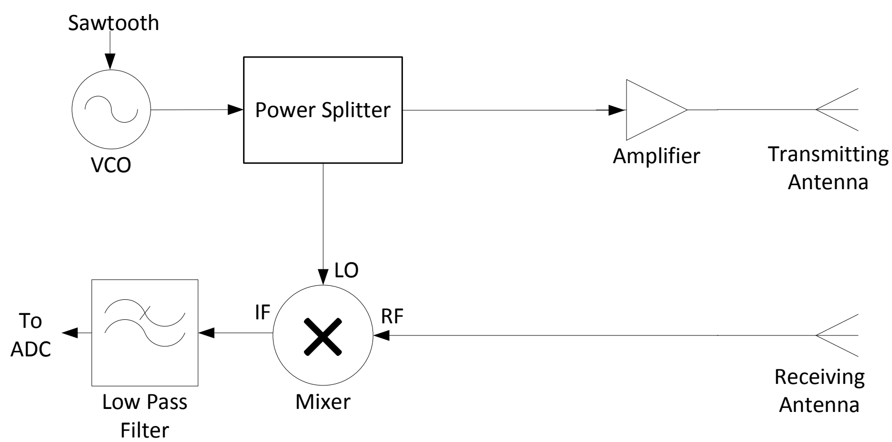

Figure 6: RF module in design specification

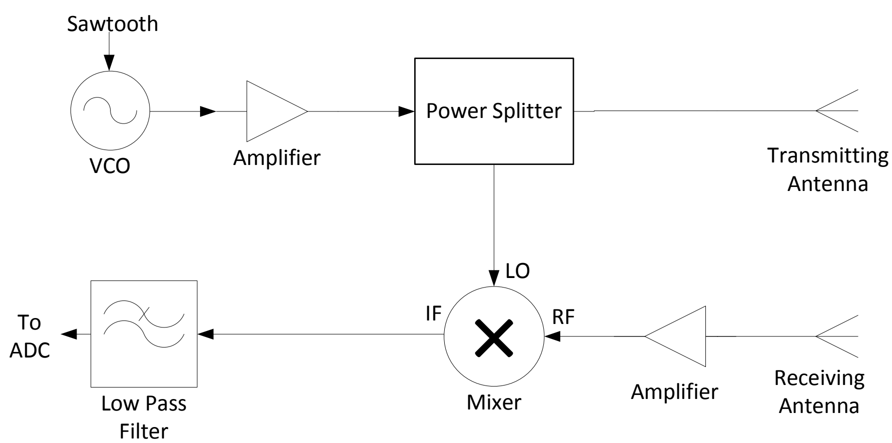

Figure 7: Updated RF module in model device

3.2 Scanner and Gears

The mechanical design of the final prototype was simplified in two ways. First, as can be seen in Figure 1, the frame's suspension tower and wires were removed. After constructing the scanner and frame, we found this additional support was not necessary to hold up the mass of the system. In future versions, this will likely remain true as the parts will be lighter than in the current device.

Second, the scanning head movement mechanism and placement of the potentiometers were changed. The original design called for a chain and sprocket system that would allow the scanning head to be moved in the y-direction by a crank at the base of the device and in the x-direction by manual pushing. A potentiometer was to be attached to the axle of each sprocket to record the position of the scanning head in the two dimensions.

To simplify the prototype, this complex system of chains was replaced by a long handle attached horizontally to the base of the scanning head. The user now moves the antennas in both directions by pushing and pulling the handle. Position measurement is still done using two potentiometers; however, they are mounted such that a sprocket attached to a potentiometer is able to roll along a chain affixed to a static portion of the frame, as shown in Figure 8.

The y-position potentiometer, for example, is mounted on the scanning head and joined to a sprocket which is rolling on the chain attached to the edge of the linear slider beneath it. When the scanning head moves, the axle of the potentiometer rotates as dictated by the sprocket moving along the chain.

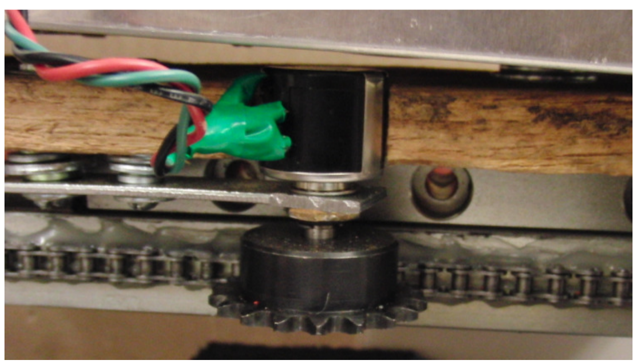

Figure 8: New positioning system design in model device

This design change when initiated when we found out that a supplier would not be delivering our required parts in time for the demo. However, once the new design was in place, it became evident that the old design was needlessly complicated.

