Demonstration System for a Low-Power Seismic Detector and Classifier

by

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Abstract

A low-power seismic detector and classifier was designed and implemented which was able to detect the footsteps of a person from as far as 35 meters away. Throughout the design an emphasis was placed on using low power circuitry and efficient algorithms. The test platform to demonstrate the concepts of the design utilizes a revolutionary low-power microcontroller and Digital Signal Processor (DSP) from Texas Instruments, Inc.. The DSP is a fixed-point processor that is underclocked to minimize power consumption and the microcontroller has idle modes which consume microamps of power. The system is designed to run on battery power, and uses solar power to continually charge the batteries during the day. Lastly, a “Commercial Off the Shelf” RF module allows multiple sensors to communicate with themselves to triangulate position, or to relay detections and commands to and from a base station.

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Publication of this thesis does not constitute approval by Draper or the sponsoring agency of the findings or conclusions contained herein. It is published for the exchange and stimulation of ideas.
I always enjoy reading the acknowledgment section of my fellow colleagues’ thesis documents. It is the one section of the report where you get to take a glimpse into the author’s life and learn about the people who influenced them. Sir Isaac Newton once said, “If I have seen further [than others] it is by standing on the shoulders of giants”. I prefer to take a more humble approach and say it is because I have had the shoulders of the great people who have helped me that I have seen so far.

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Chapter 1

Introduction

Recently, there has been a great emphasis on low power circuit design. This has revolutionized many areas in computers and electronics. One area specifically benefitting from the improvements in lower power consumption is sensors. Sensors can now run for weeks with the power of only a couple Lithium Ion batteries. This means they are cheaper to operate, and more importantly, they require less human intervention because the operator does not have to replace the batteries as frequently. Texas Instruments, Inc., has an Ultra-Low-Power Microcontroller which only draws 2.5 uA of power in certain operating modes [13]. New advances in programmable parts are being made as well. Combining this low power mentality in an area which has not had much research is the goal of this thesis.

When a person or animal walks along the ground they emit seismic waves as a result of the impact. These waves then propagate through the ground. A geophone is a sensor that is able to measure the amplitude of these seismic waves in the ground. Geophones can be used to measure everything from a car driving by to an outright earthquake. The critical part is then establishing algorithms that allow the device to differentiate seismic waves coming from a person versus other seismic activity.

This project is an improvement to current technology in a number of regards. First, it will focus on low power components. Next, it focuses on the development of simple yet effective algorithms to detect and classify people. Numerous algorithms exist for classifying data, however, most of them are not intended for low power
applications. The algorithms utilized for this project will need to be relatively simple so they can run in a low power environment, but also still need to maintain their effectiveness in classifying people. Lastly, is the consideration of alternative forms of energy. This area is frequently overlooked when designing systems, but will no doubt become more important in future designs with our diminishing supply of natural resources. Combining all these areas in a working prototype will help advance sensor technology as well as general design principles.

The methodology behind the design of this system was to create a platform that later could be built upon and expanded. The scope of the project is quite expansive and some areas have had more attention than others. Every attempt has been made to clearly document all the aspects of the project so that in the event that someone chooses to pursue an aspect of the project at a later point the design and results will be at their disposal.

1.1 Background

The ground, like any other elastic medium, allows waves to propagate through it. The impact from a footstep hitting the ground can be distinguished from as far as 100 meters away under ideal conditions [12]. The maximum distance is directly related to the attenuation rate of the ground and the type of wave being studied. There are four types of seismic waves that propagate through the ground: compression, shear, Rayleigh, and Love. These waves have varying diminishing amplitudes as they travel through the ground. The Rayleigh wave diminishes as $1/R$ while the shear and compressional waves diminish as $1/R^2$ [11]. The Love wave, which is caused by the layering of the soil, is not really considered. In footstep detection, the most important wave is the Rayleigh wave. It is a wave which travels along the surface of the earth. Its components expand in two dimensions and diminish exponentially with depth [11]. As a result of this, the wave can be detected at much further distances than the body waves (compressional and shear). Another thing to consider is how the energy from a footstep gets partitioned into the three waves. The shear and compressional waves
which are body waves contain roughly 26% and 7% of the energy, respectively, while the Rayleigh wave contains 67% of the energy [11]. Therefore the Rayleigh wave is the critical wave for footstep detection. Not only does it propagate through the ground over greater distances, but it is also where the bulk of the energy from a footstep gets transmitted. It is also possible to extract bearing information from the Rayleigh wave using a three-axis geophone [11].

1.2 Previous Work

There are numerous algorithms for classifying data, however, most of them require massive amounts of computational processing power or memory. For instance, Succi et al, used a Levenberg-Marquardt Neural Network Classifier to track vehicle data [10]. This produced good results, but it required 6MB of dynamic memory for its matrix processing. In a low powered embedded system running a classifier of that nature would require too much power.

Kenneth Houston and Dan McGaffigan at Draper Laboratory have done a significant amount of research in the area of personnel detection using seismic sensors [3]. Most systems prior to their work was transient based. The downfall of that approach is that many real-world signals unrelated to human locomotion look like transients. A systems designed like that will have either a very high false alarm rate or else will be insensitive. They introduced the idea of using spectrum analysis on envelope-detected seismic signals. This method not only produced reasonable detection ranges but also was significantly better at discriminating footsteps from other types of seismic sources. This work is the basis for the algorithms that were utilized in the system.

1.3 Research

Continuing the work on the algorithms developed by Kenneth Houston and Daniel McGaffigan, it became desirable to examine how different geological and topological
features affected the ability to detect and classify footsteps. Also, it became desirable to collect data from other ambulatory creatures, such as horses, to determine if there was noticeable features which would allow the system to discriminate from horses while still maintaining a simple algorithm.

The other area in which the project was expanded was to look at alternative forms of energy to power the system. There are many forms of energy on the planet. Wind, vibration, water, coal, oil, wood, nuclear fusion, and solar all produce energy that can be transferred into electrical energy. Considering the application of this project as a small, low-powered sensor, it is important that the energy source be able to convert the energy into electrical energy efficiently and that the mechanism are relatively small.

Energy can be readily converted from one form to another. However, most techniques do not yield enough electrical energy to sustain a system. Amirtharajah has proposed using ambient vibrational energy to power electrical devices [1]. Vibrational energy does not yield enough energy to power the prototype, but solar energy is a viable solution. Current research is around 20% efficiency which means for a 1 cm² solar cell 20 mW of energy can be obtained [2].

Photovoltaics are materials that when sunlight hits them an electron is released causing it to generate an electrical current. Photovoltaics are the cheapest way to produce electricity for smaller systems and often times the simplest and cleanest to operate. The problem with solar power is the sun is almost never directly overhead, except in the tropics. At a latitude of 45 degrees the solar radiation may vary from 92% (early summer) to 38% (early winter) [9]. At higher latitudes the distance from the sun to the earth becomes further and also the scattering of the sun’s radiation from gases in the atmosphere becomes significant when considering the use of solar power as well. Furthermore, it is important to take into account the natural landscape such as mountains, altitude, and cloud cover. All these variables make solar power a very inconsistent source of energy. Figure 1-1 shows some of the typical solar isolation amounts in the United States.

In 1839, Edmond Becquerel was the first to discover that when sunlight is absorbed
"Worst Case" Solar Insolation (kWh/m²/day)

Source: Sandia National Laboratories

Figure 1-1: Solar Isolation (kWh/m²/day) in the U.S.
by certain materials it can produce an electrical current. It was not until the 1950 and the advent of solid-state devices that people were able to do something meaningful with this information. The space program was the first application for solar cells and in 1954 a 4% efficient silicon crystal was developed [9]. As early as 1958 a small array of solar cells was used to provide electrical power to a U.S. satellite.

Photovoltaic cells are created by doping a material like silicon with a substance like Boron or Phosphorus which has one less or one more electron respectively. A junction forms between the doped silicon and the undoped silicon. When a photon strikes the cell it contains enough energy to release the extra electron and allow it to move across the junction. A grid is set up to gather the current from a number of cells and different currents and voltages can be constructed depending on how the grid is arranged.

The most common photovoltaic cell used today is the single crystal silicon cell. The silicon is highly purified and sliced into wafers from single-crystal ingots, or grown as thin crystalline sheets or ribbons. Polycrystalline cells are available as well but are inherently less efficient, but they are cheaper to produce. Some of the most efficient cells are made from Gallium arsenide; however, they are very expensive. Currently, there has been a lot of focus on thin films made from amorphous silicon. Copper Indium Diselenide and Cadmium Telluride may also provide viable low-cost solutions. The thin films do not require a lot of material and have great manufacturability. Another area which is receiving a lot of attention is multijunction cells. This will allow the cell to use more of the spectrum from the sunlight giving higher efficiencies.

