School of Engineering Science
Simon Fraser University
8888 University Drive
Burnaby, BC
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January 16, 2012
Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Project Proposal for Portable Emergency Response FMCW Radar

Dear Dr. Rawicz,

Attached to this letter is our team's proposal for a Portable Emergency Response FMCW Radar, as per our Engineering Science 440 class. This product will be designed such that it can be used by emergency response personnel in a wide range of low visibility applications.

What makes our product so appealing is its versatility. Designed to be hand-held, durable, and adaptable to variable range scales, it is a product that can be used in numerous professions that pose visibility problems. Firefighters, search and rescue personnel, and police officers are just a some of the professions that would benefit from this system.

In this document, we have outlined the numerous problems faced by emergency personnel, an overview of our project's design, sources of information, a projected budget and proposed funding, a tentative schedule which detailing our milestones, and a team overview. This proposal will also examine other possible solutions to this problem and briefly discuss why a FMCW radar is the best option.

Shift Technologies is composed of a five-member team whose knowledge and skill set is second to none. Borna Vojdani, Laurent Ye, Mehdi Stapleton, Nelson Meira, and Steve Rickards are all fourth-year engineering students majoring in electronics, computer, or systems engineering. Should you have any questions or concerns regarding our proposal, please feel free to contact myself via email at mps8@sfu.ca.

Sincerely,

Mehdi Stapleton

Mehdi Stapleton
President and CEO
Shift Technologies

Enclosure: *ERadar - Proposal for Portable Emergency Response FMCW Radar*

SHIFT TECHNOLOGIES

ERadar	Portable Emergency Response FMCW Radar
Project Team	Mehdi Stapleton Steve Rickards Laurent Ye Borna Vojdani Nelson Meira
Contact Person	Steve Rickards sdr2@sfu.ca
Submitted to	Dr. Andrew Rawicz —ENSC 440 Steve Whitmore — ENSC 305 School of Engineering Science Simon Fraser University
Issued Date	January 16, 2012
Revision	1.0

Executive Summary

"The only thing worse than being blind is having sight but no vision."
Helen Keller

Our eyes allow us to perceive the world around us in all its subtlety and guide us confidently through the world. Despite their incredible adaptability, they suffer obvious limitations when it comes to low visibility situations because the visible spectrum can be easily absorbed and blocked.

Imagine being a firefighter who is desperately searching for survivors. Heavy smoke obscures part of your vision, while white hot flames blind the other. You can only inch forward as your eyes fight to decipher obstacles and hazards. Uncertainty dominates every step you take.

The National Fire Protection Association (NFPA) estimated that 32343 firefighters in the United States were injured in 2010 [1] under these conditions and it is not hard to see why. The physical exertion required coupled with blinding situations make a challenging job dangerous. Many tools have been developed for low visibility situations such as Infrared imaging or Light Detection and Ranging (LIDAR). The shortcomings left by the performance and adaptability pitfalls of these tools in short distance, emergency response situations, call for the development of new technologies that offer a greater visibility, portability, and usability in non-ideal environments. Such challenges like excessive environmental heat, visibility barriers such as smoke and fog, and target masking via environmental obstacles can be overcome by employing short wave, high frequency radar technologies, which are safe to the human body.

At Shift Technologies, we aim to use Frequency-Modulated Continuous-Wave (FMCW) radar as an imaging device for rescuers in low visibility situations. We envision a rugged inexpensive handheld device that will allow the rescuers to scan their field of view to obtain an overhead view of the environment to view potential hazards and obstacles. Our device will work for ranges up to one hundred meters and provide a resolution of approximately twelve and a half centimetres. When compared to current solutions, ours provides the best compromise between range, resolution and cost.

Shift Technologies is a group of five fourth-year engineering students with strong backgrounds in electronic circuits, signal processing and programming. In the next twelve weeks, we hope to design and implement a proof of concept FMCW radar system and the required signal processing apparatus. To reduce cost, we will utilize a predesigned radar system and perform the signal processing on an iPhone. Thus, the aim is to develop and implement the signal processing algorithms as an iOS app. Currently the entire project is currently budgeted at $750 and we have already obtained $700 in funding from ESSEF.

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List of Figures and Tables

Glossary

ESSEF	Acronym; Engineering Student Society Endowment Fund
CCRS	Acronym; Canada Center for Remote Sensing
FMCW	Acronym; Frequency Modulated Continuous-Wave
LIDAR	Acronym; Light Detection and Ranging
PD	Acronym; Pulse Doppler (radar methodology)
iOS	Apple's mobile operating system.
MATLAB	Mathworks' high-level technical computing language

Introduction

Emergency response personnel are trained to remove people from perilous situations. Firefighters escorting survivors out of burning buildings or search and rescuers locating missing hikers are just two heroic situations where endangered civilians are located and taken to safety. What happens when the location of the person, or persons, in trouble isn't immediately known? Smoke can engulf entire buildings, preventing firefighters from looking for survivors; search and rescuers have massive search areas that must be meticulously combed through in order to find a lost hiker. The whole premise of an emergency response system is to know where possible survivors are and deliver the necessary help quickly-so what happens when we don't know where they are?

Now, imagine a tool that can provide 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. A device with such capabilities would be an extremely valuable asset to numerous professions that require work in dangerous environments; however, its real value would only come with its versatility and ability to be used in a wide variety of applications. Hence, a determining factor to the versatility of this imaging tool would be its adaptability, portability and feasibility.

