ERadar

Post Mortem
Portable Emergency Response FMCW Radar

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Issued Date	April 27, 2012
Revision	1.1

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1 Introduction

The Portable Emergency Response Frequency-Modulated Continuous Wave (FMCW) Radar system is a device that provides emergency response personnel with a detailed overhead image of a low-visibility environment. Regardless of the amount of light, smoke, or vegetation in a user's foremost direction, an accurate picture of the surroundings can be produced.

The ERadar Portable Emergency Response FMCW Radar system high-level block diagram is shown below in Figure 1.

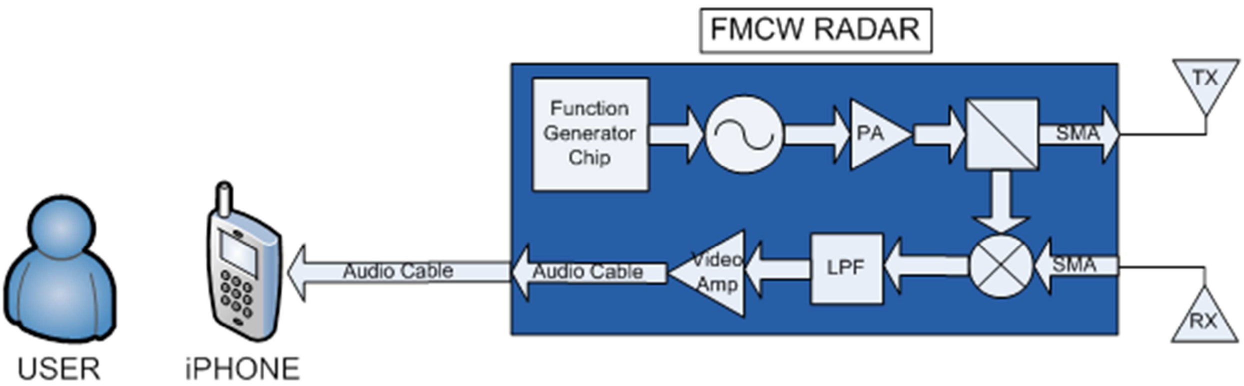

Figure 1: FMCW Radar system high-level block diagram.

The product design consists of three main sub-systems: the imaging device, the real-time processing terminal and the user interface. The imaging device will comprise of a directional beam transmitting antenna and receiver capable of penetrating low-visibility environments in order to reveal targets within its beam-width. The transmitting antenna will be optimized for transmission of a 2.4 *GHz* (centre frequency) signal and capable of producing a sufficiently powerful signal to range profile moving and stationary targets at 150 meters from the hand-held radar system. The transmitter will be paired with a directional receiving antenna able of detecting return echoes from objects at ranges in excess of 150 meters. The antennas will be packaged compactly with the front-end function generation circuit and back-end analog filtering circuit alongside the signal processing terminal and user interface unit. The antennas will be light and unobtrusive to the personnel carrying the device.

Over the past 13 weeks, Shift Technologies have been working vigorously to produce a proof-of-concept model. This document provides a summary of the process and results of this dynamic and challenging project.

2 Current State of the System

Our finished product consists of the radar hardware- coffee cans, RF components, and PCB- enclosed within the case, two 6 V battery supplies, and the iPhone app as a general user interface. We have successfully developed two signal processing algorithms in MATLAB that analyze the radar data: 1-D Range Plot and 1-D Real Time. Furthermore, we were also successful in converting 1-D Range Plot into Objective-C to be put into an iPhone application. All of the components meet the requirements for a proof of concept model.

Hardware

The portable coffee can radar system was derived from Dr. Gregory L. Charvat's teaching webpage [1]. The listed block diagrams and schematics were slightly modified and then utilized for this project. As mentioned above, the radar system operates with a center frequency of 2.4 *GHz*, as specified in Dr. Charvat's documentation. The function generator chip creates the required modulating waveform for the oscillator and a synchronization square waveform of equal duty cycle and period as the modulating signal. The video amplifier circuitry is composed of three stages: the first amplifies the intermediate frequency output, or return echo signal, for an approximate 22 *dB* gain, while the remaining two stages are used as a low-pass filter for the return echo with a cut-off frequency of 15 *kHz.*

The function generator and video amplifier circuit's components were converted to primarily surface-mount components in preparation for the PCB layout. The radar case was made out of ABS plastic and contains all of the hardware components. The two 6 *V* battery packs, radio-frequency components, function generator and video amplifier PCB, and antennas have all been secured in such a way that they can be removed if required. Furthermore, the top piece of the case can be removed easily in order to access all of these components. The exterior of the case has master on-off switch (dual-pole, single throw) for all of the electronics components and a mounting position for the iPhone.

