

Small, Lightweight Speed and Distance Sensor for Skiers/Snowboarders

Air Force Research Laboratory

Design Team 5

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Executive Summary

Performance analysis aids/devices are an essential component of training methodologies in modern athletics. In recent years, professional grade equipment is becoming more readily available to amateur and recreational athletes. In snow sports like skiing, this top down migration of technologies for training has been slow to develop. Now is an excellent time to leap into the market for portable devices targeted at ski enthusiasts. For skiers, the primary information necessary to compare the performance of individuals is speed; a device that would allow users to measure their speed, in order to record progress, would be a welcome entry to this consumer sector.

This document proposes a design for an inexpensive speed and distance sensor that can be used by snow sports enthusiasts of all skill levels. By using low cost materials, maintaining minimal power consumption of on-board electrical devices and harnessing the size benefits of high frequency Doppler detection the proposed design will allow for the production of a useful and robust product for all skiers and snowboarders. The project is sponsored by the Air Force Research Laboratory and is the third iteration of a speed/distance recorded for skiers.

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Introduction

When training for any sport, some sort of performance metric is required in order to see improvement in technique and expertise. In skiing and snowboarding, the most important metric is speed. Speed is critical in all aspects of snowboarding and skiing. In freestyle competitions, achieving the optimal speed for lift off is necessary to safely hit a jump. For downhill and slalom competition the fastest competitor wins, so knowing one's speed is extremely vital to success. The main goal of this project is to make a device that is relatively cheap compared to similar devices on the market. This type of device could serve amateurs and budding athletes with the most important metric in snow sports. Our design is to be custom tailored to skiers and snowboarders. We wish to accommodate ergonomics, ease of use, robustness and power performance into a product that anyone can take benefit from.

Background

There have been two attempts to design a project, with similar specifications, before at MSU. The first attempt was during the spring of 2008. The design team created a device that implemented GPS as its basis of measurement, and paired it with a Bluetooth device. The biggest problem encountered was the large error when turns were involved in the route. Other problems with the device included lack of waterproofing and a bulky size¹.

The second attempt, during autumn of 2009, used a system which relied on GPS and an Inertial Navigation System. Inertial Navigation System (INS) uses multi-axis accelerometers and gyroscopes to measure the speed. It is good for short term measurements, but accuracy decreases over time. The combined system used GPS as a long-term reliable source of input, and INS as a local short term error checking. This combined system offered accurate results. Unfortunately, this design attempt failed due to the complexity and time limitations².

The current marketplace device Tech 4 O SI- Ski 1 Speedometer uses Doppler radar technology to measure the speed of the user³. The Tech 4 Speedometer also has a simple and safe display to the user. The Speedometer comes in two portions, the Wireless radar module, and the display stopwatch. The radar module attaches to the belt or leg, and the display can be clipped to any available loops on the user. One drawback of the system is the dual component design, losing one will render the entire product useless. We intend to produce a single component design with a low production price that will be easily replaceable.

Despite the benefits of GPS speed detection our design task is to implement a speed detector using Doppler radar. There are several issues to tackle using this method of speed detection, including (but not exclusive) scatter noise, signal acquisition, and normal speed mapping. By developing a prototype using Doppler radar we hope to find out how this type of speed sensor compares to the other methods used by previous design teams.

Doppler radar devices use the principles of the Doppler shift to calculate the speed of targeted objects. The Doppler effect is a change in the frequency of a reflected wave based on the relative speed of an object⁴. For example, a train sounds its horn at a given pitch. As the train approaches a listener, the pitch of the horn sounds higher, because the wave has shifted to a higher frequency. As the train passes and moves away from the listener, the pitch decreases because the frequency decreases.

A Doppler radar device uses this effect to calculate the speed of nearby objects or the speed of itself. The device emits multiple pulses, and receives a reflection of the wave. Due to the velocity of the object, the reflected wave has a different frequency. The difference in the frequency is used to calculate the velocity of the target. This can also be used to calculate the velocity of the emitting device by assuming the wave is reflected off a stationary object (like the ground).