There are drawbacks with the use of solar energy. For one thing, it only works when the sun is out so batteries will be required during the evening hours or if the device is buried underground. Also, the solar cells are fragile so they will need to be protected from adverse weather conditions.
1.4 Overview

Ultimately, the goal of the project is to produce a bread-board prototype that is able to correctly detect and classify people. In order to accomplish this the device needs to incorporate many types of electronics. It will require a sensor to acquire the data, an Analog-to-Digital Converter (ADC) to convert the data to digital form, and a low power Digital Signal Processor (DSP) to process the data. In addition, the device will incorporate a radio frequency (RF) transmitter to relay data back to the operator when it has detected something. Low power devices will be featured in the design, and solar power as a means of powering the device will be explored.
Chapter 2

System Architecture

The clearest way to understand how the system processes data is to analyze it from a signal perspective. The next couple paragraphs describe the path a signal takes from when the sensor picks up vibrations all the way to the determination of whether or not the signal is classified as a person.

The geophone is an external sensor with a stake on it that penetrates the ground. It generates very small electrical voltages depending on the intensity of the propagating waves in the axis that the geophone is arranged in. The geophone is biased to fluctuate around 1.5 V, the middle of the full range input to the Analog-to-Digital Converter (ADC). This allows use of a single supply voltage for the front-end electronics and maximizes the signal voltage range. The geophone plugs into the prototype board through port J3. The port is able to support up to three seismic channels of data, however, currently the system is only utilizing a single channel. The other two channels could be used to concurrently process data from two other single-axis geophones or the data from one three-axis geophone.

When the signal arrives at the board it is initially filtered through the analog circuitry. It is filtered through two analog lowpass filters and one highpass filter. These filters bandlimit the signal to prevent aliasing. Then the signal goes through a single gain stage. Following the gain stage, the signal is sampled by a 12-bit ADC built into the microcontroller. The sampling rate is controlled by one of the internal timers on the microcontroller and is set at 1 kHz. After eight samples have been
collected by the ADC, the microcontroller directly writes the data into a certain memory location within the DSP through the Host Port Interface (HPI). Every 1200 samples, or 1.2 seconds at a 1 kHz sampling rate, the microcontroller takes the DSP out of its low-power mode and requests the DSP process the next block of data.

Figure 2-1: Signal Processing Path

Figure 2-1 shows the stages of the signal processing chain. The DSP begins by passing the data through a digital bandpass filter allowing signals within the range of 10 Hz to 40 Hz to pass. This bandpass range is geology dependent but was fixed for this project. The next step is critical for the detection process. The important part of detecting footsteps is the periodicity of the footsteps on the ground. The time of each distinct impact on the ground is the critical information that needs to be retained, as opposed to, the exact frequency content received at the sensor, which can be quite variable. An absolute value is performed on the whole signal to create an envelope of the received signal, which will peak for each distinct footstep. After this, the data is decimated and lowpass filtered again to prevent aliasing. The decimation
occurs in two separate steps; first by 5 and then by 2. The decimation removes high frequencies in the envelope data so as to smooth out the footstep pulses. It also allows the Fast Fourier Transform (FFT) to be smaller to get the frequency resolution that is required. A moving window technique employing a Hanning Window is then utilized because the amplitude of the data is changing as the distance from the person to the sensor changes with respect to time. Next, a 1024-point FFT is performed to convert the data into the frequency domain. The FFT returns the values of the frequency components as complex numbers. A function converts those real and imaginary parts into magnitudes, and the data is scaled to make it easier to differentiate the signal from the noise. A two-pass normalization is performed to estimate the background level. Then the background signal (converted to decibels) is subtracted from the seismic signal (also in decibels) so the detection is based on normalized signal levels. Lastly, the footstep discriminator algorithm is called to decide whether the footsteps are from a person. The details of the discriminating algorithm will be discussed later.

2.1 Digital Signal Processing

A Digital Signal Processor has specific hardware to expedite signal processing routines. It is a fixed-point processor to reduce power consumption. Using a fixed-point processor increases the complexity of the design and requires careful design to keep the signals scaled and in an appropriate range. Also, floating-point calculations take many additional clock cycles on a fixed-point processor so they should be avoided.

The way numbers are represented in the processor is an important aspect of the design stage. Using a fixed-point processor allows the programmer to pick any arbitrary number of bits to represent the integer portion of the number and the fractional component. As long as the representation remains consistent the operations will produce the correct results. Texas Instruments has provided a number of common DSP functions to assist developers using their processors. Whenever possible, these functions were utilized because they are written in assembly and attempt to maximize the efficiency of the algorithms for the hardware platform. The DSP Library functions
generally use a Q15 number representation, which means there is no integer portion, 15 bits of fractional data and one bit to represent the sign of the number. Therefore, all the numbers represented throughout the signal processing chain are scaled between -1 and 1.

2.1.1 Bandpass Filter

The Infinite Impulse Response (IIR) bandpass filter allows frequencies from within the range of 10 Hz to 40 Hz to pass. Originally, it was designed to be a 4 pole filter, 2 poles for the lowpass component and 2 poles for the highpass component, however, there were some difficulties getting the biquads to function properly. A simple 2 pole bandpass filter was resorted to, to get the system working. Within a Digital Signal Processor the easiest way to implement an IIR filter is through the difference equations. The single pole difference equations for the highpass and lowpass filter are described in the equations below.

\[
\text{Highpass} : Y_i = \frac{N - 1}{N} * Y_{i-1} + X_i - X_{i-1}
\]  
\[
\text{Lowpass} : Y_i = \frac{N - 1}{N} * Y_{i-1} + \frac{1}{N} * X_i
\]

where \( N = \frac{\tau}{T} \), \( \tau = \frac{1}{2\pi * f_{\text{cutoff}}} \), \( T = \text{sample period} \)

To create the highpass filter \( T = 1/1000 \), \( \tau = 1/(2\pi * 10\text{Hz}) \), and \( N = 16 \). The lowpass filter is realized in a similar fashion with \( T = 1/1000 \), \( \tau = 1/(2\pi * 40\text{Hz}) \), and \( N = 4 \). This produces the following difference equations for the bandpass filter.

\[
\text{Highpass} : Y_i = \frac{15}{16} Y_{i-1} + X_i - X_{i-1}
\]
Lowpass: \[ Y_i = \frac{3}{4} Y_{i-1} + \frac{1}{4} X_i \] (2.4)

The fractional components are scaled as fractional components within the processor with 1 being represented by 32,767. Both of these filters are coded in assembly and can be found in Appendix F in the files `hp_filter.asm` and `lp_filter.asm`.

2.1.2 Envelope Detect

After the signal has been filtered it looks like the signal shown in Figure 2-2. Notice how the impact from the footsteps generates both positive and negative waves. The frequency of these waves is controlled by the terrain. The goal however is to treat this whole block as one impact and then determine the frequency that the impacts are occurring. In order to do this the absolute value function changes the sign of all the negative going waves and flips them about the axis so they are positive. This generates an envelope for each of the footsteps shown in Figure 2-3.

2.1.3 Decimation

Oversampling followed by decimation has several benefits. Oversampling allows the use of a less stringent analog antialiasing filter, which has a lower precision than a digital filter. In addition, a digital filter does not drift with temperature or time. The decimation stage requires a lowpass filter to prevent aliasing. The unique thing about decimating is that the function is the same as a regular Finite Infinite Response (FIR) filter except it is only necessary to do the operations on the values that will exist after decimating. It is implemented in assembly as a standard FIR filter that only runs on the samples that exist after decimating. Thus if it is decimating by two it only runs on every other sample and if it is decimating by 5 it runs on every 5th sample. For this application, the decimation operation is divided into two parts to limit the size of any filter. The other benefit of decimating is it smooths out the waveform. The same sample data after a decimation of 10 in shown in Figure 2-4.
Figure 2-2: Signal After Bandpass Filter

Figure 2-3: Envelope Detection
2.1.4 Hanning Window

Before the Hanning window is applied to the data there is a window buffer function which takes advantage of the specialized hardware on the DSP to handle circular buffers. A circular buffer is able to loop through the same memory space without shifting data. It is a feature prevalent in DSPs and very handy when doing signal processing operations. The function keeps adding new data to the end of a buffer and outputs a linear array with the next set of data to run through the window. The window function simply multiplies all the values in the output by the Hanning Window coefficients. The coefficients for the Hanning Window were realized in Matlab and a plot of the window is shown in Figure 2-5. The data after it passes through the window is shown in Figure 2-7. The window contains about 8.5 seconds worth of footstep data and the sampling rate is now 100 Hz after the decimation by 10.