Signal Processing

The signal processing terminal uses a frequency-domain approach to resolving targets and further target-locking. Due to inherent hardware limitations such as coupling between antennas, gain saturation at the audio input port and the large beam-width; various filtering and preconditioning algorithms were implemented in order improve target acquisition, locking, and tracking. The signal processing algorithm is efficient in removing severe distortion due to strong antenna coupling as well as other low frequency clutter; furthermore, the algorithm is able to attenuate stationary targets when moving target trajectories are desired and vice versa. The design also maintains an ability to adjust the range of interest ('depth of field') of the radar which facilitates improved performance when operators have foreseen knowledge of the target terrain and range limitations inherent of the environment. The algorithm is able to discriminate noise 'false alarms' from true target data with high probability and using 'persistence' events - able to maintain target-lock despite high noise or low SNR (signal-to-noise ratio) environments. The 1D range profiler is designed to be as time-efficient as possible in every aspect of preconditioning and target-locking and tracking. This time efficiency has allowed the signal processing to operate in 'real-time'; hence, alternating between recording and processing with no significant loss of continuity.

Software

For the software, we were tasked with capturing data on to the device and converting the MATLAB code into objective C for the iOS platform. Originally, we intended to capture data using the AUX input of the iPhone. Unfortunately, the iPhone does not support stereo AUX input, thus, we needed to buy GuitarJack, which provided stereo AUX in, and then program the interface. Concurrently, we converted the MATLAB to objective C. In addition to the eight MATLAB functions, we needed to implement matrix manipulation functions, memory allocations, filtering functions and FFT functions.

3 Deviation of the System

Our goal at the beginning on this project was to design a proof-of-concept model for our radar system; hence the components of our project meet the proof-of-concept functional requirements. Most of the deviations in our project can be attributed to challenges encountered in the software aspect. Although the majority of challenges were overcome, the time constraint of this project forced us to make sacrifices on our deliverables.

Hardware

All of our basic functional hardware requirements set out for our radar were realized. The majority of the electronics for our system were utilized from Dr. Charvat's portable radar project; however some modifications were made to the original circuit that were specifically made to accommodate our project. These modifications included adding a voltage divider to increase or decrease the strength of the synchronous square waveform and modifying some of the resistor values.

The hardware packaging resembled the initial design all with one exception: how the coffee-can antennas were secured. It was never fully thought through how the cans would remain stationary during use and be able to be taken out if ever required. However once preparations began for securing all of the interior components of the case, it was quickly realized that a method needed to be devised to hold the antennas in place. The simple, but efficient, solution to this was to utilize bungee straps that would tightly wrap around the coffee fans and be secured via a nut and bolt. This remains only a proof-of-concept method for mounting the coffee can antennas.

Signal Processing

The signal processing terminal was able to achieve all required processing tasks for 1D range profiler in outdoor or open area environments - in a time-efficient manner. Due to the high-variability of return echo strength from even stationary targets, the algorithm is unable to fully remove all stationary targets within the field of vision which detriments its ability to perform in close-quarter environments.

The 2D range profiler was never realized due to time constraints; however, the 1D range profiler was configured to facilitate easy transition from 1D to 2D terrain mapping by organizing all separate target trajectories into discrete modules which can be compared and correlated individually with multiple 1D scans in order to lock onto targets with azimuthal angle accuracy.

Software

Ideally, we hoped to create an identical imitation of the Matlab code; however, there were a few changes. Due to the nature of memory allocations, it was simpler to implement multidimensional arrays as a linear strip and address the indices correctly. Also, the filter function was not available**,** however, convolution and filtering are identical if we only consider the first N samples of the convolution result. Lastly, printing the results on the iPhone is not as a simple plot function due to the limited number of pixels. This resulted in decimation of the results to fit into the iPhone screen.

4 Future Plans

The completed project only represents a proof-of-concept model; hence there are many different aspects of this project where more work would be beneficial. Shift Technologies believes that there is significant potential for future development of this product.