Design Specification

The device that Design Team 5 proposes to make is a light weight, temperature resistant speed sensor. The device will use a Doppler radar system in order to calculate the speed of the user. With this data the device can calculate average speed, maximum speed, and distance travelled during a given run. The device will be intuitive and simple to use. For safety's sake, the device display will be disabled when motion is detected. Due to the colder nature of the operating environment, some special needs must be met. The device must function in cold temperatures, down to -10°F. This device must also last on internal battery power for at least two hours. Lastly, the method of operation for the device will be simple. In segments of one minute intervals, the device will store peak and average speed. The device will also turn off by user input or after a default time period. Finally, the data can either be saved or deleted on the device, and be transferable to another computer. All these features are detailed below for easy reference:

- **Measurements** (minimum one minute intervals)
 - Average speed
 - Max Speed
 - Distance Travelled
- **Safety**
 - Lightweight (< 2 lbs.)
 - Disabled display during recording
 - Weather resistance
 - Low temperature operation (-10F)
- **Power and Efficiency**
 - Auto-off after 10 minutes of inactivity
 - At least 2 hours of battery life
- **Operation**
 - Data storage requirement for at least 10 minutes of run data
 - Data report on LCD or data export to external device

Conceptual Design

Our design for the speed and distance sensor will utilize a Doppler radar system. The device will have a user interface that allows users to access previously stored data or begin the speed and distance tracking process. Our device will have three main components: the radar device, the control system, and the user interface. Each subsystem must be designed for optimal price, performance, and feature set.

Radar Device

The radar device is a Doppler noise radar. The radar works by transmitting electromagnetic waves towards the ground and receiving the reflected waves. The reflected waves are then mixed with the transmitted waveform to determine the frequency shift. From the frequency shift, the instantaneous speed can be determined. From the speed the distance can be derived by the control system.

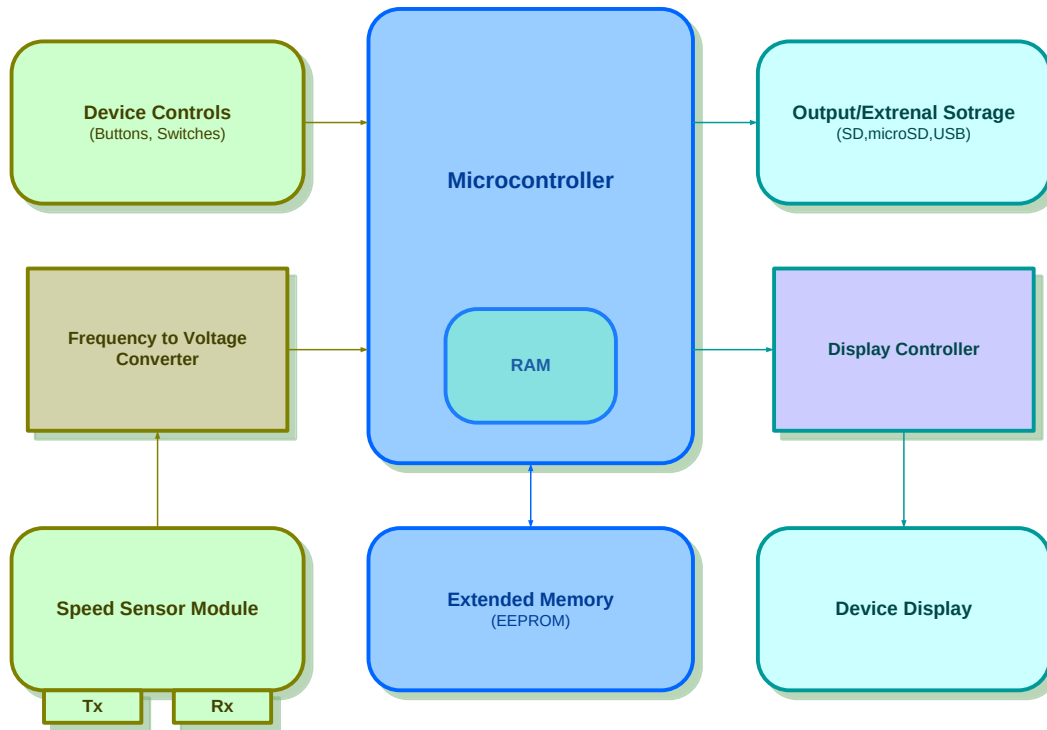
Control System

The device will be controlled by a microprocessor. The microprocessor will receive input from the user through the user interface, receive, process, and store data from the radar device, and finally store data for future viewing or uploading.