Shift Technologies is proposing a product that will meet all these requirements for emergency response personnel. The device would scan the area in question and process the return signals in real time. After processing, an overhead view would be displayed on an LCD interface or stored for further processing or analysis. Regardless of the capture method, the multiple frames of incoming data would be used to stitch together by the processor into a two-dimensional (2D) image of the area in question. Furthermore, to meet the versatility requirements as stated above, the device must be portable, lightweight, and battery powered.

In addition to the demand for such a product in the professions described above, the Canada Centre for Remote Sensing (CCRS) is another market that would utilize this kind of tool for surveying purposes. The CCRS provides data for accurate three-dimensional positioning in Canada [2] and an imaging tool like this could be utilized to help them with this task. Furthermore, a portable device capable of surveying large areas would assist the agency's Emergency Management Team accomplish its main goal of supplying products to facilitate emergency response [3].

This proposal will discuss Shift Technologies' design considerations for an emergency response imaging device. While outlining possible technologies, each option's viability will be discussed and the chosen methodology will be justified. This document also includes a system overview, budgeting information, scheduling, and an informative company profile of the design team working for Shift Technologies.

System Overview

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 transmitter and receiver capable of penetrating low-visibility environment in order to relevant targets within its beam-width. The imaging device will successively scan azimuthally across the terrain of interest which in turn, will gather a finite set of 'beam-widths' for further processing. The raw data is fed in real-time to a processing terminal which filters out clutter and noise in the received signal and extracts the range and velocity data of such targets. Subsequently, the set of 'beam-widths' or terrain sections analyzed by the imaging device are stitched together by a 2D interpolation algorithm. Lastly, the generated 2D cross-section of the low-visibility environment is sent to an LCD monitor and graphical user interface.

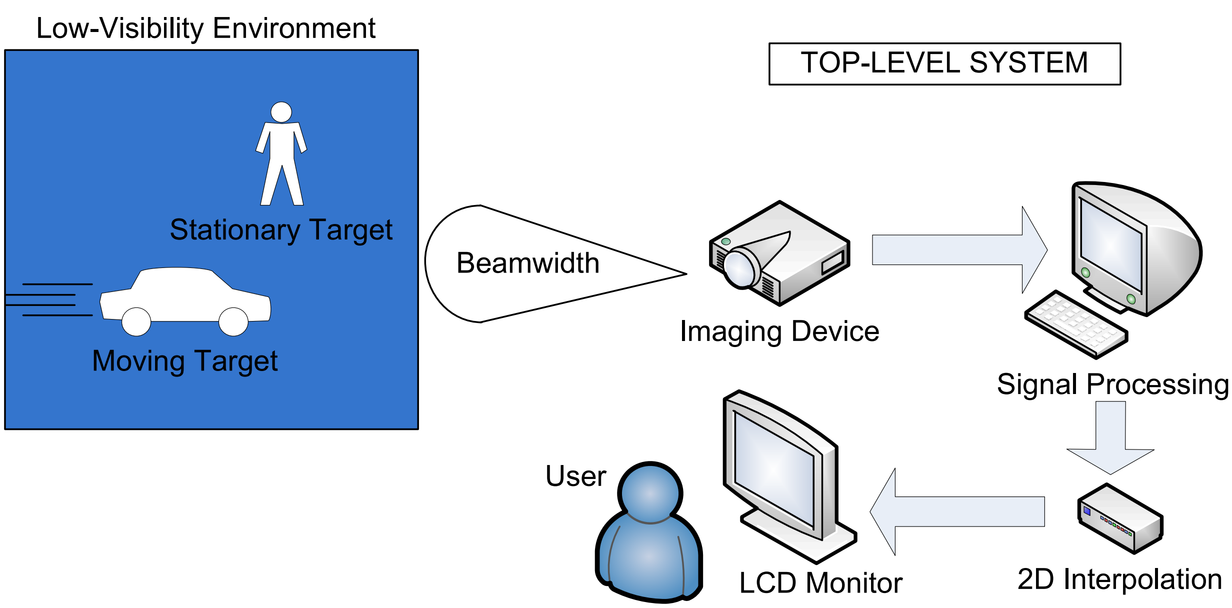


Figure 1: Top-level block diagram for the *ER*adar

Existing Solutions

Infrared imaging, technically referred to as infrared thermography or thermal imaging, is a 2D imaging technique that utilizes infrared radiation. The images produced through an infrared imaging system are called thermograms; each thermogram is a representation of thermal distribution throughout the surface of the measured entity and allows the detection and representation of any object or energy source that is not at the absolute-zero temperature because all objects with a non-zero temperature emit infrared radiation. As a result, this does not require an ambient source of radiation to "illuminate" the object.

Beyond cost and complexity, infrared imaging systems are susceptible to unwanted noise generated from the environment and nearby entities [6]. Furthermore, objects emitting higher intensities of infrared radiation can severely mask less intensive objects from detection. This shortfall calls for the advancement of other detection and ranging techniques that employ different sources radiation which penetrates visibility obstacles and resolves masked entities behind them.

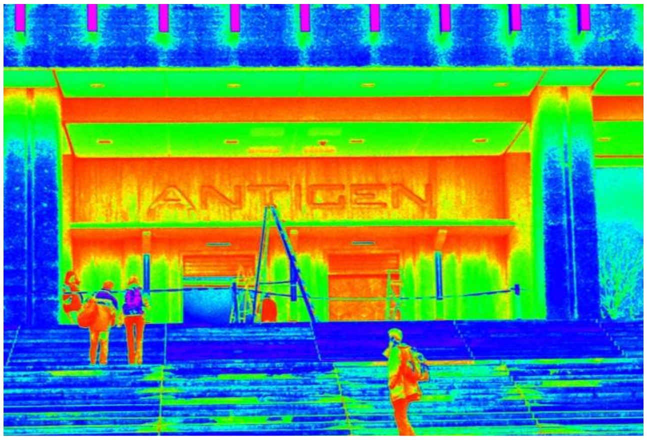


Figure 2: Infrared thermogram

LIDAR Technology

Light Detection and Ranging (LIDAR) is an optical detection and ranging technique that can measure the distance (ranging) and surface properties, such as the reflectivity or absorption, of a remote target. The LIDAR detection and ranging methods employ different wavelengths of radiation. Primarily, wavelengths that can carry a focused laser beam are required as LIDAR imaging and ranging requires the direct illumination of the target.