2.1.5 Fast Fourier Transform

The Fast Fourier Transform (FFT) routine was provided by Texas Instruments in their DSP Library. The project uses a 1024-point FFT which gives a frequency resolution of 0.098 Hz per bin. The output from the routine segments the numbers into real and imaginary components. The phase information is not useful for this application.
Figure 2-5: Hanning Window

Figure 2-6: Hanning Window Applied to Footstep Data
and can be disregarded. The convert_to_mag function, in Appendix F, converts the output from the FFT to a number representing the magnitude information. It computes the absolute value of the data, squares the real and imaginary component and then finds the square root of the number. The square root function was provided by Ken Turkowski [14]. The function computes the square root using only fixed-point numbers. After the data has been converted to a magnitude, the DC frequencies are removed from the spectrum and the data is scaled. The data after the FFT and scaling looks like Figure 2-7.

2.1.6 Spectral Normalization

It is very clear where the first, second and third harmonics are from the FFT output in Figure 2-7. The problem is this data are not normalized relative to the background level. In order to normalize the data a two-pass normalization is performed on the data. This calculates the average on both sides of a moving center point, and then calculates the mean within the center. Ideally, the peaks in the FFT will fit into the gap in the center. If the average of the center points divided by some threshold is above the average of the sides then the center value gets replaced by the average from the sides. It requires two passes because after the first pass a large peak will create
two smaller peaks in the output. The second pass helps to smooth out those smaller peaks so that when the operation is finished there is an array which approximates the background level of the spectrum. The width of the sides and the width of the center section can be adjusted in the \texttt{normalization.h} file. Currently, the length of the sides is 16 samples and the length of the center is 9 samples. Lastly, every point in the output of the FFT is subtracted by the background level multiplied by two.

### 2.2 Footstep Detection Algorithm

The footstep detection algorithm is based on the work by Kenneth Houston and Daniel McGaffigan [3]. Footstep data was collected from three days of testing in a few parks around Massachusetts. The data was recorded with a 16-channel acquisition system running into a laptop and a two channel portable DAT machine. A GPS receiver was also carried by the individual and the data was later downloaded to a computer to provide a ground truth. The test setup used to collect the data is described in further detail in Chapter 4. After collecting the data, Matlab was used to post-process the data and come up with the feature set used to distinguish footsteps.

The first criterion is that the frequency of the first harmonic for the footsteps be in the range of 1 Hz to 3 Hz. This is the frequency range of the impacts from a person’s feet hitting the ground. It is remarkable how periodic the footsteps of most people are when they are walking normally. In addition to the frequency component, the peak also has to be greater than a certain threshold relative to the noise level. The next aspect of the detection algorithm is to verify that either a second or third harmonic exists and that one of them is above another threshold level. The algorithm finds the first five peaks in the range of 1 Hz to 10 Hz. Then it determines if the peaks it acquired meet the requirement to classify it as a footstep.

The digital bandpass filter at the beginning of the signal processing chain is very important in determining how well the algorithm performs detections and classifications. The environment and terrain can have a huge impact on the waveforms that are observed when a person walks on the ground. In future versions one would want
to consider an adaptive bandpass filter that automatically fine-tunes the frequency of its passband. Also, there could be intervention from the user to pick a specific land terrain for where the sensor will be operated.
Chapter 3

Design Description

The design of the footstep detector can be broken down into four major areas: analog design, digital design, RF design, and power design. The analog design includes all the electronics that are necessary to filter and amplify the small voltage signal coming from the geophone. The digital design contains the microcontroller and DSP, and all their supporting circuitry. These chips do the analog-to-digital conversion (ADC) and process the data to detect footsteps. The microcontroller also handles the user interface to control various settings. The RF design is mainly an off the shelf product which is used to allow multiple boards to communicate with each other or for the sensor to communicate with a base-station. Lastly, the power design contains all the circuitry to support power from a battery, solar power or an external power supply. If the system were deployed in the field the ideal solution would be to have the solar power charge the batteries during the day and provide power for the system, and at night power the system via battery power. Also included in the power design is the power management scheme. Systems are shutdown when they are not in use and the processors are put into low-power modes when they are not actively processing data. These areas will be discussed more fully in the following sections.
3.1 Analog Design

The analog design has a separate power and ground plane from the digital area. The geophone provides a very small voltage that varies depending on the amount of seismic activity. This output needs to be amplified and filtered before it can be sampled by the ADC. A portion of the schematic which handles the analog frontend is provided in Figure 3-1 for reference. The sections will be discussed later.

![Figure 3-1: Analog Frontend Stages](image)

3.1.1 Geophone

A geophone is a small instrument for measuring ground motion. It is part of a category of sensors called seismometers. Seismometers usually consist of a mass suspended by a spring, with the mass being either a magnet that moves within a moving coil, or a coil moving within the field of a fixed magnet. The geophone is an electromagnetic seismometer, which produces a voltage across the coil that is proportional to the velocity of the coil in the magnetic field, and thus approximately proportional to the velocity of the ground. There are two variants of geophones a one-axis version and a three-axis version. As the names imply, the one-axis version measures surface waves travelling in one axis while the three-axis version provides circuitry to measure propagating waves in all three axes. For this application only a single axis geophone
is used, but the system is capable of handling a three-axis geophone.

3.1.2 Filtering

The sampling rate is set at 1 kHz. Therefore, to prevent aliasing the Nyquist frequency of 500 Hz must be observed. A lowpass filter with a cutoff of approximately 300 Hz will prevent any antialiasing. Two stages of single pole lowpass filters are provided, Figure 3-1. The first one is a simple RC filter with a cutoff of 15.92 kHz to prevent RF noise from getting into the analog inputs. The second lowpass filter is a single-pole active filter with a cutoff of 482 Hz, and is followed by another RC passive highpass filter with a cutoff of 0.98 Hz. The highpass filter prevents any DC signals from passing through and being amplified. The equations used to calculate the cutoff frequencies are shown below. Chapter 5 provides the actual measurements taken from the boards. Figure 3-2 shows the Matlab plot of the analog circuitry.

\[
\text{Lowpass 1: } f_{\text{cutoff}} = \frac{1}{2\pi \times RC} = \frac{1}{2\pi \times 100 \times 0.1\mu F} = 15.92kHz \tag{3.1}
\]

\[
\text{DCgain} = 1 \tag{3.2}
\]

\[
\text{Lowpass 2: } f_{\text{cutoff}} = \frac{1}{2\pi \times R_2C} = \frac{1}{2\pi \times 1\text{M} \times 330pF} = 482Hz \tag{3.3}
\]

\[
\text{DCgain} = \frac{-R_2}{R_1} = -31.65 \tag{3.4}
\]

\[
\text{Highpass 1: } f_{\text{cutoff}} = \frac{1}{2\pi \times RC} = \frac{1}{2\pi \times 162k \times 1\mu F} = 0.98Hz \tag{3.5}
\]

\[
\text{DCgain} = 1 \tag{3.6}
\]
Figure 3-2: Bode Plot for Analog Frontend
3.1.3 Amplification

The amplification is through a single stage instrument amplifier, Figure 3-1. A low on-resistance CMOS analog switch is used to select whether a single 464 kΩ resistor or the 464 kΩ in parallel with a 32.4 kΩ resistor control the gain. The microcontroller is able to control the line GEO_X_SEL to determine which gain setting the amplifier is in. With only the 464 kΩ resistor there is 40 dB of gain, while with the two resistors in parallel the approximate resistance is the value of the lower one, 32.4 kΩ, and the gain is approximately 60 dB.

3.2 Digital Design

The digital design is comprised of the microcontroller, DSP, and all the supporting circuitry. The main functions of the microcontroller are to control the power to all the subsystems, change various settings within the subsystem, control the user interface, sample the data, and transfer the data to the memory of the DSP. The DSP processes the data and executes all the signal processing operations. After performing the detection algorithms, it reports to the microcontroller when a positive detection has been made.

3.2.1 MSP430F149 Microcontroller

The MSP430F149 (MSP) is a new generation of low-power microcontrollers developed at Texas Instruments. This microcontroller is able to run on less than a milliamp of power and has a whole host of features as well. There are numerous I/O ports on the microcontroller which allow control over all the subsystems, a built-in 12-bit ADC, and two UART ports for serial communications. In addition, the MSP has 60 KB of flash to store program code and 2 Kb of RAM.

The MSP is able to do the job that three or four ICs would perform in a traditional design. Since the number of digital I/O lines required for the design is relatively low, the MSP is able to manage the job of controlling digital lines that a separate FPGA
or CPLD would normally handle. The UART ports allow communications between
the host computer and the RF unit. The flash memory is large enough to store all
the MSP program code as well as all the program code for the DSP. The DSP would
usually have its own flash chips to store its program code in, and external memory
to process data. Having less components reduces the size of the system and more
importantly the power consumption.