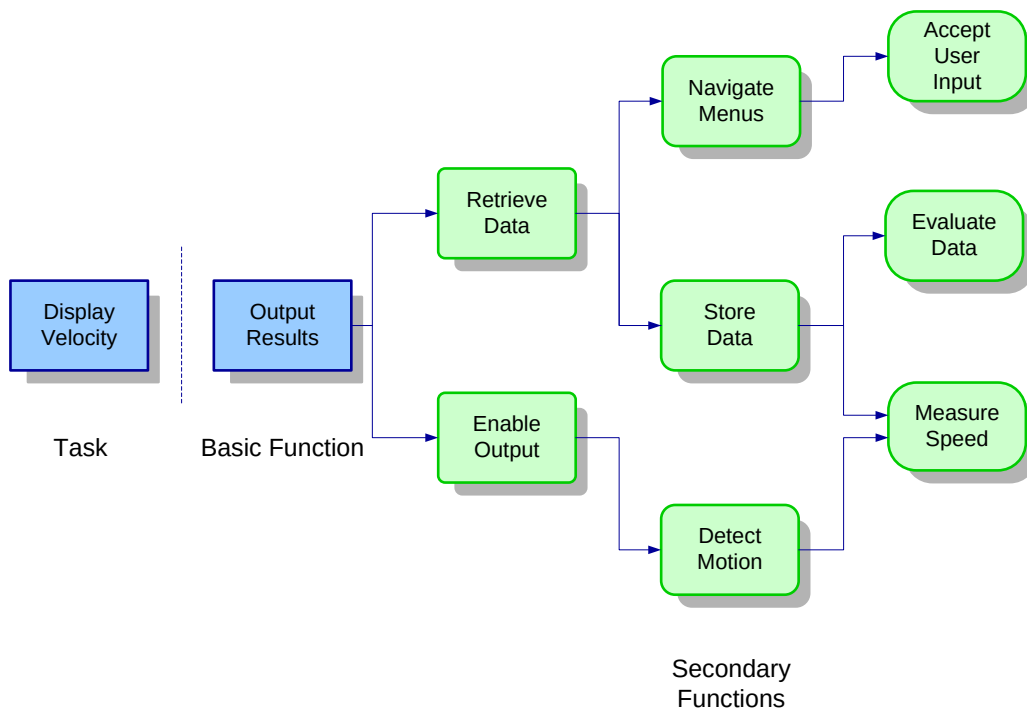
User Interface

The user interface will consist of a LCD or OLED screen that displays the menu options. The display must be able to be manipulated while wearing winter clothes and operate in below zero temperatures. At the users command, the device will be able to retrieve previously stored data, or begin the tracking process. The user will be able to navigate the options through the use of pushbuttons for easy manipulation.

The basic hardware layout was created via these three subsystems:



FAST Diagram



Ranking of Conceptual Design

Because our conceptual design (Doppler detection) had been more or less decided from the beginning of the design process we decided to focus our feasibility matrix more towards component choices in our proposed design. The following considerations came into mind during component research:

- **Component Complexity**
Ease of programming or system integration.
- **Component Cost**
Price in comparison to lowest cost option.
- **Power Consumption**
Subjective power consumption rank, also based off of lower power consumption of component category.
- **Size**
Subjective measure for volume budget in the final design.
- **Temperature Limits**
Top marks for meeting or exceeding -10°F , mid marks for $\leq 0^{\circ}\text{F}$, low marks otherwise.

Specific performance metrics of the radar subsystem included:

- **Detection Distance**
Max detection range using pulses, with good marks around 15ft.
- **Detection Mode**
Continuous wave mode, pulse mode, or both

The feasibility matrix for our component options can be seen in *Addendum* section of this proposal (p16).