Hardware

The hardware specifications for the electronics of our system are believed to be sufficient moving forward with a marketable product. The design set out by Dr. Charvat, with our modifications, met all desired requirements it is believed no further work is required on the electronics. The PCB design also met all expectations for both a proof-of-concept and marketable product. Small modifications could be made to the PCB that includes modifying the mounting hole's location and size and changing the function generator and operational amplifier to surface-mount components.

Significant work could also be done to the case to ensure that it is suitable for the harsh conditions of certain emergency response personnel. Although durable enough to withstand general abuse, the current design with ABS plastic would be susceptible to breaking due excessive force, such as being dropped from anything above three feet. Furthermore, sealing the case to protect the internal components of the system needs to be taken into consideration. The current design protects the electrical components from rain however it is not able to guarantee protection from water damage. Other considerations that need to be taken into account would how the case would put up with excessive heat. Different considerations for the material of the case may need to be considered for a marketable product.

Signal Processing

The signal processing algorithm for 1D range profiling is sufficient for emergency response search and rescue applications as well as firefighter applications in outdoor or open area environments; however, for close quarters the signal processing is unable to fully compensate for the hardware limitations - large beam-width of antennas and antenna coupling - resulting in sub-par performance. In the future with improved hardware, the signal processing terminal will support stronger filtering of incoming data and close proximity target acquisition and tracking.

In future iterations of the signal processing algorithm, target tracking will be able to be performed for 2D applications. The emergency response personnel will be able to scan azimuthally with the radar device, and the signal processing will be able to acquire target locks that will persist as the angle is changed and subsequently plot a 2D image of the low-visibility terrain.

In later stages of testing the 1D range profiler, the algorithm was able to identify certain key characteristics of target cross-sections, and in doing so able to potentially discern and categorize various classes of targets. The most important future application of cross-section evaluation is having the ability to discern human and inanimate targets.

Software

In the future, we hope to increase speed, to implement 2D ranging and to port our work on to device with native stereo AUX in. This will ideally lead to real time imagine with the radar as well as added functionality.

5 Budgetary and Time Constraints

Budget

Table 1 outlines the projected and actual costs of each of the components of ERadar up to April 25, 2012.

Table 1: Projected versus realized costs of ERadar.

Required Materials	Projected Cost	Realized Cost
Coffee Can Radar Kit	**$400**	**$292.48**
- Portable Radar System (MIT) [1]		
iOS Developer's Software Kit	**$100**	**$110.88**
- *Apple* iOS Developer's Program		
PCB Layout Costs	**$200**	**$183.63**
- PCB (*AP Circuits*)		$114.20
- PCB Components (*Digikey*)		$69.43
Hardware Packaging of Radar	**$50**	**$53.83**
- Case material (ABS Plastic)		$10.00
- 4" Holesaw, miscellaneous tools		$19.61
- Bungee cords, adhesive velcro, split sleeved tubing		$24.22
Unexpected Costs	**N/A**	**$187.60**
- GuitarJack		$167.65
- Express Shipping (Broken GuitarJack)		$19.95
Totals:	$750	$828.42

Upon examining the discrepancies between the projected and realized costs, the stark difference between the two stems from the unexpected cost of purchasing the GuitarJack. Had the iPhone had a stereo-input, we could have eliminated this cost and been over $100 under budget. This is a huge accomplishment and testament to the planning of Shift Technologies; to end up under budget of our expected costs, while still meeting are specified requirements, makes all of us extremely proud of how the financial aspect of the project was managed.

Shift Technologies was fortunate enough to receive $700 in funds from the ESSEF. The remaining costs of the project were team-funded and will be divided up equally.

Time Constraint

Table 2 outlines the projected and implemented dates for each milestone of ERadar.

Table 2: Projected and implemented deadlines for ERadar.

Item	Proposed	Implemented
MIT Coffee Can Radar Built	January 1	January 8
Signal Processing – MATLAB Variable Range, 1-D Range Plot Interpolation	January 22	January 29
iPhone – Graphical User Interface	January 22	January 24
iPhone – Interface with Compass	January 30	January 24
MATLAB to Objective-C Code (1-D Range Plot)	February 11	April 21
Case Construction	February 16	February 23
Signal Processing – MATLAB 1-D Real Time Interpolation	March 12	April 22
Packaging of all Components inside of Case	April 1	April 20
Signal Processing – MATLAB 2-D Range Plot Interpolation	April 1	*Not Implemented*
MATLAB to Objective-C Code (1-D Real Time)	April 5	*Not Implemented*
MATLAB to Objective-C Code (2-D Range Plot)	April 8	*Not Implemented*
Completed Testing	April 10	April 25

Although optimistic at the beginning of this project to sticking to the proposed deadlines, Shift Technologies slowly fell behind schedule and were forced to modify certain deliverables. Before the semester began, our team began preparations for this project. By the end of January, we felt that we had put ourselves in an optimal position moving forward. However as the project progressed and we began to convert the MATLAB code into objective-C, we ran into numerous problems- both small and large scale- that set us back significantly. At the start of this project, we had several ambitious signal processing algorithms beyond the basic 1-D interpolation. However as the complications arose, we really only had time to fully commit to having the 1-D interpolating method on the iPhone.