The MSP is able to address 64 kB memory locations. Table 3.1 shows the memory
map for the MSP. The MSP program code occupies the memory address locations
0x1100–0x5FFF about 20 kB of space, while the DSP occupies the flash memory
locations 0x6000–0xC600 about 26 kB of space.

<table>
<thead>
<tr>
<th>Memory Byte Address</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x0000–0x01FF</td>
<td>Registers</td>
</tr>
<tr>
<td>0x0200–0x0FFF</td>
<td>Ram</td>
</tr>
<tr>
<td>0x1000–0x10FF</td>
<td>Information Memory</td>
</tr>
<tr>
<td>0x1100–0x5FFF</td>
<td>MSP Program Code</td>
</tr>
<tr>
<td>0x6000–0xC600</td>
<td>DSP Program Code</td>
</tr>
<tr>
<td>0xFFE0–0xFFFF</td>
<td>Interrupt Vectors</td>
</tr>
</tbody>
</table>

Table 3.1: Microcontroller Memory Map

User Interface

The user interface allows the user to interact with the system and control various
modes of operation. The commands are given over an RS232 serial link. Currently,
the serial connection is set to run at 19200 bps with 8 data bits, no parity bit and
one stop bit; however, those settings can easily be modified in the code.

When the system is first powered the user is presented with the main menu shown
in Figure 3-3. The main menu has three standard sections. The header information
for the project is shown on the top of every screen. A message area is used to display
feedback to the user. The actual menu screen is in the center and allows the user
to select various submenus, such as, the VC5509 menu, Geophone menu, and ADC
menu. By pressing the letter associated with the menu the appropriate submenu is
brought up. These menus serve a dual purpose in the system. When the system was designed this is how the system was tested. As various subsystems were brought online they were tested by generating commands from the microcontroller to verify that they were functioning correctly. Now, the menus serve to test the subsystems again if something is not operating correctly and allow the user to make changes to the system settings.

The VC5509 menu, Figure 3-4, regulates when the DSP is booted, how code gets loaded into the DSP, and when signal processing is started. Also, this controls how the DSP code gets saved into the flash of the microcontroller. First, the code is loaded into a buffer location in the DSP memory and then it is transferred over to the flash of the microcontroller. Starting the signal processing operation turns on the geophone channel and starts the ADC on the microcontroller.

The Geophone menu, Figure 3-5, controls the geophone channels. The gain settings can be modified for any of the channels, and power to the analog subsystem can be turned on or off.

The ADC menu, Figure 3-6, allows the user to poll various channels on the ADC to find out their instantaneous values. Both the geophone and test input channels can be polled, and there is an internal temperature sensor in the microcontroller that can be checked.

The Misc menu, Figure 3-7, has a few miscellaneous features that were programmed in the system, but not really necessary for normal operation. The temperature can be checked and power supply voltage. The message area can be cleared, and the running time of the processor since it was powered on can be displayed.

**Port Description**

The MSP has up to 48 digital I/O lines to control various subsystems and interface with other components. Many of the ports on the MSP can be configured to perform special functions as well. For instance, the ports that are used to receive the ADC signals can either be selected as I/O ports or the inputs to the ADC. Obviously, when the ports are selected to perform special functions it reduces the number of I/O ports
Figure 3-3: Main Menu

Figure 3-4: VC5509 Menu

Figure 3-5: Geophone Menu

Figure 3-6: ADC Menu
available. All of the I/O ports can be configured to read or write to the port. The I/O ports are used to control the power for the DSP chip, seismic analog filtering and amplification, the RF power, and RS232 chip. Furthermore, they are used to transfer data back and forth between the DSP using the Host Port Interface (HPI).

The ports on the MSP are configured by writing to specific registers. Each port has its own register to control: whether it is a port or special function, and the direction of the port (read or write). There is a register to read the data from the port or write data to the port. In addition to all the above configurations, Port 1 and 2 on the MSP are also able to receive interrupts as well. The ports are all set to their initial values in the function initialize_ports() within the initialize_system() routine. Table 3.2 shows the initial values of all the registers associated with each of the ports. The PxSEL register determines if it is a special function (high) or the standard port (low). PxDIR sets the direction of the port as either an output (high) or input (low). PxIE enables the interrupts for the port. Interrupts can only be enabled on port 1 and port 2. PxIES determines which edge the interrupt should trigger on, the rising edge (low) or falling edge (high).
Table 3.2: Initial Configuration of Port Registers

Clocks

There are three different clocks on the MSP. The master clock (MCLK) runs the CPU. The LXT2 oscillator is divided by 4 which gives a frequency of 1.23 MHz. During the low-power mode this clock gets shutdown. The subsystem clock (SMCLK) is used by the peripherals. This clock is the same frequency as the MCLK but does not get shutdown in the low-power modes. Lastly, there is the auxiliary clock (ACLK) which runs at 32,768 Hz. The ACLK is used to keep system time, and control slower events such as the sampling rate for the ADC.

Timers

There are two timers on the MSP, Timer A and Timer B. Timer A is used to keep the running time of the processor. It is connected to the ACLK which runs at 32,768 Hz and every 0x8000 ticks it generates an interrupt to add a second to the time. Timer
B is also connected to the ACLK but it is used to generate the sampling frequency for the ADC.

**Analog-to-Digital Conversion**

The ADC is used to convert the analog levels from the seismic sensor into digital values. The converter is a 12-bit successive-approximation converter so the digital values range between 0x0000 and 0x0FFF.

The sampling rate for the ADC is controlled by Timer B. This allows for a known sampling rate in the system. Whenever Timer B counts up to the number in its register it generates a pulse on the out signal. The ADC uses this pulse to trigger the next conversion. Timer B is connected to the ACLK which runs at 32,768 Hz therefore counting to 0x0020 gives a sampling rate of approximately 1 kHz and 0x0040 gives a sampling rate of 500 Hz.

The microcontroller has an internal temperature sensor that can be used to determine the temperature of the processor attached to one of the ADC inputs. Also, the microcontroller is able to determine the supply voltage.

**Serial Interface**

The serial interface communicates with the host computer through the RS232 connections and the RF module. The MSP has two built-in UARTs which facilitate serial communications. Both UARTs use the SMCLK as their source for baud rate generation. The SMCLK runs at the same frequency as the MCLK but is not shutdown during the low power mode.

**Flash**

The MSP has 60 KB of flash on-chip. Through control registers the MSP is able to not only read the flash memory contents but is able to erase and write to the flash memory directly as well. The voltage required to write to the flash is controlled internally and is transparent to the user. The flash memory is different from normal RAM in that a line cannot be reset high after it has had data written to it. Thus, in
order to reprogram a memory location it needs to be erased first and then it can be reprogrammed. When a memory location is erased all the bits get reset high. Also, an erase operation erases a whole segment of flash memory which is 255 bytes and not just a single word. It is important to have interrupts disabled while writing or erasing from flash.

**JTAG Interface**

The JTAG port is an IEEE Standard (1149.1-1990 Standard-Test-Access Port and Boundary Scan Architecture) that allows a host computer to program the MSP, set breakpoints in the code, and read the contents of registers and memory. It is crucial when debugging the software to use the debugger to get information about the MSP. The computer has a pod which connects to the parallel port of the computer to communicate with the processor.

### 3.2.2 TMS320VC5509 Digital Signal Processor

The DSP is the workhorse for the system. It is a fixed-point processor and performs all the signal processing algorithms. The DSP is underclocked to use less power and contains idle modes for low power consumption when it is not processing data. The microcontroller loads the data from the ADC directly into the DSP memory while it is in an idle mode. After it has finished loading 1.2 seconds worth of data it wakes up the DSP and instructs it to process the next data block. While the DSP is processing the block of data the microcontroller fills a different block of memory, and keeps alternating between the two memory locations. It takes approximately 200 ms for the DSP to process the data, and after finishing it returns to its idle mode.