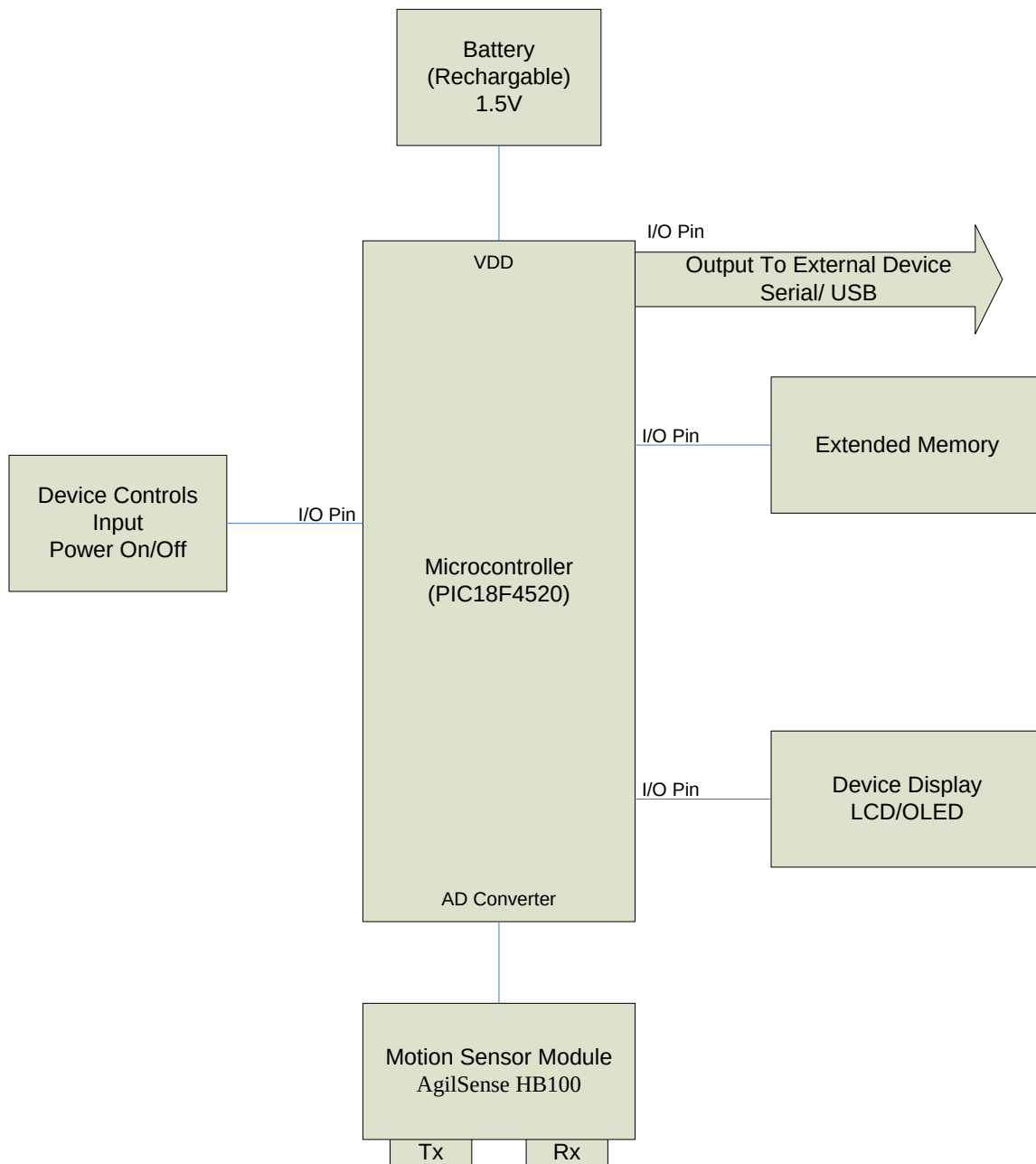
Proposed Design Solution

The principle features of our speed and distance sensor design are ease of use, accurate measurement results and robust performance. The device must be easy for the user to activate and use. We plan to accomplish this by developing easily navigable menus and by providing pushbutton controls that are able to be easily manipulated while wearing winter attire. In addition to ease of use, the device must produce accurate measurement results. This will be accomplished through extensive testing and experimentation with the radar module and microprocessor to ensure that the components are delivering precise results. Our device will be encountering several adverse conditions that must be accounted for. These include cold weather operation, wet environments, and possible impact situations. Our device will compensate for these through the use of an enclosure that ensures separation from the surrounding environment and device security to prevent breakage of the device.