LIDAR imaging methods are closely tied to radar imaging techniques. By combining ranging and detection with multiple progressive measurements, LIDAR systems can be employed to computationally reproduce three dimensional representations of remote objects and scenes. The major deterring factor that limits the usage of LIDAR techniques is need for a line of sight because fundamentally, LIDAR imaging requires unimpeded reception of the transmitted beam to the measurement target .

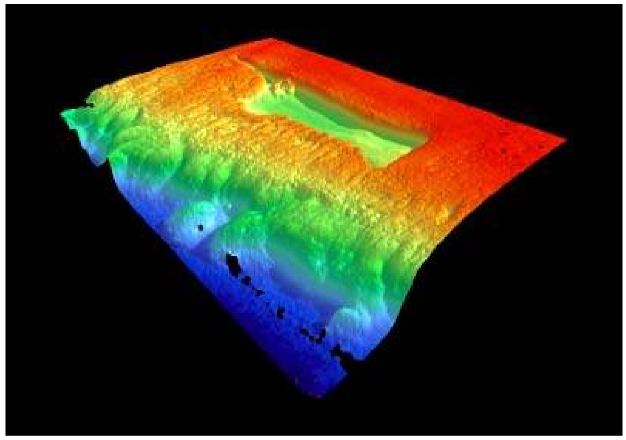


Figure 3: LIDAR mapped reef plane

The FMCW Advantage

Frequency modulated Continuous Wave (FMCW) radars possess major advantages in the detection and ranging of slow moving targets of varying sizes over traditional radar technologies. The most pronounced advantage of the FMCW radar over legacy radars, such as the Pulse Doppler (PD), is the resolution and motion detection of relatively small, slow moving targets such as an injured child. As PD radars rely on the Doppler effect, all moving entities in a scene, regardless of relative velocity, will impose a threshold noise factor on the received data [4]. This imposes a constraint in which slow moving entities of velocity below the noise threshold cannot be reliably detected. In addition, due to the nature of transmission and operation, PD radars are more complex in construction, design, and cost. The characteristics of each solution is summarized in the table below.

Table 1: Comparison of imaging technology

Technology	Range and Penetration	Complexly	Application Performance
Thermal Imaging	Moderate	Moderate	Moderate
LIDAR Imaging	Low	High	Poor
FMCW Radar (microwave)	Moderate	Moderate	High
Pulse Doppler Radar	High	High	Moderate

Proposed Solution

The project criterion requires the final product solution to satisfy three core areas: adaptability, portability and feasibility.

The adaptability criteria refers to the product being able to penetrate any low-visibility environment to resolve targets at near to far ranges as well as the ability to efficiently filter clutter and noise from the received signal at the processing terminal. For these reasons, radar is the medium of choice for imaging terrain. The microwave frequency range will easily propagate through smoke and other visibility-hindering environments. Furthermore, there are highly efficient and well-established algorithms to remove noise from the received signal [5]. For firefighting applications, radar systems will allow the user to navigate smoked filled rooms to rescue victims; whereas, other sophisticated instruments such as thermal imaging will be unable to resolve human targets due to the large presence of thermal noise (i.e. fire) in the environment. Radar presents further advantages over other imaging techniques due to its ability to detect the Doppler shift of moving targets and thus, determine the targets' headings and velocities.

The portability of the product is an equally essential aspect of the solution, especially for fire-fighting and other emergency response applications. A cumbersome LCD monitor, signal processing terminals, power supplies and imaging device could severely hinder the practicality and marketability of the product. To overcome the portability criterion an iPhone is used as the LCD monitor, user interface, and signal processor. The imaging device is chosen to be a 'Laptop Radar' system design developed by MIT professor Dr. Gregory Chavat [6]. The light-weight antenna design coupled with the sleek iPhone provides a highly-versatile product solution.