3.3 Low Frequency Amplifier

As designed, the incoming mixed signal is sampled by a high speed analog-to-digital converter (ADC) and is sent to the computer via a microcontroller for processing. Upon testing, it was quickly discovered that the input voltage into the ADC from the RF module only had an amplitude of approximately 1.5 V peak-to-peak and was centered around 0 V. Our ADC converts a voltage between 0-5 V into a digital value, so clearly, we would achieve better accuracy reading a signal that varied with a 5 V peak-to-peak voltage and stayed positive.

To solve this problem, we introduced a low frequency amplifier (supporting a frequency of around 400 kHz) and offset adder circuit as illustrated in Figure 9.

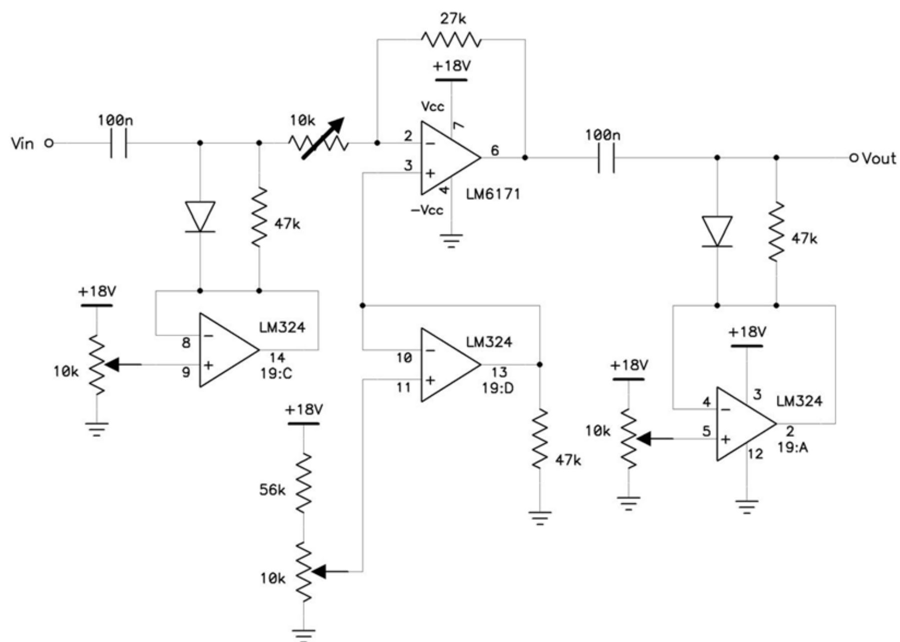

Figure 9: Low frequency amplifier and offset adder schematic

A challenge experienced in the construction of this circuit was choosing a single-supply, preferably rail-to-rail operational amplifier that was fast enough for our purpose. Had we not used a single-supply amplifier, we would have required an additional power regulator and several extra batteries just to power this small addition. We found the LM324 to be a usable solution, and along with a number of potentiometers, were able to amplify the signal to 0-5 V for accurate measurement with our ADC.

3.4 Data Capture and Processing Algorithms

Our data capture module collects radar data each time the radar head's location potentiometer data indicate that the head has moved at least a specified distance. In our initial design of our data processing algorithm, we operated under the assumption that the distance intervals between data collection would be consistent since the scanning head was moving slower than the ADC could sample. Unfortunately, we found during testing that this was not the case, making it difficult to align all of the sweeps to produce the overhead views.

Our processing algorithm was hence updated by placing each of the radar readings from a single sweep into a 2D matrix according to its position data, rounding the positions to fit the grid as necessary. As we do not want to add information to the picture by using traditional interpolation methods where pixel values are guessed, we use a 'smearing' method to fill in missing elements in the grid with previous scan values until the next scan value is reached, resulting in the effect of dynamic pixel sizes. Missing values are not filled at the edges of the grid, which result from the user not sweeping the full possible distance.

As all of the 2D matrices were on the same coordinate system, this modification meant that we could produce the overhead images by simply layering the 2D matrices to produce a 3D matrix from which we could take the correct slices.

In addition, as we felt that our scan images did not lack in contrast or contain a lot of noise, the filters to correct for these problems were not added to the view window. The brightness and 40dB filters were still kept as user selectable options and were quite useful in helping distinguish the objects within the images.