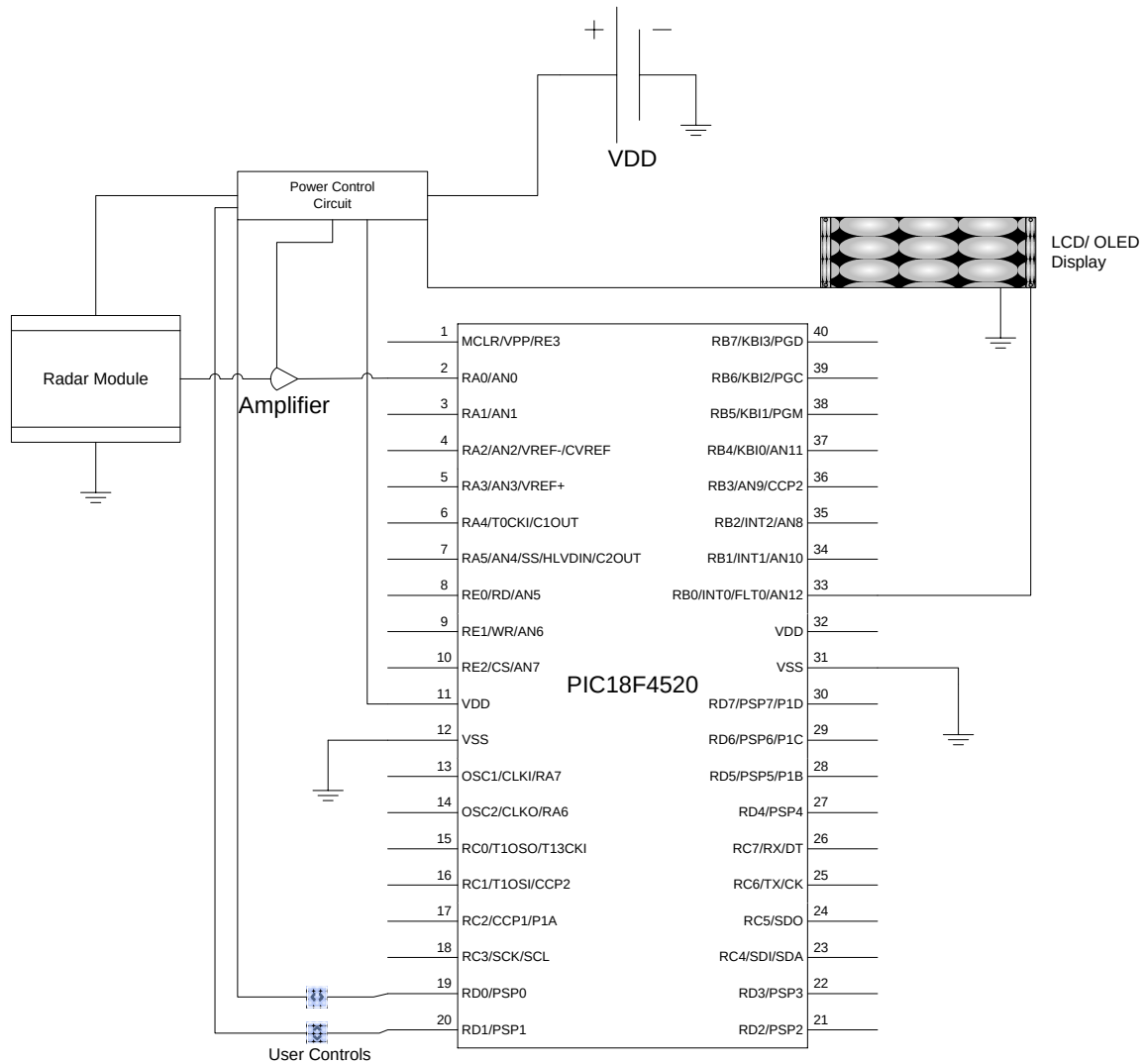
In order to program the microprocessor to control the device we will be using Microchips MPLAB Integrated Development Environment in conjunction with the MPLAB ICD2. These allow the microprocessor to be programmed in C, making the process much simpler and allows for more flexibility in software design.

To test our device and ensure that the radar module is outputting correct voltages in relation to the speed the device is travelling, our team has developed a speed testing device consisting of a DC motor and a paper disk. The DC motor is connected to a variable power supply to control the speed of the motor. This allows us to calculate the speed of the disk and correspond that to the output of the radar module. We will also perform field tests on the device using a platform such as a car or bicycle.