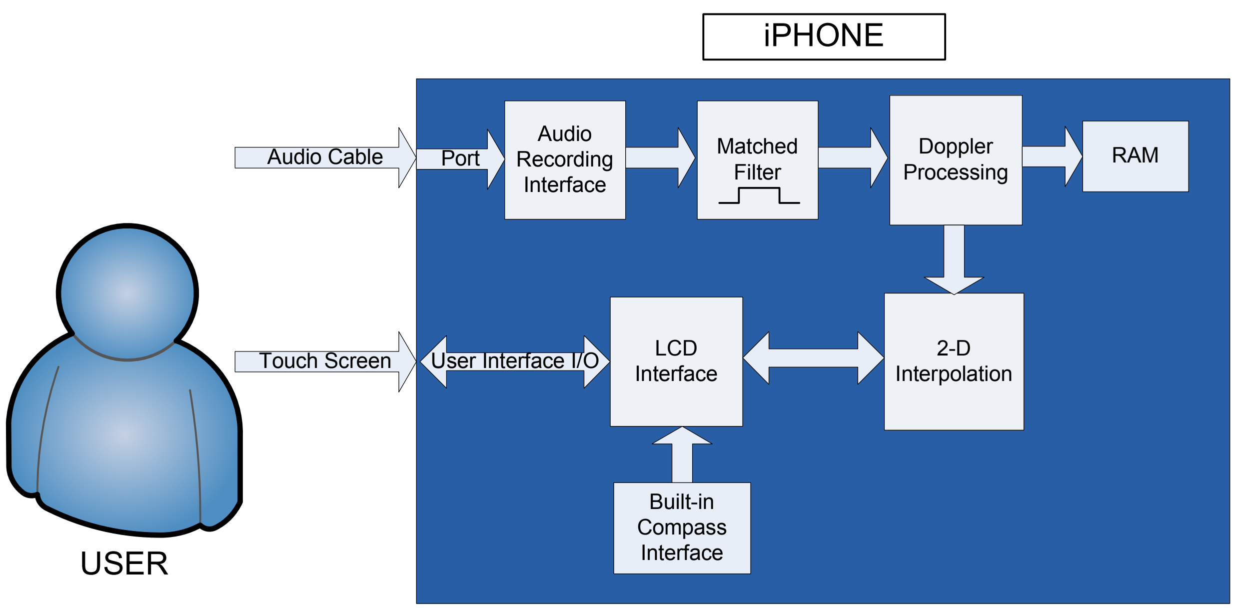


Figure 4: Block diagram of iPhone interfacing

The feasibility criterion embodies the need for a cheap, robust and time-acceptable solution to the design problem. The aforementioned FMCW Radar system design will consume the bulk of the monetary resources of the project due to its use of radio frequency circuitry; however, the do-it-yourself radar system is considerably cheaper than its 'pre-assembled' counterparts — so much so that the total budget of the radar system, antennas included, is comparable to the price of just a single high-end antenna element. The ubiquitous nature of the iPhone and related products allows funds to be conserved due to the acquisition of such devices prior to project involvement. Lastly, sophisticated design tools for the iPhone are readily accessible for quick start on implementing an application (apps).

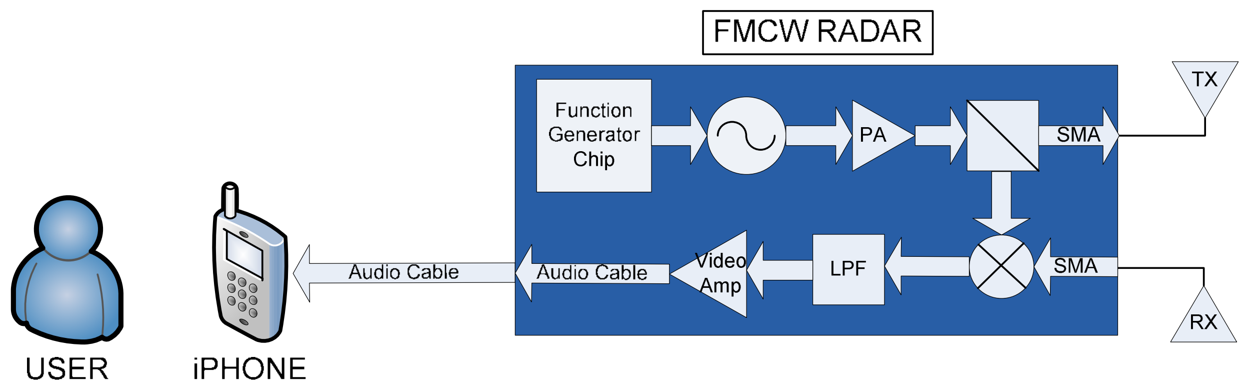


Figure 5: Block diagram for the FMCW radar component

FMCW Radar Theory

Unlike classical pulse radar systems which measures the round-trip time from transmitter to receiver ass a phase shift in the carrier wave, frequency-modulated continuous wave (FMCW) systems utilizes the difference between the time-dependent frequency characteristics at the transmitter and the frequency of the received echo for range detection. If the frequency is modulated by a triangular waveform, the transmitted and received frequencies are shown below in Figure 6 [5].

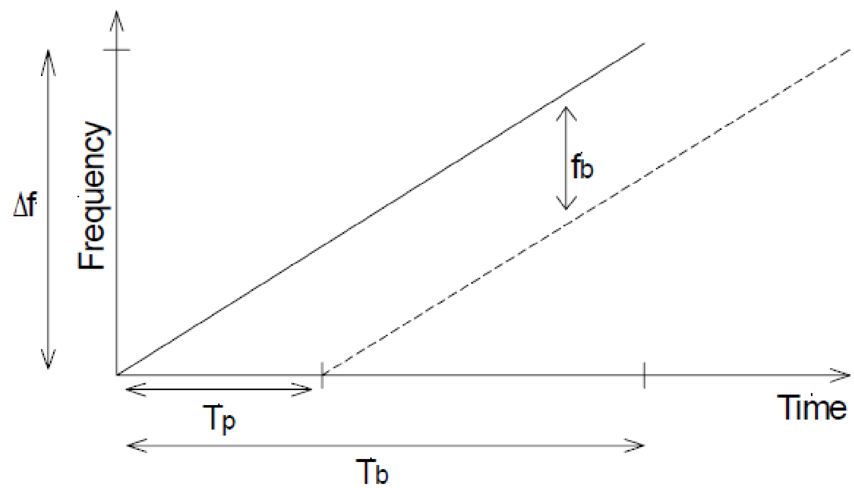


Figure 6: Reference to article: The up-ramp portion of the transmitted frequency sweep of the FMCW radar and its delayed received counterpart