As in typical Engineering 440 fashion, a lot of our deadlines came down to the final two weeks leading up to the presentation on April 27. Once final exams were completed, all group members committed close to 100% of their time to ensuring we had a finished project to demonstrate. Despite the flurry of last minute activities, Shift Technologies was satisfied with its productivity and willingness to stay focused over the past four months.

6 Interpersonal and Technical Experiences

Mehdi Stapleton

I began throwing ideas for capstone projects back and forth with fellow teammate Nelson Meira back in Spring of 2011. The idea of radar was brought up, after I had just completed a cooperative education at Kongsberg Mesotech, under the supervision of Dr. Peter Fox - one of the masterminds behind the RADARSAT-2 project launched by MacDonald, Dettwiler, and Associates Ltd. (MDA) back in 2004. Nelson was quick to point out the daunting nature of our task, but agreed to the idea as long as I was confident in his ability to contribute substantially to the project - he would.

Dr. Fox had instilled in me a strong desire to be a part of close-knit team of talented individuals working on a project which spanned many areas of training after seeing his current venture of building a revolutionary type of sonar system at Kongsberg. When I set about looking for strong group members to undertake this project, I was very quick to latch on to Laurent Ye - who I knew was a perennial high performer and could be relied upon for any software-related tasks as well as had a firm background in communication theory-which would be invaluable in a radar-related project. Having been told a brief overview of the proposed project Laurent quickly introduced Borna Vojdani and Steve Rickards as strong candidates who he knew could be relied upon no matter the task. The first thing that struck me about Borna was his passion, it didn't take much selling before his eyes widened and he knew he had to take on this challenging capstone project. Conversely, Steve was an unknown quantity - I knew he was clever from the engineering grapevine, but aside from that I had no idea what his level of commitment would be to the project. This was ironic since he turned out to be the most driven for success of all of us.

Due to my strong background in communication theory and past Matlab projects in audio speech processing and multimedia communication, I adopted the role, alongside Nelson, of designing the signal processing algorithm responsible for target acquisition and tracking. We would also work together to build the first crude prototype for the radar hardware, starting the winter break before the official start of the Spring 2012 semester. The roles fellow teammates quickly begin to materialize simultaneously, as Laurent and Borna gravitated towards the iPhone software interface and Steve assumed the role of team leader and hardware designer.

The progress on the signal processing side was originally quite a hurdle, trying to overcome the sharp learning involved in FMCW theory and radar processing. The 'start-up' templates provided through the

Dr. Chavrat's course webpage, quickly became obsolete as we tried to achieve high-accuracy, long range, and low SNR applications for the ERadar product. Due to the limited nature of resources on target-tracking and indoor applications using FMCW, the signal processing task quickly turned to trying to manufacture our own methods of target-locking and tracking as well as achieving a variable range algorithm which could function in low-visibility or high clutter environments.

With the first major milestone completed for the signal processing algorithm, and quite content with ourselves for having developed a time-efficient method of predicting target trajectories, as well as organization of target trajectories into easily manipulated vectors, we set out to perform a barrage of outdoor field tests in order to validate our custom algorithm. And it was working. At this point in early march with the first iteration of a functional 1D range profiler completed, I set about trying to refine the performance. The 2D range profiler still ever-present in my mind; however, without a completed iPhone interface the algorithm would be unable to extract azimuthal angle data, gathered by the iPhone compass, and hence unable of any 2D interpolation. In hindsight, I should have started completing a real-time application of the 1D range profiler at this time instead of upgrading the filtering and target-locking. This resulted in a time compressed version of a real-time profiler in late March.

Overall, I am very proud of everyone's accomplishments and contributions to the radar project, with all aspects of the software, hardware, and firmware clicking together when they needed to. I know everyone came away from the project with a sense of pride in completing what we set out to do in October of 2011, and I would work with any of my teammates without a seconds notice if given the opportunity again.