3.5 3D View

During testing, we discovered that having a 3D view would greatly improve the user's ability to locate the landmines buried in the ground, giving both location and volume information. Based on the *contourslice* MATLAB function, we were able to easily generate 3D underground plots. Unfortunately, this was quite a processor intensive process, so in future versions of our device, our 3D image generation methods would definitely need to be improved.

4 Difficulties and What We Would Do Differently

A major unexpected difficulty encountered by entire Solumspect team was the construction of the mechanical structure. No one in the group had much experience in building wooden structures, but everyone suspected that it would be easy. While it was not a big challenge physically, the whole construction took much longer than expected due to our collective lack of experience. Multiple trips to the hardware store for parts that we forgot or didn't realize we would need also added a delay.

As a result, if we were to repeat this project, we would start mechanical structure construction much earlier. To save time, we would also make sure to thoroughly discuss and determine all of the construction materials before going to the store. We had determined all of the required dimensions before we started construction, but we had not specifically defined the types and number of bolts, screws, and joint connectors, which resulted in several incorrect purchases and necessitated the extra trips.

5 Future Plans

We have received interest from the Archeology department at SFU for possibly acquiring our device. GPR is used in archeology as a non-destructive way to determine the contents of the ground; most recently, this technology has been used to unearth mass graves in former war zones where it is important to expose remains without disturbing possible criminal evidence. If we were to pursue this opportunity, additional work would be required to make the device more robust.

To do this, we would need to replace the metal case that contains all of the electronics with a custom box. The analog circuits would be put on a PCB, as opposed to the breadboards that they are on now. As well, the user interface would be updated to make it more usable to a non-expert user. We estimate that this extra work would require roughly 40 hours of additional work from each team member.

To commercialize the product for humanitarian use, we feel we could make further improvements to improve usability in real-world conditions. Firstly, the frame structure would be made more portable by placing a hinge between the frame and the base. Also, the image processing algorithms, such as the one used to produce the 3D view, could be improved to assist the user in analyzing the given situation more easily. Finally, we would need to replace the lantern batteries with a battery that can be recharged and has larger capacity (e.g. a car battery).

6 Budget and Timeline

6.1 Budget

Table 1 compares our proposed spending with the actual costs, rounded to the nearest dollar.

Table 1: Proposed vs. actual costs

Component	Proposed Cost	Actual Cost	Amount Over
Radio Frequency Electronics	$700	$545	-$155
Low Frequency Electronics	$20	$95	$75
Microcontrollers	$100	$119	$19
Power Sources	$80	$40	-$40
Mechanical Parts and Components	$200	$451	$251
Total	**$1100**	**$1234**	**$150**

While our actual total cost exceeds that of our proposed total cost by $150, this additional amount can be covered by the 20% contingency that was included in our initial project proposal. The increased cost can be attributed to the unexpectedly high fees for shipping parts from US-based suppliers, as well as our underestimation of costs and unnecessary purchases of parts for the mechanical structure. Fortunately, borrowing several RF components from SFU Engineering Science professor Dr. Stapleton helped offset some of the costs in the RF electronics category.

6.2 Timeline

An updated Gantt chart is shown below in Figure 10, where the bordered bars show the proposed schedule and the filled bars show the actual schedule.