Derivation of FMCW Radar Range Detection

Given the standard frequency modulation waveform shown below in equation 1:

$$y = A_C \cos(2\pi f_c t + 2\pi k_f \int_{-\infty}^{t} m(t)dt) \quad (1)$$

Where f_c is the carrier frequency, k_f is the sensitivity factor of the modulation, and m(t) is the modulating signal. Substituting in the up-ramp linear portion of the triangle waveform for m(t) and assuming a unity sensitivity factor, the above equation becomes the following signal:

$$y = A_C \cos(2\pi f_c t + 2\pi \int_{-\infty}^{t} f_0 + \left(\frac{\Delta f}{T_b}\right) t \, dt) \quad (2)$$

Taking the integral results in:

$$y = A_C \cos(2\pi f_c t + 2\pi f_0 t + \frac{1}{2}\left(\frac{\Delta f}{T_b}\right) t^2) \quad (3)$$

The term f_o refers to the initial frequency at the start of the frequency sweep and $\Delta f/T_b$ is the chirp rate of the FM waveform. The received echo will be a time-delayed version of the above transmitted by waveform presented in equation 3, by some time τ:

$$r = A_C \cos(2\pi f_c t + 2\pi f_0 (t - \tau) + \frac{1}{2}\left(\frac{\Delta f}{T_b}\right)(t - \tau)^2) \quad (4)$$

The transmitted and received waveforms are subsequently 'mixed' or multiplied together at the front-end of the receiver circuit and low passed filtered to remove the high frequency mixer output:

$$z = \frac{A_C}{2}\cos(2\pi f_0 \tau + 2\pi\left(\frac{\Delta f}{T_b}\right)t\tau + 2\pi\left(\frac{\Delta f}{T_b}\right)\tau^2) \tag{5}$$

The frequency of the low-passed filtered mixer output shown above in equation 5 is equal to $\left(\frac{\Delta f}{T_b}\right)\tau$, which is the chirp rate multiplied by the round-trip time delay. Hence, the range to the target can be calculated given that the time delay is equal to 2R/c; whereby, R and c are the range of the target and the speed of light, respectively.

Sources of Information

This project encompasses a broad range of engineering and requires a certain level of knowledge and expertise in specialized fields of study. Fortunately, our team at Shift Technologies comes from a very diverse background of engineering- computer, electronics, and systems options. As the project progresses, we will obtain information from a wide variety of sources including textbooks, creditable articles from the Internet, past employers, and friends with experience in designing iPhone applications.

The main source of information, and also the primary foundation behind this project, was the work on portable radar devices done at Massachusetts Institute of Technology's (MIT) Lincoln Laboratories. The material on MIT's online coursework [7] and Dr. Gregory L. Charvat's project webpage [8] have provided an in-depth look at radar detection systems. Dr. Charvat's page also includes a detailed list of instructions and required materials to build our FMCW coffee can radar kit. Furthermore, the signal processing software given by the webpage was used as a starting point for our code.

One of the interesting challenges faced in this project is our team's inexperience with the iOS software developer's kit. However, all members of Shift Technologies have experience in programming with C or C++ at Simon Fraser University and we believe that this basic understanding will allow for a short learning period in regards to the design of an iPhone application. As we begin to work on more complicated matters within the user interface, there will be a dependence on information provided by the internet and colleagues who have experience with developing applications.

Budget

The tentative budget outline for the portable FMCW radar is shown in Table 2. Each of the items listed in the table also include a more detailed description of the desired equipment. The estimated unit costs within this table are from various creditable sources and are believed to be accurate. However in order to account for any error, in some cases some items have been overestimated by as much as 10% to provide for contingencies. Note that for the coffee can radar kit, a detailed bill of materials can be seen in Appendix A [8].

Table 2: : Tentative budget outline for portable FMCW radar system

Equipment:	Estimated Unit Cost:
Coffee Can Radar Kit - See Appendix A for full BOM	$400
iOS Developer's Software Kit - Apple iOS Developer's Program	$100
PCB Layout Costs - Replace breadboard with PCB	$200
Hardware Packaging of Radar - Metal shielding, plastic casing	$50
Total Cost:	**$750**

Funding

As per any large project, our group will be pursuing sources of funding to assist us in the completion of this project. After presenting a written and oral presentation to the Engineering Student Society Endowment Fund (ESSEF), we were fortunate enough to be granted $700 to help fund our project. The money given to us by the ESSEF should be enough to cover a large portion of our anticipated costs. In the event that more funds are required, we will be looking to receive support from the Wighton Development Fund or the Department of Engineering Science. Our team will look into the Wighton Development Fund for reimbursement for the coffee can radar kit.

The estimated total cost of $750 outlined in Table 2 represents the maximum anticipated funds required for this project. However, if required, several cost cutting actions may be taken in order to reduce the overall cost of the project. First, our group is looking into a possible method of putting an iPhone application onto a device without going through the Apple App Store. The $100 fee charged by Apple allows for an application to be sold in the App Store, however at this point we have no intention of marketing the application and are only looking to download it onto a handful of personal devices. The second cost-cutting proposal involves the estimated cost of the PCB. This price was derived from a multi-layer board roughly 2" by 4", approximately twenty standard size holes drilled, and a standard 0.064" laminate material. It has already been discussed however that it may be more effective to only use a top and bottom layer board in order to significantly reduce our cost down to roughly $70 [9]. Any additional costs that are not covered by our received funding will be equally shared by all of the group members.