A memory map for the DSP memory is shown in Figure 3.3. The DSP has Dual-Access RAM (DARAM) as well as Single-Access Ram (SARAM) built into the chip. The MSP can only access the lower 32 kB of DARAM through the HPI. All program code for the DSP is stored in SARAM beginning at memory address 010000.
<table>
<thead>
<tr>
<th>Memory Byte Address</th>
<th>Contents</th>
<th>Memory Word Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x0000C0-0x000FF</td>
<td>Direct Access Variables</td>
<td>0x000060-0x0007F</td>
</tr>
<tr>
<td>0x000100-0x001FF</td>
<td>Interrupt Vectors</td>
<td>0x000080-0x000FF</td>
</tr>
<tr>
<td>0x000200-0x002FF</td>
<td>HPI Read Area</td>
<td>0x000100-0x00017F</td>
</tr>
<tr>
<td>0x000300-0x0003FF</td>
<td>Boot Code</td>
<td>0x000180-0x0001FF</td>
</tr>
<tr>
<td>0x000400-0x0007FF</td>
<td>DARAM0 (stack)</td>
<td>0x000200-0x0003FF</td>
</tr>
<tr>
<td>0x000800-0x000BFF</td>
<td>DARAM1 (data, const)</td>
<td>0x000400-0x0005FF</td>
</tr>
<tr>
<td>0x000C00-0x0019FF</td>
<td>DARAM2 (bss)</td>
<td>0x000600-0x000CFF</td>
</tr>
<tr>
<td>0x001A00-0x007FFF</td>
<td>HPI Write Area</td>
<td>0x000D00-0x003FFF</td>
</tr>
<tr>
<td>0x008000-0x00BFFFF</td>
<td>DARAM3 (filter,window data)</td>
<td>0x004000-0x005FFF</td>
</tr>
<tr>
<td>0x00C000-0x00DFFFF</td>
<td>DARAM4 (delay buffers)</td>
<td>0x006000-0x006FFF</td>
</tr>
<tr>
<td>0x00E000-0x00EFFF</td>
<td>DARAM5</td>
<td>0x007000-0x007FFF</td>
</tr>
<tr>
<td>0x010000-0x013FFF</td>
<td>SARAM0 (program code)</td>
<td>0x008000-0x009FFF</td>
</tr>
<tr>
<td>0x014000-0x017FFF</td>
<td>SARAM1 (coefficients)</td>
<td>0x00A000-0x00BFFF</td>
</tr>
<tr>
<td>0x018000-0x01BFFFF</td>
<td>SARAM2 (frequency data)</td>
<td>0x00C000-0x00DFFF</td>
</tr>
</tbody>
</table>

Table 3.3: DSP Memory Map

**Bootloader**

As stated before, the code for the DSP is actually stored in the flash memory of the microcontroller. The MSP indicates to the DSP that it should copy all the program code into the HPI Write area which the MSP can access. The HPI Write area contains the code blocks shown in Table 3.4. The General Purpose I/O pins on the DSP control which configuration the processor boots up in. It is configured to boot from the Host Port Interface in its current configuration. The ROM bootloader sets the initial state of the CPU registers and then keeps the DSP in a loop while the microcontroller loads the DSP memory with the code. After the microcontroller has finished, it sets register 0x0061 with 0x0300, the memory location for the bootloader, and register 0x0060 with 0xFF00 the sentinel that the DSP recognizes to begin executing instructions at the memory address specified by register 0x0061.

**DSP Algorithms**

The DSP performs all the functions that were described in the last chapter. First it shifts the data down to take out the DC offset from the ADC. This is a simple subtraction of a constant offset from the data. Next it performs a highpass and
Table 3.4: HPI Write Memory Map for Saving Program Code

<table>
<thead>
<tr>
<th>Memory Byte Address</th>
<th>Contents</th>
<th>Memory Word Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x001A00–0x001AFF</td>
<td>Boot Code</td>
<td>0x000D00–0x000D7F</td>
</tr>
<tr>
<td>0x001B00–0x001BFF</td>
<td>Interrupt Vectors</td>
<td>0x000D80–0x000DFF</td>
</tr>
<tr>
<td>0x001C00–0x001DFF</td>
<td>DARAM1 (data, const)</td>
<td>0x000E00–0x000EFF</td>
</tr>
<tr>
<td>0x001E00–0x002BFF</td>
<td>DARAM2 (bss)</td>
<td>0x000F00–0x0015FF</td>
</tr>
<tr>
<td>0x002C00–0x005BFF</td>
<td>SARAM0 (program code)</td>
<td>0x001600–0x002DFF</td>
</tr>
<tr>
<td>0x005C00–0x0070FF</td>
<td>SARAM1 (coefficients)</td>
<td>0x002E00–0x00387F</td>
</tr>
</tbody>
</table>

lowpass single order IIR filter to remove the frequency content that is not needed for the algorithm. After that an envelope detect is performed. The data is decimated to focus in on only the envelopes associated with footsteps. Then the data is passed through a moving window. Next an FFT routine is performed and the output gets converted to a signed-magnitude number. A two pass normalization is performed and the background level is subtracted from the data. Lastly, the detection routine is performed.

The DSP uses different memory locations to process the data. The initial values after they are received from the MSP are stored in DARAM in the HPI Write area. All the initial routines are performed on the data in the same memory location. After the decimation, the data is added to a circular buffer. This circular buffer discards the oldest data values and adds the new data values to the end of the buffer. The buffer is stored in DARAM4 memory. The output from the window function is stored in DARAM3. The FFT converts the data to the frequency domain and then uses SARAM2 to convert the numbers to a real values for the 2-pass normalization. The detection routine is performed in this same memory location. All the coefficients for the various filters are stored in SARAM1.

**JTAG Interface**

The JTAG port for the DSP is very similar to the one on the MSP. It allows Code Composer, the programming suite developed by Texas Instruments: to download code to the processor, set break points, and view memory contents. The pod connects to
the JTAG port on the processor and connects to the computer through the parallel port.

### 3.2.3 Host Port Interface

The Host Port Interface is the set of communication procedures used to facilitate communication between the two processors. The interface utilizes 16 data lines to send and receive complete words in one transfer and 8 control lines to regulate communications between the two processors. The microcontroller is able to read and write directly to the first 32 kB of memory in the DSP. This memory is dual-access memory so two buses can read from the same location concurrently. Obviously only one bus can write to a location at a time. There are specific locations setup in the DSP memory for reading and writing instructions to the microcontroller. The microcontroller writes commands in the allocated memory location in the DSP and then initiates an interrupt when the DSP is supposed to acknowledge the next command. The DSP has a similar communication for communicating information back the MSP. The most commonly used command from the DSP is the one to print a message to the user. During a print message command, the DSP packs the characters into words in the HPI Read section and then sends the print command to the microcontroller. The beginning of the array tells how many characters are in the string.

<table>
<thead>
<tr>
<th>COMMAND</th>
<th>CODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRINT_MESSAGE</td>
<td>0x0100</td>
</tr>
<tr>
<td>STOP_PROCESSING</td>
<td>0x0200</td>
</tr>
<tr>
<td>PROCESS_DATA_BLOCK_1</td>
<td>0x0100</td>
</tr>
<tr>
<td>PROCESS_DATA_BLOCK_2</td>
<td>0x0100</td>
</tr>
<tr>
<td>CLEAR_PROCESSING_BUFFERS</td>
<td>0x0300</td>
</tr>
<tr>
<td>GET_VC5509_VERSION</td>
<td>0x0900</td>
</tr>
<tr>
<td>COPY_TO_HPI_WRITE</td>
<td>0x0999</td>
</tr>
</tbody>
</table>

Table 3.5: HPI Command Codes
3.3 RF Design

The RF is controlled by the microcontroller through the second UART port. This port is programmed to run at 9600 bps, but can easily be increased in the software. The RF module is made by Maxstream and it transmits and receives in the 900 MHz band. It provides a half duplex virtual serial link with 100mW(+20 dBm) transmit power and -110 dBm receiver sensitivity. The module has its own buffering scheme and puts itself into a low power mode when it is not transmitting or receiving any characters. The microcontroller simply sends the characters to the module through an RS232 port and the Maxstream transparently transmits them to the other modules within range. If the Maxstream is not able to correct errors from the transmission the characters get discarded. It is up to the application to send or receive acknowledgements and retransmit if necessary.

Currently, the RF subsystem has only been used to echo the data that is appearing on the RS232 output. It can also read in responses from a remote terminal to modify settings within the system. In future designs the RF port could be used to network a number of sensors together. It could communicate the information in a network and multiple sensors could be used to either triangulate on a certain position or else track a person the whole way through the range of all the sensors.

3.4 Power Design

The power design is very critical for the sensor. In the field the system should run for a long time without the need for human intervention. The system uses solar power to run the system and charge the batteries during the day and automatically switches to battery power when the solar power has diminished below usable levels. The voltage coming out of the solar panels changes depending on how much sunlight is striking the panels. This voltage is regulated to 9.1 V with a buck converter and provides the power to charge the batteries and power the system. Two more buck/boost converters provide the power for the 3.3 V power plane and 5 V RF power. The system as it is
currently designed would have a lifetime dependent only on how often the batteries need replacing from the constant charging and discharging.

### 3.4.1 Solar Power

The solar panels incorporated in the design were manufactured by Siemens, and use thin film technology based on Copper Indium Diselenide (CIS). They are able to produce battery charging levels even in low-light environments. Additionally this is a commercially available part in a black-anodized aluminum frame with a glass covering to protect the cells. A picture of the solar panel is shown in Figure 3-8. Unfortunately, the size of the panel is rather large for a sensor application (12.9” by 8.1”). The solar panels produced 2.5 W of power even on cloudy days.