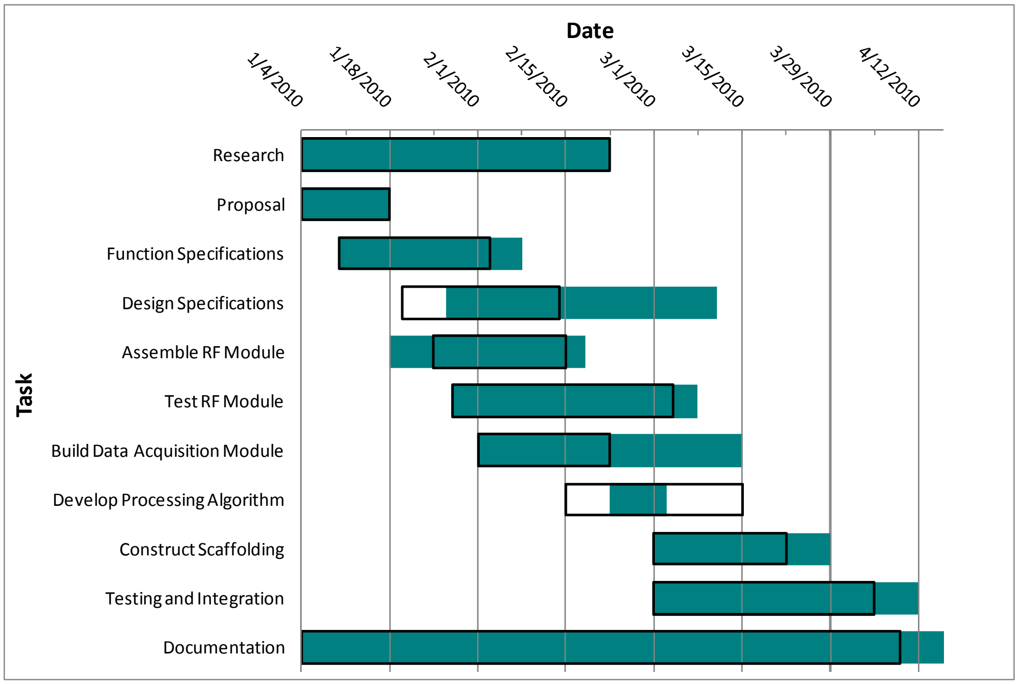

Figure 10: Gantt chart comparing proposed vs. actual schedule

Many of the task completion dates were initially underestimated, taking about a week longer than planned. We had expected to complete our design specifications early in order to leave more time to build the components. However, the additional research required to complete the design specifications meant that we could not meet this goal. This had a carry-over effect to the data acquisition module, which underwent several changes during the design phase.

The most troublesome delay was during mechanical construction, where we faced many challenges that were not anticipated. The resulting delays to integration meant that our testing process had to be pushed back more than we would have liked.

Even with these challenges, as our original schedule contained contingency time by basing the tasks off a 12 week schedule instead of the actual 13 weeks available, the additional time we required did not cause any problems to the completion of the project.

7 Group Dynamics

Overall, the group got along very well. Without a designated team leader, individual people were able to step up to take lead in areas where they were most experienced. This lead to a very positive group environment where everyone was at the same level of superiority.

For the whole semester (with the exception of the last 2 weeks), we held regularly scheduled weekly meetings. These high-level meetings allowed the whole team to come together and make sure everybody was on the same page with respect to how the project was progressing. This also allowed everyone to set specific tasks to work on during that week.

In addition to these scheduled meetings, we also often worked together on the various components of the project. This allowed collective brainstorming to solve any problems we may have had.

8 Individual Reflections

8.1 Michael Ages

A valuable experience I gained from this project concerned the RF electronics component. In the Fall of 2009, I took the high frequency electronics class offered in Engineering Science. It was very valuable to get to practice the concepts I learned in this class with a real physical system. Also, the experience with the mechanical design and construction of our device was a great learning experience. We found this portion of the project very challenging because none of us had a background in mechanical design. The challenge mainly came from the rigidity of the mechanical components. We were all used to electrical and software systems where the spatial extent is rarely an issue because wires could always be made longer and made to turn corners. The rigid mechanical components require that they be placed such that they don't interfere with any other components and we often found that our design ideas needed to be revised due to this constraint.

The greatest thing I gained from this project is the confidence that with the right people and hard work, I can complete any project. We took on a very ambitious project, but because we had done our research and planned well, there was never a doubt that we would get it done. At every step, we made contingency plans to deal with setbacks. For example, we bought extra parts of many of our electronic parts; when our microcontroller burnt out roughly two weeks before the demo, we only lost the few hours it took to get our replacement up and running. Due to this careful planning, we had no major setbacks during the term. This lack of setbacks also helped keep the project fun. The fact that we were always moving forward and never duplicating work made every step of the project fun and exciting.

In terms of team dynamics, I think we worked very well together. Our weekly meetings always had an agenda, and when working together, I think we did a very good job of keeping on task. We all knew that each of us was fully dedicated to the project and in the end, I think we absolutely did the best we could given the three and half months we had to complete this project.

8.2 John Berring

At the beginning of the semester, I had a few misgivings about the size and complexity of the project we had decided to undertake. Despite all our pre-semester research, I was still unsure whether or not our device would work, even if built correctly. Looking back, however, I am glad that we took the risk of attempting a large project that we could have failed to complete. This semester has been an incredible learning experience for me, and had we chosen an easier project, I may not have picked up as much knowledge as I did.

Overall, this project seemed like a crash course in RF electronics, analog electronics, and simple mechanics. I spent a lot of time re-learning things or applying knowledge that I had already supposedly learned. Some topics which I had to quickly remember include MATLAB image processing, Fourier analysis, simple electrodynamics, analog to digital conversion, and mechanical systems. Oddly, the last point in this list proved to be the most frustrating aspect of the project. We left the device construction until near the end as it seemed to be a trivial problem. This turned out not to be the case and construction dragged for a few weeks longer than expected.