Schedule

A Gantt chart which indicates our tentative schedule for the construction of the *E*Radar is displayed below in figure 7:

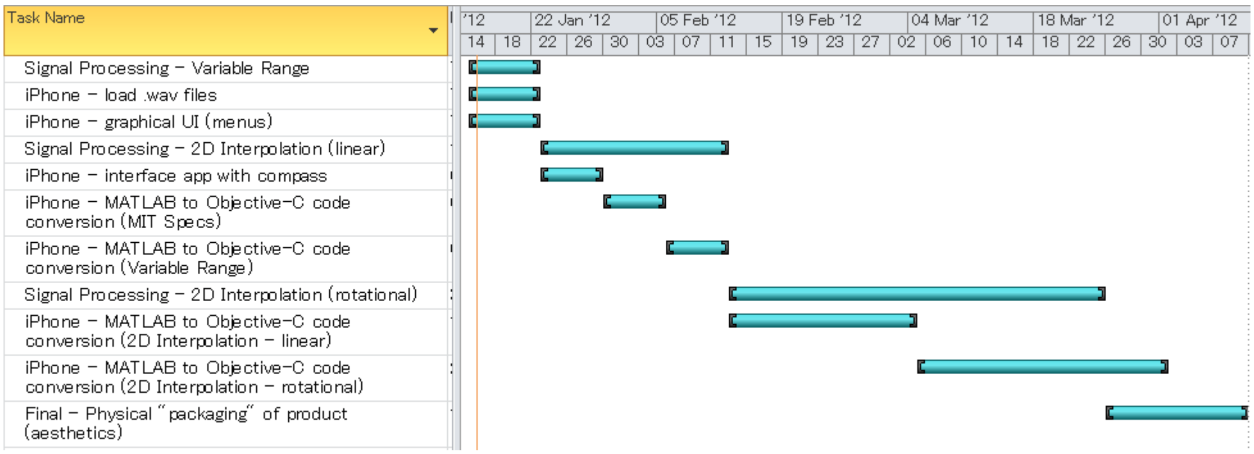


Figure 7: ERadar project schedule

Not included in the chart are two already completed tasks (the physical construction of the cantenna radio and the analysis of the MATLAB code to ensure that the radio is in working order) and the continuous task of documentation, which occurs throughout the project schedule. The project schedule is also represented below, in Figure 8:

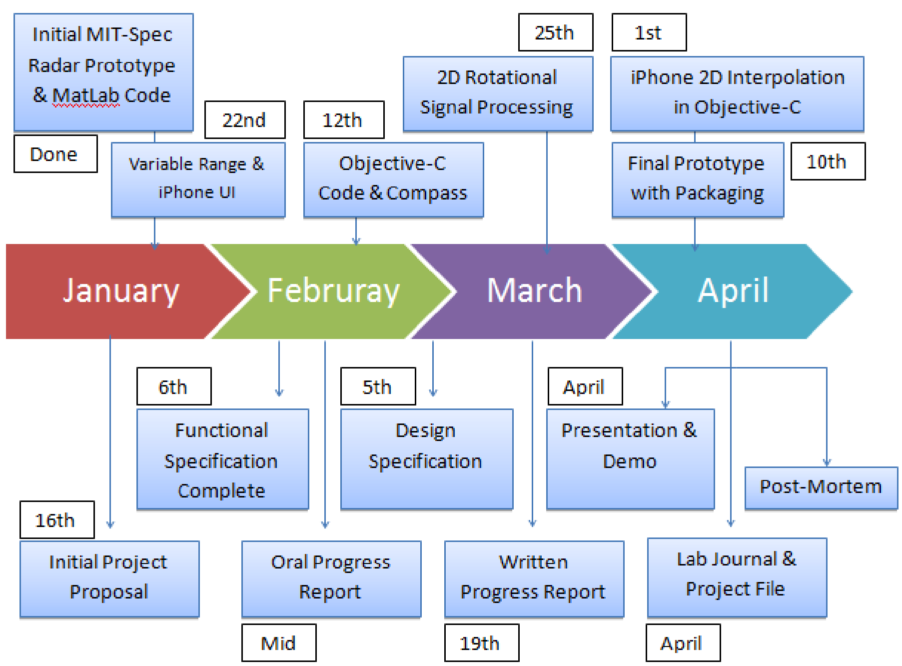


Figure 8: Milestone chart of our project schedule, including course deadlines

Team Organization

Shift Technologies is a motivated team of fourth year engineering students consisting of Mehdi Stapleton, Laurent Ye, Borna Vojdani, Nelson Meira, and Steve Rickards. One of the strongest assets of this group is its diverse background in engineering expertise; with three different engineering options, each member has a designated speciality which makes things very convenient for delegating tasks for this project. Furthermore, one of the qualities that sets Shift apart from most companies is the team's relationship outside of this course. Each member has taken a handful of courses with one another and the bonds created in the past will strengthen Shift Technologies as a company.

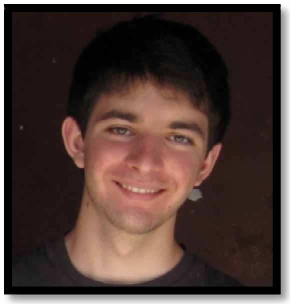
Based on the complex nature of this project, two streams were initiated that work on the two aspects of the portable radar device: signal processing and the iPhone application development. Because of the magnitude of work required in both the radar and its portability, it was decided early on that the best way to manage the team's time efficiently was to have two steams work in tandem. The individual tasks of each stream have been divided up amongst the company.

Each member has been designated a specific technical field of work based on their strengths. President and CEO, Mehdi Stapleton, has taken it upon himself to manage the radar portion of this project based on his strong background and previous experience in signal processing. Nelson Meira, General Manager of Shift Technologies, will also be assisting Mehdi with the signal processing of the radar. Nelson's documentation skills will also be utilized throughout the project on various assignments. The task of designing an iPhone application has been given to Laurent Ye, Chief Engineer, and Borna Vojdani, Vice President of Operations. They were both obvious choices for this assignment based on their backgrounds in computer and systems engineering. Finally, Shift's Chief of Finance Steve Rickards will be working extensively with the hardware packaging of the radar. Steve will also be assisting Laurent and Borna with the iPhone application as the project moves forward.