![Solar Panel](image-url)
3.4.2 Battery Charger

The battery charger is a Maxim part that is able to regulate the current going to the batteries. It charges up the batteries and then shuts off when it senses that the batteries are charged. It is also able to provide power to a load while it is charging. This is used to run the system while the battery charger is charging the batteries. Four AA NiMH batteries are used in the system to give a nominal voltage of 4.8 V on the power bus when it is running off battery power.

3.4.3 External Power

External Power can be supplied to the board as well. This is mainly for lab environments and during testing. The voltage for the supply should be 6V and there is diode protection circuitry to protect against reversed supply connections.
Chapter 4

Test Procedure

In order to ensure that the system was designed and working correctly, various levels of tests were performed. A bottom-up test procedure was employed to verify that each component by itself was operating correctly and then integration tests were performed to confirm that the whole system was functioning correctly.

4.1 Unit Level Testing

A complete test procedure was written to validate all the components of the system after the board was fabricated. The procedure examines all the power and ground connections to make sure there are no short circuits. Next, signals controlled by the microcontroller are tested. Last are basic functional tests to achieve communication with the subsystems and communications between the two processors through the HPI. The procedure is shown in Appendix D.

After the hardware was debugged, unit-level testing was performed on all the signal processing routines. They were each run individually with simulated test data. Then the same data was put into Matlab and the routines were verified against the results from Matlab for their accuracy.
4.2 System Testing

In addition to the testing for the signal processing routines, Matlab scripts were developed which generated simulated footstep data. These scripts were used to perform system level testing. The data from the scripts was furnished directly to the ADC of the microcontroller without any frontend analog processing. At this point the signal processing routines were debugged until they were able to process the data and give the expected results. At each stage in the signal processing chain the data could be verified against the Matlab results. When the signal processing functions were at a sufficient level then actual data, recorded on DAT, was played into the system through the sensor input. The DAT stores the time of day when the recording was made and that was used to determine the distance from the sensor via the GPS data.

4.2.1 Data Collection

Three days were spent collecting footstep data that was used to develop the algorithms and later test the system. The data was recorded on both a Sony portable DAT machine and a 16 port data acquisition system connected to a laptop. The course had 9 single-axis geophone sensors and 2 three-axis geophone sensors. It extended for 100 meters on each side of the sensor array. A graphic showing the configuration of the array is shown in Figure 4-1.

The test sequence involved the subject conducting two normal walks through the course, a stealthy walk, and then a jog through the course. There were waypoints along the way, to coordinate where the person was on the course. As the person crossed each waypoint they announced over the radio which waypoint they were passing. A GPS receiver was worn by each person as they went through the course and it recorded the GPS coordinates of the person every two seconds. This data later became the ground truth that was used to determine the effective ranges for detection. A background run was also performed at each location to determine the ambient background level. Lastly, for two of the locations horse data was collected to see if modifications could be made to the algorithm to discriminate a person from
a horse.

Figure 4-1: Footstep Data Collection Setup
Chapter 5

Results

Overall the system performed quite well. Considering the scope of the project, it is amazing that the system worked at all. The detection ranges ended up not being as far as originally hoped for, however, it still performed well. Typical detection ranges were on the order of 10 meters depending on the environmental conditions and the weight of the person. Having lower noise in the system would allow the system to differentiate footsteps from further distances.

5.1 Detection Performance

The detection ranges for a number of the test runs are shown in Table 5.1. These tests were performed at three different locations in Massachusetts and a couple of different types of walks were used. The first location was Great Brook Farm State Park (GB). Only one location was used at Great Brook and the terrain was an open field with a dirt path. The next location was at Harold Parker State Forest (HPSF). Two locations were used at Harold Parker: a dirt path through a wooded area, and a dense foliage area that was on a hill. Lastly, a location in Acton was used to collect horse data. Each run was analyzed three times by the system to determine detection ranges. The sensor in the middle of the array was the one used for all the tests. Also, the number of false positives was recorded as well. The subject data is recorded in Table 5.2. The environmental aspects of the area play a tremendous role.
in the detection ranges of the system. For some of the runs, the system was not able to detect the person until they were right at the sensor, and in other locations the system could detect footsteps from 35 meters away. There is system lag due to the length of the FFT as well. The FFT represents 8.5 seconds of data which suggests why some detections were made after the subject passed by the sensor. Also, the sensor array is 5 meters offset from the trail. The way the person walks also plays a role in the detection ranges of the system. If the person walks in a stealthy fashion then it is very difficult to pick up the footsteps until they are right at the sensor. Unfortunately, the frequency spectrum collected from the horse data is very similar to the spectrum from people and it is very difficult to differentiate a horse from a person with the current algorithms.
<table>
<thead>
<tr>
<th>Location</th>
<th>Track #</th>
<th>Subject</th>
<th>Type</th>
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Table 5.2: Subject Data

5.2 Analog Performance

A Hewlett Packard Dynamic Signal Analyzer was used to measure the frequency response, phase response, and noise floor of all the analog channels of both boards produced. Only one channel of data is included for each board, but the tests were run on all the channels. The results for the other channels are within acceptable tolerances of the first. The values are lower than 40 dB and 60 dB because the signal is decreased by the active filtering stage. Also, the gain-bandwidth product of the op-amps is only 500 kHz.
Figure 5-1: Magnitude, Phase and Noise Plots for Board SN101
Figure 5-2: Magnitude, Phase and Noise Plots for Board SN102
5.3 Solar Power

The solar panels were taken outside and measured at various points in the day with different cloud cover. Even on cloudy days the solar panels were able to put out approximately 2.5 W of power. As the table in the power section will show, even with everything turned on and the RF running, the system only requires about 400 mW of power. This means the solar panels should be more than adequate to run the system and power the batteries at the same time even on cloudy days or in the winter time. Obviously, this data is for the Boston area and other locations would have different solar intensities.

5.4 Power Usage

The power usage is shown in Table 5.3. The microcontroller is always running because it controls the other subsystems. The RF requires a significant amount of power to transmit and receive signals. Perhaps a system where the RF unit was only transmitting and receiving at set intervals would help lower the power consumption because the RF subsystem could be shutdown when not in use.

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Table 5.3: Power Usage

5.5 RF Range

The Maxstream 9Xtream-96 provides a 9600 bps serial link. The range was tested by setting up two transceivers and moving one of them successively further away from the other. The Maxstream does not try to resend messages that it cannot correct.
the errors in, instead, it just discards the messages. Typical ranges for 100% packet
transmission were on the order of 300-500 meters when the radios were placed on the
ground like they would be on the sensor. Using a half-wave antenna it was possible
to attain ranges of 750 meters.
Chapter 6

Conclusion

Overall this project has had very positive results. The project was a massive undertaking for one person to conduct. A picture of the final prototype board that was produced is shown in Figure 6-1. The design involved many aspects including the requirements, schematic capture, board layout, creating a test plan, debugging components, and system integration. Furthermore, the documentation aspect has been a critical component as well. Designers these days do not work in a little box. Designs get revised at later dates and clear documentation becomes necessary to allow other designers to pick up where you left off. It is my desire that if at a later point someone is interested in continuing to work on this project the time it will take to get familiar with the project will be greatly reduced as a result of this documentation.

The design contained a number of areas which had a higher chance of failure in the system. It is fun to use the cutting-edge technology, but there are some pitfalls which come with that as well. For instance, the DSP was a pre-release part. There were many functions that were not documented yet and they way they worked had to be discovered through experimentation. Also, the datasheet did not contain accurate information on some of the aspects of the chip. The lack of any extra memory to boot the DSP was another risk. If time permitted it would be better to include the memory and also work on setting up the DSP to boot from MSP. Then when the system was past the prototyping stages the memory could be removed. Fortunately, everything ended up working in the end, but in the future a more conservative approach should
probably be taken. Usually, a project of this scale requires at least two revisions. A first cut prototype version to make sure everything works as expected and then the final design. True to most projects, the funds were limited and there was not enough money to fabricate two boards.

The amount of knowledge gained from this project is indescribable. The design had to be taken all the way from the initial design stages to the final tests. Having never actually routed and laid out the parts on a board before, a lot of learning was associated with that. Also, my background is more in hardware design and most of the signal processing routines required some learning. The results achieved are very notable, but there will always be room for improvement.

Figure 6-1: Prototype Board
6.1 Future Enhancements

There are endless possibilities for this system from intruder detection around a home to earthquake detections. Future versions will probably want to investigate a smaller package for the system. Ideally, the system should fit into a package right in the sensor.