While some of the knowledge I have gained in the past four months has come from learning from my own mistakes, the vast majority of it has come from my team members. Without their expertise, there is no way this project would have been completed. If, for example, I was given 16 months to personally build a ground penetrating radar system from scratch, I wouldn't have been able to do it. The time that I would have had to set aside to relearn things that Graeme, Mike, and Jeremy already knew would have been far too great. Finally, everyone in the group showed extreme dedication to the project throughout the entire term. I'm incredibly pleased with how well things went and would change very little if I had a chance to redo the last semester.

8.3 Graeme Cowan

During the preliminary stages of developing and researching our idea, I was a bit apprehensive about tackling such a demanding and potentially risky project. None of us were sure that it would be possible to build a ground penetrating radar device given our limitations in time, funding, and knowledge. In the end, reaching the finished project was extremely satisfying and I learned a lot along the way.

A major factor that made this project so enjoyable was the group that we assembled. We were all dedicated students willing to put in the time to complete a challenging project and we all brought different skills to the group. Additionally, our project allowed everyone to contribute and learn as it incorporated many different areas of knowledge: microcontroller programming, computer data transfer interfaces, graphical user interfaces, mechanical structure construction, and high and low frequency electronics.

I learned a lot during this semester from online researching and reading books, but I undoubtedly learned much more from my team members. I had no prior experience with high frequency electronics, and with the help of my team members Michael and John, I have finished this semester with a much better understanding in a realm of engineering of which I had been previously unexposed. I also gained a wealth of knowledge from Jeremy, who knows much more than I do about microcontrollers, their programming, and the data transfer protocols that go with them.

I hope that I was also able to teach my group members a thing or two during the course of this semester. A couple weeks into the project, I learned that I had significantly more low frequency analog circuit design experience than anyone else in the group. As such, I quickly stepped up to lead our circuit designing process. I was happy to be able to share my knowledge and help us move quickly towards a well-designed finished product.

I was somewhat surprised at how diligently we worked on the project throughout the whole semester. Given four months and only a couple required documentation deadlines, it wouldn't be very surprising to finish the last couple weeks before the demo with a major backlog of work to do. We did not find this was the case. From the very beginning of the semester we scheduled weekly meetings and self-assigned specific tasks and goals to accomplish. This worked very well to spread the work throughout the semester and keep everyone on task.

8.4 Jeremy Yoo

The past four months of working on this project was quite an adventure. With very little background in high-frequency electronics, I was initially concerned with the big scope that we had set for our project. However, I knew that everyone in the team was fully committed to our goal and that we would not give up until we had reached it. Thinking of the many stressful situations that we encountered, I can definitely say that perseverance had an important role in our accomplishments.

Looking today at the successful product we were able to produce, I believe the great group that we put together had a lot to do with our success. Aside from the fact that we were all continuously working towards a successful and high-quality product, everyone had a different speciality that allowed us to effectively tackle all of the different components of our project. Many parts of the project could not have been accomplished without the knowledge that each member brought to the team.

The opportunity to manage our own schedule and progress was one of the most rewarding parts of the project and a good break from the traditionally pre-determined course schedule. It allowed me to always keep the big picture of the project in mind and better see how each task was a piece of the puzzle; deadlines were more than just due dates for assignments to be handed in. I also saw the benefits of our contingency planning when external challenges were added in the mix through broken parts and shipping issues.

From the technical side, leading the microcontroller and software interfacing components of the project helped me gain a better understanding of developing algorithms for systems that are strongly dependent on time. As we were operating near the limits of the microcontroller's processing speed, I had to consider how each instruction affected the speed of our capture routine. This required optimizing code down to the clock-cycle level, something that I didn't previously have to worry about in everyday software design.

The opportunity to work on building the physical structure was also an excellent learning experience, especially since mechanical design is not something that I have had a lot of exposure to in the past. As frustrating as the many mistakes were, I was able to appreciate how much more important careful planning is when working with wood compared to electronic components – it's clearly far more work to replace a metal bracket than it is to replace a resistor!

I truly enjoyed working on this project and would not hesitate to work with the group again on a future project. The resulting product exceeded my expectations and through all of the many challenges, I gained a plethora of practical engineering experience that could not be taught in a traditional classroom setting.

9 Conclusion

SFU's Engineering Science 305 and 440 courses enabled the Solumspect team to successfully design, build, and test a functional ground penetrating radar system capable of detecting simulated landmines made of metal and plastic. All of the team members learned a great deal about project development, time management, and general engineering through personal investigation and mutual collaboration. Having gone through the whole experience, we were able to make recommendations for future work, as well as identify tasks that we would have done differently given what we know now. Overall, this project was a very satisfying experience for all those involved and a big step towards more effective low-cost landmine detection.