Due to the sheer magnitude of work required for this project, Shift Technologies has applied several policies to help stay on top of its work. Weekly meetings have been organized to discuss both short and long term goals of the group. These meetings are, for the most part, quite informal and Shift Technologies prides itself on its member's focus and willingness to discuss the matters at hand. Generally, Steve Rickards acts as the mediator to ensure everything is running smoothly and that the meetings stay focused on the tasks at hand. To make certain that any group work is cohesive in both content and style, Shift Technologies will be utilizing Google Documents to observe its member's rough work. Once the skeleton structure of a document is completed, Nelson Meira acts as a formatter and gathers together each member's sections for the finished product. Finally, a Google Group has been set-up to act as a communication station for all of its members.

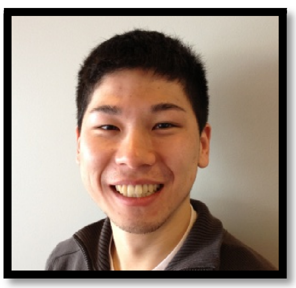
All members of Shift Technologies understand the amount of work that Engineering Science 440 encompasses. Though the task is daunting, the team is prepared to give their highest level of professionalism and work ethic to ensure the completion of this project.

Company Profile



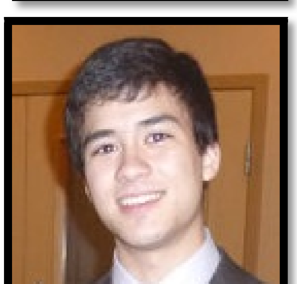
Mehdi is currently a fourth year Electronics Engineering student at Simon Fraser University. He is a SFU Gordon B. Schrum Scholarship recipient and Canadian National AP Scholar. He has worked at Verathon Medical Canada as a Jr. Electrical Engineer and Kongsberg Maritime Canada as an Electrical Engineer.

Steve is a fourth year Systems Engineering student at Simon Fraser University with past co-op experience at Teleflex Canada. At Teleflex, he worked extensively with Altium Designer and made several PCBs both for test benches and commercial products. After graduation, he plans to continuing working in a hardware specific field. In his spare time, he enjoys playing hockey and spent two years on the Simon Fraser University Men's Ice Hockey team.



Laurent is a fourth year engineering student at SFU. He has done two coops as a Test Engineer and as a Research Co-op. He is looking forward to applying his skills in developing and testing this exciting project.

Borna is a fourth year engineering student, passionate in the field of hardware and software integration and wireless communication. He aspires to use his education in pursuing a career in the automotive design and development industry. In His spare time, Borna builds useful contraptions, watches hockey, takes photographs and explores new music of various genres.



Nelson is a fourth year electronics engineering science student. His determination and dedication to the program was rewarded by the SFU Faculty of Applied Science Dean's Honour Roll and has resulted in accumulating extensive knowledge on microelectronics and its applications in communications, control, and computing. Nelson spent 8 months working as a Junior Automation Engineer at Pearson School Systems, an industry leader in Student Information Systems and performance solutions.

Conclusion

As this document outlines, the FMCW radar system provides very exciting opportunities to improve the quality of emergency response by assistance in low visibility situation in a rugged, portable and easy to use platform. At Shift Technologies, we are excited by this prospect and are devoted to developing an effective tool.

We are confident that our FMCW radar system will surpass existing technologies by providing the necessary coverage through low visibility environments. Furthermore, the microwave beams used for such imaging are harmless to humans. Combined with its low cost, our system will deliver unmatched performance and cost effectiveness to emergency responders.

The timeframe for our project is laid out in the Gantt and milestone charts and our budget and funding resources are also laid out in this document. Furthermore, this document also outlines our sources of information, research material and the necessary theory and hardware components for our FMCW radar system.

References

[1] National Fire Protection Association. (2011, November) Number of firefighter injuries down eight percent from 2009. [Online]. http://www.nfpa.org/newsReleaseDetails.asp?categoryid=488&itemId=53998

[2] Natural Resources Canada. (2011, December) Natural Resources Canada, Canada Centre of Remote Sensing. [Online]. http://www.nrcan.gc.ca/earth-sciences/about/organization/organization-structure/canada-centre-for-remote-sensing/11740

[3] Natural Resources Canada. (2011, February) Natural Resources Canada, Emergency Management, Activities in Canada. [Online]. http://www.nrcan.gc.ca/earth-sciences/about/organization/organization-structure/canada-centre-for-remote-sensing/emergency-management/1897

[4] ICx Technologies. (2012, January) Frequency Modulated Continuous Wave (FMCW) Radars Have Advantages Over Pulse Doppler Radars For Ground Surveillance. [Online]. http://gs.flir.com/uploads/file/tech-notes/tech%20note5%20-%20fmcw%20v%20pulsed%20radars.pdf

[5] Graham Brooker. (2006) High Range-Resolution Techniques. [Online]. http://www.acfr.usyd.edu.au/pdfs/training/sensorSystems/11%20High%20Range-Resolution%20Techniques.pdf

[6] 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

[7] MIT Lincoln Laboratory. Introduction to Radar Systems. [Online]. http://www.ll.mit.edu/workshops/education/videocourses/introradar/

[8] Gregory L. Charvat. (2011) MIT IAP 2011 Radar Course Cantenna Radar System. [Online]. http://www.glcharvat.com/Dr._Gregory_L._Charvat_Projects/Cantenna_Radar.html