Steve Rickards

Before this course began, I had already decided who I was going to work with for this project. Not only was I able to work alongside my good friends, but I had the privilege of working with some of the brightest young minds at SFU. I believe that our respective engineering fields and group dynamics set us apart from all other groups this semester, and there is no one else I would have done this project with instead of these four talented engineers.

This was definitely one of the most challenging courses I have undertaken at SFU; however the amount that I learned both technically and about myself rivals nothing else that I have done in the past. I took on the majority of the hardware aspects of this project due to background in PCB design and mechanical aptitude. Although I had some past experience with Altium Designer during my last co-op, it was quite the learning experience for me doing the entire design process on my own and then having a circuit board sent off to an outside company to be made. My past experiences in my high school shop class and job at *KMS Tools* also made me the prime candidate for designing and constructing the case. Although it is something I had done in the past, it was again a learning experience trying to get a hold of all of the necessary materials and tools needed for this project. Finally, I also took on the unofficial role of team leader in the sense that I was in charge of ensuring that the group always had an open line of communication and acted as a mediator during meetings.

There were definitely times where there were disagreements and animosity between us, however the main goal of completing this project always prevailed and we always pulled through. I really saw my leadership skills flourish in this environment and I believe it was a strong asset to our team. With that said however, the members of Shift Technologies are quite capable of organizing themselves and I have the upmost confidence that the project would have been completed even without my leadership qualities.

Overall I'm quite happy with the final product and the way our team organized ourselves this semester. If I could go back and do things differently, I would only have started working on this project more seriously in the previous semester. It was difficult to start this course and be expected to have the majority of your project figured out for the project proposal only two weeks into it all. I feel that if our group had ironed out definitive deliverables before the semester started, rather than the approach of "we'll see how far we get," we would have been better prepared leading up to the final weeks of the project.

As this project started to come to an end however, a huge sense of pride and accomplishment started to build for what myself and my group members had accomplished. Although certain aspects were completed with little time left, I was extremely pleased with the commitment and tenacity that my team members showed in attempt to complete this project on time. Though I wish our group would have been able to complete more aspects of this project that we set out in the start, I am still extremely satisfied with our results. The personal and technical skills gained in this project are a milestone to my education career and SFU.

Laurent Ye

Overall, this was an enjoyable project and I learned a lot. The challenges I faced in this project will help me tackle real life problems. This includes: researching and characterization of the problem is key to understanding how to solve it, fully analyzing your solution in order to ensure it meets all requirements and planning to be on time and on budget.

For our protect, we didn't do enough researching and characterization of the problem. As a result, we weren't able to tackle problems as efficiently as possible. For example, the 2D ranging could have been more easily implemented if we had a mathematical model before starting the project. Defining an algorithm or a model is critical for creating an plan of attack. From real time imaging to trajectory tracking, we had so many ideas we wanted to implement and never really settled on one. We bounced between ideas and ended up somewhere in the middle.

In addition, the discovery of mono AUX input on the iPhone could be easily avoided if we simply did more research. This would have saved us time and money. Instead of spending hours trying to interface with it, a dedicated device would have worked instantly, and instead, of spending $160 on the GuitarJack, we could have used the extra money on better antennas. In industry, this is costly and it could mean the difference between a competitive product or a flop. Therefore, I am glad I was able to experience this problem in the classroom before heading out into the job environment.

Lastly, we were unable to deliver a device that meets our Design and Functional Spec simply because we underestimated the time for each section to be completed. We never considered our course load, work, or sports when planning our time. One major cause of the incompleteness is that we were too idealistic. The goals we set were well defined but there was no concrete approach to solving the problem. This rendered our approaches inefficient and definitely slowed us down.

In hindsight, these problems could have easily been avoided but the lessons taught were invaluable and they will aid and shape my decisions in the future.

Borna Vojdani

Due to the strong presence of leadership roles within our project group, my roles within the group, my personal goals and objectives for the project, as well as those that attributed to the success of other members in the group were clear and concrete from the first day of the semester. My passion and knowledge of the technicalities surrounding practical engineering using today's off the shelf products and hardware allowed our group to immediately come up with potential design solutions. From here, I had the opportunity to dedicate myself to the proposed solution, taking advantage of the most recent advances in mobile programming and handheld computing. Our success in programming a handheld device to do the complex task at hand could not have been feasible without the dedicated contribution of several group members including myself.