Design Block Diagram



Initial Schematic



The hardware layout will be assembled on a breadboard provided by the ECE Shop for our first prototype. For testing purposes our Doppler module will be attached to long jumper leads in order to provide ease of movement for the testers. The breadboard will be placed in a portable container, perhaps a backpack, and the Doppler module will be placed in close proximity to the ground. The PIC will be programmed to record data to its internal memory and we will analyze the data to verify the accuracy of the system. We will design a final PCB layout once we have confirmed proper operation of the prototype along with a device housing to accommodate the custom circuit board, batteries, display, and radar module.

Risk Analysis

There are a number of risks associated with our module that our design team must take into consideration. Most of the risks focus on accuracy of our system and safety for the user, which are the two highest priorities.

In terms of accuracy, we must make sure the Doppler module is precise in its detection of velocity. Without correct results, our system is useless. We must also factor in that quick turns and twists are used for tricks and to control speed in snowboarding and skiing. If the device is mounted incorrectly to our user, rotational velocity could skew our detected velocity, and the device will report incorrect speeds.

For safety of the user, we must be aware that the device is intended to be worn on the user, or mounted on skis or a snowboard. In sports such as snowboarding and skiing, participants can fall from large heights or at high speeds. The location and casing of our device should take this into consideration and minimize damage to the user.

In an effort to protect both the user and the device, we must be aware that we are housing electrically run equipment and a battery in an environment of frozen water. We must ensure our casing is water proof, both to prevent water damage to critical components, and prevent electrical shock to user.

Further risks involve both the device and the environment. These risks consist of our devices operation in the cold temperature, and the rapid jerks due to falling. Cold temperatures could drastically affect how our components work. The most likely to fail first would be the LCD screen. We must ensure that the screen is cold-temperature worthy, or replace it with a different option. In regards to the fall damage, all components must be securely mounted. Fall damage could cause our device to fail if wires come loose or a component becomes damaged.

Project Management Plan

Tasks for the project have been divided based on individual team member's interests and area of expertise. The team is divided into two sub-teams: microcontroller programming and Doppler sensor design. Contingent upon the successful operation of a Doppler module (prefabricated or custom) the two teams will focus solely on device operation and integration.

Design and Simulation

The design team will decide on device operation process flow and perform feasibility tests in the laboratory to determine whether certain components or techniques will be useful for the project. Through laboratory tests the team will learn what issues need to be focused on, what will and will not work for the project. Simulations for component interface will be carried out as necessary. Simple programming will be performed by all team members to become comfortable with programming a PIC. Choosing and purchasing components will be ongoing during the design process.

Prototyping

Once design and component acquisition has been completed the team will prototype the device in preparation for testing. Breadboard prototyping responsibilities will be evenly distributed to all design team members. During this time power design and measurement will be performed to guarantee proper efficiency and ensure all power requirements are met. The objective of this phase is to produce an operating proof-of-concept for testing and analysis.

Testing

Testing will be performed in order to calibrate the device for real world operation. Plans for testing will include a skateboard test to model flat surface behavior of the device and (weather permitting) a down slope snowboard/ski test. The team will take time during this phase to adapt the design to any flaws or lack of features that may be encountered in a live action scenario. Development of a build and testing procedure for the final build phase will be performed to prevent mistakes during construction.

Final Product Build and Testing

Once we've integrated new design additions from the testing stage we will design a PCB layout for the final device and custom housing to contain the PCB, batteries and modules. We will construct the final device using the building guideline and prepare the final device for demonstration.

Distribution of Labor

Members of the design team have each been given unique roles during the duration of project development as well as their sub-team designation. The roles can be seen in table below.

<i>Doppler Sensor Module and Analog Design</i>	Kunal Verma	Project Manager
	Justin Erskine	Web Master
<i>Microcontroller Programming and Interface Design</i>	Tim Ross	Documentation Prep
	Temika Cage	Presentation Prep
	Ben Guild	Lab Coordinator

Microcontroller

There are a vast variety of microcontrollers to choose from in the marketplace. The ECE shop has provided all ECE 480 students with a PIC18F4520 and the design team has determined that this microcontroller provides sufficient support for our proposed design. The ease of use for this microcontroller makes it a great candidate for our initial prototyping. Later on in the design process we may decide to upgrade to a better microcontroller for improved data handling and processing.