Another area that would be interesting to explore is to see if it is possible to use the RF modules to communicate with other nearby systems and then triangulate the bearing of the person being tracked based on the information from several sensors. These could be used to follow a person through an entire array of sensors.

Hopefully, as time progresses solar panels will become more efficient and cheaper. Currently, the number of solar cells needed to power the system makes for a rather large array, but as new photovoltaic technologies are explored no doubt the arrays will become smaller and cheaper.

6.1.1 Algorithm Improvement

Obviously the area of algorithm development is something that can always be improved. As more tests are conducted with the system over a wider variety of conditions there is likely to be more enhancements to the algorithms. It would be nice to have a confidence level coming from the algorithm. This confidence level could then be used to set various warning levels or actions that should be taken.

Time domain algorithms could be examined to determine if it is possible to use those methods in conjunction with frequency data to get more accurate algorithms that detect at further distances. Alternatively, the system could be easily redesigned to do math intensive tracking algorithms. More memory could be added to the DSP and the DSP can be clocked at up to 200 MHz. This opens up a whole set of possibilities for tracking algorithms.
6.1.2 DSP Technology

As DSP technology improves the DSP should be able to have more functionality, with less power. The TI DSP that was used in the design was a TMX part which means it had not been fully tested and not guaranteed to meet all the specifications in the datasheet. In future versions, the production level part should have better performance and power usage.
Appendix A

Schematics
SEISMIC FILTERING AND AMPLIFICATION
Appendix B

Parts Listing
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<tr>
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4/15/02
Appendix C

Assembly Drawing
Appendix D

Test Procedure
Personnel Detector
Test Procedure

Elliot Ranger
6/26/2002
**TEST INFORMATION**

Board Number
Name of Tester
Date

**EQUIPMENT:**

<table>
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<tr>
<th>MANUFACTURER</th>
<th>NAME</th>
<th>MODEL</th>
<th>SERIAL NUM.</th>
<th>DRAPER NUM.</th>
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<td>Multimeter</td>
<td>89 IV</td>
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<td>Digital Oscilloscope</td>
<td>TDS 3014</td>
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<td>Hewlett Packard</td>
<td>Dynamic Signal Analyzer</td>
<td>3562A</td>
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</table>

**SETUP**
CONTINUITY TESTS

Instructions: Make sure Jumpers EJ5, EJ6, EJ7, EJ8, EJ9, EJ10, EJ3, EJ2, EJ4, EJ2, EJ1, EJ11, EJ12, EJ13 are connected.

GROUNDS ALL CONNECTED
With one probe on TP10 check for continuity between:

- EJ5
- EJ7
- EJ8
- EJ9
- EJ10

POWER NOT SHORTED TO GROUND
With one probe on TP10 check to make sure there is no continuity between:

- TP7
- TP6
- TP8
- TP1
- TP5
- TP3
- TP4
- TP2
- TP12
- TP13
### 3.3V POWER TEST

Instructions: Remove all Jumpers except for EJ5, EJ6, EJ7, EJ8, EJ9, and EJ10. Use an external power supply to provide 6V of power from TP6 (EXT_PWR+) to TP11 (EXT_PWR-).

- Record the voltage at TP1 with S1 on
- Turn S1 off and on and observe at least a 100ms pulse (active low) at U17 Pin 2
- Sweep the power supply voltage from 3.5 V - 10 V ensure that the voltage at TP1 stays at approximately 3.3 V
- Determine the input voltage that causes the Voltage at TP1 to drop below 3.1 V

### MSP

#### CLOCK MEASUREMENTS

Instructions: Program the MSP through the JTAG port with the test program.

- Record the frequency of MCLK at TP14
- Record the frequency of ACLK at TP16

#### RS232 TEST

Test that the MSP is able to echo characters back to the computer

#### PORT TEST

Toggle the following signals:

- VC55_ENA
  - Record the voltage of VC55_3VD at TP4
  - Record the voltage of VC55_CORE at TP2
  - Turn ON the VC55 and observe at least a 100ms pulse (active low) at U18 Pin 2
GEO_ENA

Record the voltage of GEO_PWR at TP3

RF_ENA

Record the voltage of RF_PWR at TP5

Instructions: Connect Jumper EJ1. Toggle RF_ENA and observe at least a 100ms pulse (active low) at U16 Pin 2

RF_PWRDN (J4 PIN 2)

GEO_A_SEL (U2 PIN 6)

GEO_B_SEL (U4 PIN 6)

GEO_C_SEL (U3 PIN 6)

RS232_ENA (Characters should not be displayed on the terminal when turned off)

ANALOG TEST

Instructions: Connect a Jumper across EJ4. Turn on GEO_ENA with the MSP.

SEISMIC MEASUREMENTS

Instructions: Connect a signal analyzer to the positive input and measure the output at Test out.

GEO_A:

Record the small signal gain

Record the high frequency -3db point

Record the noise floor

GEO_B:

Record the small signal gain

Record the high frequency -3db point

Record the noise floor

GEO_C:

Record the small signal gain
Record the high frequency -3db point
Record the noise floor 

**VC5509**

Instructions: Turn on VC55_ENA with the MSP.

**CLOCK MEASUREMENT**
Instructions: Program the VC5509 through the JTAG port with the test program.

Record the frequency of CLKOUT at TP25

**LEDs**

Observe that LED0 lights
Observe that LED1 lights
Observe that LED2 lights

**HPI**

Instructions: Select the HPI menu item.

Verify that the MSP can write a character into The VC5509s memory and the VC5509 can read it
Verify that the VC5509 can write a character into The MSPs memory and the MSP can read it

**RF INTERFACE**

Instructions: Connect a Jumper across EJ1. Turn on RF_ENA with the MSP. Turn the RF echo ON from the MSP.

Send characters from one of the Evaluation Board Maxstream modules to the board in question and Observe that characters are correctly echoed back
SOLAR INTERFACE

Instructions: Ensure that Jumper EJ3 is removed. Use an external power supply to provide power from TP7 (SOLAR+) to TP9 (SOLAR-).

Set the voltage of the power supply to 12 V
And record the voltage at PIN 1 of EJ3

Sweep the voltage of the power supply from 12 V - 21 V and ensure the voltage at PIN 1 of EJ3 stays constant

Determine the input voltage that causes the Voltage at PIN 1 of EJ3 to drop below 5 V

BATTERY CHARGER

Instructions: Ensure that Jumper EJ2 is removed. Use an external power supply to provide 9.1V of power from TP6 (EXT_PWR+) to TP11 (EXT_PWR-).

Record the voltage from EJ2 PIN 1 to TP10 (BATT-)

Place an ammeter across EJ2. Connect a battery pack with 4 partially drained NiMH batteries in series from TP8 (BATT+) to TP10 (BATT-) record the amount of Current flowing through EJ2
Appendix E

TMS320VC5509 Source Code

E.1 bootcode.asm

; Personnel Detector
; Elliot Ranger
; Master of Science Thesis
; Massachusetts Institute of Technology
; in conjunction with Charles Stark Draper Laboratory
;
;
;******************************************************************************

10 ; FILENAME........ bootcode.asm
; DATE CREATED... 07/11/2002
; LAST MODIFIED.. 01/15/2003
;******************************************************************************

.global _hpi_save_code, _hpi_load_code
.sect ".text"

.hpi_save_code:

20 ; Copy bootcode to hpi write section

  AMOV #0x000180,XAR1

  AMOV #0x000D00,XAR3

  NOP

  NOP
NOP
NOP
NOP
NOP
RPT #0x007F
MOV ∗AR1+, ∗AR3+

30

; Copy vectors to hpi write section
AMOV #0x000080,XAR1
AMOV #0x000D80,XAR3
NOP
NOP
NOP
NOP
NOP
NOP
NOP
RPT #0x007F

40
MOV ∗AR1+, ∗AR3+

; Copy DARAM1 to hpi write section
AMOV #0x000400,XAR1
AMOV #0x0000E00,XAR3
NOP
NOP
NOP
NOP
NOP
NOP
NOP
NOP

50
RPT #0x00FF
MOV ∗AR1+, ∗AR3+

; Copy DARAM2 to hpi write section
AMOV #0x000600,XAR1
 AMOV #0x000F00,XAR3
 NOP
 NOP
 NOP
 NOP

60
 NOP
 RPT #0x06FF
 MOV *AR1+,*AR3+

 ; Copy SARAM0 to hpi write section
 AMOV #0x008000,XAR1
 AMOV #0x001600,XAR3
 NOP
 NOP
 NOP

70
 NOP
 NOP
 RPT #0x17FF
 MOV *AR1+,*AR3+

 ; Copy SARAM1 to hpi write section
 AMOV #0x00A000,XAR1
 AMOV #0x002E00,XAR3
 NOP
 NOP