The most important lesson that I took away from the countless hours spent on algorithms, programming, troubleshooting, and testing of our design, was that any task that may at first seem not possible can be achieved, through the deconstruction and solving of many smaller hurdles that hinder in the path. Furthermore, I gained a new level of confidence, by venturing farther beyond my perceived ability and skillset. This was achieved by working alongside with group members, whose skillsets complemented and completed mine in areas in which I lacked the necessary experience and understanding to successfully solve the problem in a timely manner. This is an important lesson that I took away from this group effort: by being open minded, trusting in the abilities of your peers and working with them to complement and complete the necessary knowledge and background, any difficult problem is no more complicated than the solving of problems in which my skills and knowledge excel in.

I am certain that my abilities as a software developer and designer increased significantly throughout this project. I was able to dramatically increase my understanding of the function of mobile and hand-held devices, their operating systems, the high-level and low-level hardware management within the device and the necessities in interacting with and collecting sensory information and data from the end user of the device.

If I were to partake in this course again and to start fresh, I would change one aspect of my workflow within the group. I would find the necessary means to work in the immediate presence of at least one other group member as much as feasible. This is an important aspect of group work that I realized throughout this semester; working alongside a partner and exchanging thoughts as you progress through the project can significantly shorten the amount of time needed in finding and solving problems with the design. As members in the group can complement each other's expertise, potential issues are generally identified before they become design problems, and this often can make or break a deadline.

Thorough out this semester, I had the opportunity of working with a group, of what I personally consider as a few of the most talented, passionate and dedicated future engineers. Looking back, I enjoyed even the toughest of the challenging times that pushed our group to the bounds of our capabilities. The amount of knowledge and experience that I gained, both in technicality, and in communication with others I find invaluable, and in no way representable by the success of our project.

Nelson Meira

Though I was completing the signal processing course concurrently with this project course, I was part of the signal processing team and aided in the development of the algorithms implemented in MATLAB. This aspect of the project added to my experience in working with analog circuitry and in designing and implementing code in MATLAB. My other main role in the group involved documentation; I was responsible for compiling the individually written parts for every document that we needed to submit, though other members did contribute to editing and reviewing the final documenting. We learned to simultaneously contribute to a collaborative work, using tools such as Google Docs as aids.

While our project entailed much technical work, there was as much difficulty in collaborating and integrating our tasks as there was in completing the tasks themselves; I feel that bulk of what I learned pertained to group dynamics, in planning and allocating tasks as a team and cooperating so as to keep us moving forward as a whole when separate individuals ran into problems. This includes experiencing the frustrations of feeling "inefficient", for example, when a problem arising in one task forces subsequent dependent tasks to be delayed —perhaps we may have underestimated or overestimated certain milestones — and learning how to remain diligent towards the completion of our project by adjusting our schedule explicitly, rather than imprudently "going with the flow" and hoping for things to work out. Our group did well in keeping track of progress; some group members were better than others at this, but our member Steve did an excellent job in managing the team and ensuring we stayed on top of things. We remained a cohesive group, even outside of our project work.

Two areas that could most use improvement involve, perhaps not by coincidence, better planning. Firstly, our group meetings occurred on time and had a planned itinerary, but discussions would tend to digress. Secondly, our testing procedures were inefficient. We did not keep consistent control cases, and rather than methodically running all tests and recording results *before* analyzing the data and attempting to solve any problems, we would tend to come up with new tests on the spot at the moment we ran into unexpected results. In both cases the problem may lay in lack of firmness, due to clashing (and unyielding) mindsets: though our disagreements didn't lead to in-fighting, we tended to lose sight of our original goals as we played with ideas whenever a new problem arose. This is not to say that we did not listen to each other, however — in fact, our discussions tended to get carried away because of push and pull between our inputs.

The Capstone (Engineering Science Project) course has proved to be a challenge in many ways, but has definitely become an important learning experience. It has provided some insight into what work in the industry may be like, as well as the opportunity for us (the students) to take on an independent role and to learn how to take initiative into our own hands.

7 References

[1] Gregory L. Charvat. (2011, January) MIT IAP 2011 Laptop Based Radar: Block Diagram, Schematics, Bill of Material, and Fabrication Instructions. [Online]. http://ocw.mit.edu/resources/res-ll-003-build-a-small-radar-system-capable-of-sensing-range-doppler-and-synthetic-aperture-radar-imaging-january-iap-2011/projects/MITRES_LL_003IAP11_proj_in.pdf