Display

The LCD display will be the main interface between the user and the device. Information taken during the ski run will be shown on the LCD screen when the user requests it. Most LCD screens are listed in the given price range. They are relatively cheap and will provide an effective display for our initial prototype. Budget permitting, the design team would like to switch to an OLED display to meet the temperature requirements of the device specification.

Radar Module

The motion sensor is the most important part related to the project. All the measurement data will be taken from it and processed to develop the information that will eventually be read by the user. Due to the complexity of building a radar module the design team decided to use an on-the-shelf part. Though there are several products to choose from, we originally decided to use an AgilSense HB100 for testing purposes. In the future we may upgrade to a model that has better signal range.

Persistent Memory

EEPROM will store all the long term data and information for future use. The cost of this item is low for the many different types available. For the initial prototype we will use

the internal RAM of the microcontroller to store data and then interface the EEPROM to dump data.

Power Source

Rechargeable batteries are very affordable and reliable. The battery we will use can provide more than enough power to fit the design specifications. The higher cost buy-in of rechargeable batteries will be recouped through the multiple reuses of the rechargeable battery. It is imperative that we develop a power regulator for our first prototype, giving us time for other design work later in the development cycle.

Enclosure

The project box must be very practical since this device is supposed to be mobile. The components of the device need to be contained for the purpose of mobility. For the prototype we will use a pre-manufacture standard case but in the future we plan to create a custom housing for the internal circuitry in order to protect the device from tough weather conditions.

Cost Breakdown	
Item	Cost
Microcontroller	\$4.00
LCD Display	\$20.00
Radar Module	\$15.00
EEPROM	\$5.00
Battery	\$10.00
Project Box	\$10.00
Total Cost	\$64.00

References

¹ "Information Links." *ECE Design Team 10*. Web. 07 Feb. 2010.

<<http://www.egr.msu.edu/classes/ece480/goodman/spring08/group10/documents/documents.htm>>.

² "ECE480: Design Team 6." *ECE Design Team 6*. Web. 07 Feb. 2010.

<<http://www.egr.msu.edu/classes/ece480/goodman/fall09/group06/>>.

³ "Amazon.com: Tech 4 O SI- Ski 1 Speedometer: Sports & Outdoors." *Amazon.com: Online Shopping for Electronics, Apparel, Computers, Books, DVDs & more*. Web. 08 Feb. 2010. <http://www.amazon.com/Tech-2831000-SI-Ski-Speedometer/dp/B000EQ82IM/ref=pd_sxp_f_r/191-3981142-2188238>.

⁴ CopRadar.com -- subsidiary of Sawicki Enterprises (1999-2000). "Doppler Principles (Police Traffic Radar Handbook)". CopRadar.com -- subsidiary of Sawicki Enterprises. <http://www.copradar.com/preview/chapt2/ch2d1.html>. Retrieved July 17, 2009.

Addendum

Feasibility Matrix	Component	Doppler Module			
Factor	Weight	Custom Module	AgilSense HB100	Infineon RON-7701	Sky Microwave 4177
Low Complexity	5	1	4	4	4
Low Cost	2	2	4	2	2
Power Consumption	4	2	4	4	4
Size	4	1	4	4	4
Temperature Limits	3	2	2	2	2
Detection Distance	4	4	1	4	4
Detection Mode	1	4	1	4	4
Total		47	71	82	82

Feasibility Matrix	Component	Microcontroller	
Factor	Weight	PIC18F4520	TI MSP430
Low Complexity	5	4	1
Low Cost	2	4	2
Power Consumption	4	2	2
Size	4	1	1
Temperature Limits	3	1	4
Detection Distance	4	-	-
Detection Mode	1	-	-
Total		43	33

Feasibility Matrix	Component	Display	
Factor	Weight	LCD	OLED
Low Complexity	5	4	2
Low Cost	2	2	2
Power Consumption	4	4	4
Size	4	2	4
Temperature Limits	3	1	4
Detection Distance	4	-	-
Detection Mode	1	-	-
Total		51	58

Notes