[9] AP Circuits. Prototype Price Estimator. [Online]. http://www.apcircuits.com

[10] USGS Pacific Coral Reef Studies. (2011, January) USGS Pacific Coral Reefs Website. [Online]. http://coralreefs.wr.usgs.gov/mapping_lidar.html

Appendix A

Callout:	Qty/Kit	Part#:	Description:	Unit Cost:	Subtotal:
RF Radar					
OSC1	1	ZX95-2536C+	2315-2536 MC VCO, +6 dBm Out	$42.50	$42.50
ATT1	1	VAT-3+	3dB SMA M-F attenuator	$9.95	$9.95
PA1/LNA1	2	ZX60-272LN-S+	Gain 14 dB, NF=1.2 dB, IP1= 18.5 dBm	$39.95	$79.90
SPLTR1	1	ZX10-2-42+	1900-4200 Mc, 0.1 dB insertion loss	$34.95	$34.95
MXR1	1	ZX05-43MH-S+	13 dBm LO, RF to LO loss 6.1 dB, IP1 9dBm	$46.45	$46.45
SMA M-M Barrels	4	SM-SM50+	SMA-SMA M-M barrel	$5.45	$21.80
Cantenna					
Can	2	TBD	TBD	$5.00	$10.00
L bracket	2	N/A	L-bracket, 7/8", zinc plated	$0.35	$0.70
SMA F bulkhead	2	901-9889-RFX	SMA bulkhead F solder cup	$4.27	$8.54
6-32 screws	1	N/A	6-32 machine screw, 5/8" length, pk of 100	$3.49	$3.49
6-32 nuts	1	N/A	6-32 hex nuts, pk of 100	$1.09	$1.09
6-32 lockwashers	1	N/A	lock washers for 6- 32 screws, pk of 100	$0.71	$0.71
6" SMA M-M Cables	3	086-12SM+	SMA-SMA M-M 6" cable	$9.65	$28.95
Miscellaneous					
Wood Screws	1	N/A	brass #2 wood screws 3/8" long, pk 100	$3.70	$3.70
Wood	1	N/A	12" wide by 1" thick 8' long wood	$14.37	$14.37
Modulator1	1	XR-2206	Function Generator Chip	$4.05	$4.05
Video Amp1	1	MAX414CPD+	low-noise quad	$14.46	$14.46

			op-amp		
Solderless Breadboard	1	EXP-300E	6.5x1.75" solderless breadboard	$7.00	$7.00
C1-4	4	SA105A102JAR	1000 pf 5% capacitor	$0.22	$0.86
R1a_1	1	MFR-25FBF-8K45	8450 ohm 1% resistor	$0.11	$0.11
R1b_1	1	MFR-25FBF-102K	102K ohm 1% resistor	$0.11	$0.11
R2_1	1	MFR-25FBF-7K15	7150 ohm 1% resistor	$0.11	$0.11
Rf_1_2	3	MFR-25FBF-1K00	1K ohm 1% resistor	$0.11	$0.34
Rg_1	1	MFR-25FBF-12K1	12.1K ohm 1% resistor	$0.11	$0.11
R1a_2	1	MFR-25FBF-17K4	17.4K ohm 1% resistor	$0.11	$0.11
R1b_2	1	MFR-25FBF-28K0	28K ohm 1% resistor	$0.11	$0.11
R2_2	1	MFR-25FBF-4K12	4120 ohm 1% resistor	$0.11	$0.11
Rg_2	1	MFR-25FBF-1K62	1620 ohm 1% resistor	$0.11	$0.11
Decoupling Cap	2	K104Z15Y5VE5TH5	0.1 uf	$0.05	$0.10
Decoupling Cap	2	UVR1E101MED1TD	100 uf	$0.03	$0.06
Trimmer Potentiometer	1	PV36Y103C01B00	10k	$0.92	$0.92
Gain Resistor	1	CFP1/4CT52R201J	200 ohm, 5%	$0.05	$0.05
Battery pack	2	SBH-341-1AS-R	4xAA battery pack with power switch	$0.95	$1.90
AA batteries	8	PC1500	AA battery	$0.54	$4.32
5V regulator	1	LM2940CT-5.0/NOPB	5V low dropout regulator	$1.77	$1.77
Audio cord	1	172-2236	3.5 mm plug to stripped wires	$2.42	$2.42
Wire ties	2	41931	4" cable ties	$0.04	$0.08
Tuning Capacitor	1	FK28Y5V1E474Z	0.47 uf capacitor	$0.21	$0.21
2M Trimmer Potentiometer	1	PV36W205C01B00	2M trimmer potentiometer	$0.92	$0.92
50K Trimmer Potentiometer	1	PV36W503C01B00	50K trimmer potentiometer	$0.92	$0.92
1uF Cap	1	UVR1H010MD	1 uF electrolytic	$0.04	$0.04

		D1TD	cap		
10 uF Cap	1	UVR1H100MD D1TA	10 uF electrolytic cap	$0.03	$0.03
5.1K Resistor	2	MF1/4DCT52R 5101F	5.1K resistor	$0.05	$0.10
10K Resistor	2	CCF0710K0JK E36	10K resistor	$0.04	$0.08
LED	1	TLHR5400	Red LED	$0.07	$0.07
1K LED Resistor	1	CCF071K00JK E36	1K resistor	$0.04	$0.04
100K Resistor	2	CCF07100KJK R36	100K resistor	$0.04	$0.08
47K Resistor	12	CCF0747K0JK R36	47K 5% resistor	$0.04	$0.48
1 uF Cap Unpolarized	1	T356A105M02 0AT73 01	1 uf tantalum capacitor	$0.31	$0.31
Total:					**$348.74**