80
 NOP
 NOP
 RPT #0x0A7F
 MOV *AR1+,*AR3+
RET

.sect "boot"

.hpi_load_code:

90

; Copy hpi write section to vectors
AMOV #0x000D00,XAR1
AMOV #0x000080,XAR3
NOP
NOP
NOP
NOP
NOP
NOP
RPT #0x007F

100 MOV ∗AR1+,∗AR3+

; Copy hpi write section to DARAM1
AMOV #0x000D80,XAR1
AMOV #0x000400,XAR3
NOP
NOP
NOP
NOP
NOP
NOP
110 RPT #0x00FF

MOV ∗AR1+,∗AR3+

; Copy hpi write section to DARAM2
AMOV #0x000E80,XAR1
AMOV #0x000600,XAR3

NOP

NOP

NOP

NOP


120

NOP

RPT #0x06FF

MOV *AR1+,*AR3+

; Copy hpi write section SARAM1

AMOV #0x001580,XAR1

AMOV #0x008000,XAR3

NOP

NOP

NOP


130

NOP

NOP

RPT #0x17FF

MOV *AR1+,*AR3+

; Copy hpi write section SARAM2

AMOV #0x002D80,XAR1

AMOV #0x00A000,XAR3

NOP

NOP


140

NOP

NOP

RPT #0x0A7F

MOV *AR1+,*AR3+
E.2 define.h

/* Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 * /
 */

FILENAME.......... define.h
DATE CREATED.......... 07/11/2002
LAST MODIFIED......... 03/04/2003
*******************************************************************************

#define TRUE 1
#define FALSE 0

#define INV_LOG2 3.321928094887
#define DC_OFFSET 16384

#define VERSION "TMX320VC5509PGE VERSION 1.20 3/04/2003"

#define MAX_BUFFER 90

/* MSP Command Codes */
#define PRINT_MESSAGE 0x0100
#define STOP_PROCESSING 0x0200

/* VC5509 Command Codes */
#define PROCESS_DATA_BLOCK_1 0x0100
#define PROCESS_DATA_BLOCK_2 0x0200
#define CLEAR_PROCESSING_BUFFERS 0x0300
#define GET_VC5509_VERSION 0x0900
#define COPY_TO_HPI_WRITE 0x0999
/ * Memory locations */
#define BLOCK1_MEM 0x1000
#define BLOCK2_MEM 0x1500

/* Detection Parameters */
#define FIRST_THRESHOLD 300
#define SECOND_THRESHOLD 250
#define THIRD_THRESHOLD 250
#define PEAK_WIDTH 2

### E.3 difference.asm

; Function Call
; ---------------
; prototype: void hp_filter(DATA *x, ushort nx, DATA *y_previous, DATA *x_previous)
;
; Entry: arg0: AR0 — signal input pointer
; arg1: T0 — number of samples in the input
; arg2: AR1 — pointer to previous output y
; arg3: AR2 — pointer to previous input x
10 ;
;
.def _hp_filter
.sect .text

_window
pshm ST1.55 ; Save ST1, ST2, and ST3
pshm ST2.55
pshm ST3.55

or #0x340,mmap(ST1.55); Set FRCT,SKMD,SATD
bset SMUL ; Set SMUL

sub #1,T0
mov T0,BRC0 ; Outer loop counter
rptblocal lp1-1
mov *AR0, T2 ; save the input value x[i] in T2
mov *AR1, T1 ; store y[previous] in T1
sub *AR2, *AR0, AC0 ; subtract x[i] − x[previous]

mack T1, #30720, AC0, AC0 ; multiply y[previous] * 30720 and accumulate
mov hi(AC0), *AR0 ; store the new output
mov T2, *AR2 ; put the previous x value in AR2
mov *AR0, *, AR1 ; put the previous y value in AR1

lp1

popm ST3, 55 ; Restore ST1, ST2, and ST3
popm ST2, 55
popm ST1, 55
ret
.end

E.4 extern.h

/∗
∗ Personnel Detector
∗ Elliot Ranger
∗ Master of Science Thesis
∗ Massachusetts Institute of Technology
∗ in conjunction with Charles Stark Draper Laboratory
∗
/∗
/*******************************************************************************

extern Uint16 timer0_counter;
extern Uint16 new_command;
extern DATA* block_memloc;

100
E.5 filters.h

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 * /
 */

_flashdata_backslash_010

#define NX_IIR 1200
#define NBIQ_IIR 2
#define NX_FIR1 1200
#define NX_FIR2 240
#define NH_FIR 31
#define D_1 5
#define D_2 2
#define NX_SIZE 120

/* delay buffers */
DATA dbuffer_bp[NBIQ_IIR];
DATA dbuffer firdec[NH_FIR+1];
DATA dbuffer firdec2[NH_FIR+1];
ushort dbuffer_index1;
ushort dbuffer_index2;
DATA iir_hp_y;
DATA iir_hp_x;
DATA iir_lp_y;

/* coefficients - bandpass IIR filter */
DATA h_bp[5*NBIQ_IIR] = { /* CSSz: a1 a2 b2 b0 b1 ... */
    -26992,
40  11483,
    1852,
    1852,
    3704,
    -31313,
104  14991,
    1852,
    1852,
    -3704,
};
50
/* coefficients - FIR Decimation filter stage 1 (N=5) */
DATA h_firdec1[NH_FIR] = {
    0,
    39,
    91,
    139,
    129,
    0,
    -271,
60  -609,
    -832,
    -696,
    0,
    1297,
    3011,
    4755,
    6059,
    6542,
    6059,
70  4755,
    3011,
    1297,
    0,
    -696,
    -832,
    -609,
    -271,
    0,
    129,
80  139,
    91,
    39,
DATA h_firdec2[NH_FIR] ={
    -56, 0, 96, 0, -221, 0, 462, 0, -878, 0, 1609, 0,
    -3176, 0, 10342, 16410, 10342, 0, -3176, 0, 1609, 0,
    -878, 0, 462, 0, -221, 0, 96, 0, -56, 0,
};

E.6 firdecimate.asm

; Personnel Detector
FILENAME. . . . . firdecimate.asm
DATE CREATED. . 09/11/2002
LAST MODIFIED. 09/15/2002

Modified code from Real-Time Digital Signal Processing

firdecimate.asm — decimating FIR filter

prototype: ushort firdecimate(DATA *x, ushort nx, DATA *h,
ushort nh, DATA *r, DATA *dbufuffer, ushort dbufindex
ushort m, ushort outsize);

Entry: arg0: AR0 — filter input buffer pointer
arg1: T0 — number of samples in the input buffer
arg2: AR1 — FIR coefficients array pointer
arg3: T1 — FIR filter order
arg4: AR2 — filter output buffer pointer
arg5: AR3 — signal buffer pointer
arg6: AR4 — signal buffer index
arg7: on stack — decimation factor
arg8: on stack — length after decimation

Return: T0 = signal buffer index

.def _firdecimate
.sect .text

_firdecimate
pshm ST1,55 ; Save ST1, ST2, and ST3
pshm ST2,55
pshm ST3,55
pshm T2
pshm T3

mov *SP(#6), T2
mov *SP(#7), T3
or #0x340,mmapi(ST1,55); Set FRCT,SXMD,SATD
bset SMUL ; Set SMUL
mov XAR1,XCDP ; CDP as coefficient pointer
mov mmap(A1),BSAC ; Set up base address for CDP
mov #0,CDP ; Start from the 1st coefficient
mov mmap(T1),BKC ; Set the coefficient array size
mov mmap(A3),BSA23 ; Set base address for AR3
mov mmap(T1),BK03 ; Set signal buffer x[n] size as L
mov AR4,AR3 ; AR3 signal buffer index
or #0x10A,mmap(ST2); CDP, AR1, AR3 circular pointers;
sub #1,T3 ; outer repeat counter NX/D
mov T3,BRC0 ; Outer loop counter
sub #2,T2 ; Decimation factor - 2
sub #3,T1,T0

bcc Decim2, T2==0 ; Check to see if decimation factor =2

rptblocal sample_loop1—1
mov *AR0+,*AR3 ; Put new sample to signal buffer x[n]
mov T0,CSR ; Inner loop counter as L—3
m pym *AR3+,*CDP+,AC0 ; The first operation
rpt CSR
macm *AR3+,*CDP+,AC0 ; The rest MAC iterations
macmr *AR3,*CDP+,AC0
mov T2,CSR
mov hi(AC0),*AR2+

rpt CSR
mov *AR0+,*AR3—
sample_loop1

b L2

Decim2:
rptblocal sample_loop2—1
mov *AR0+,*AR3 ; Put new sample to signal buffer x[n]

mov T0,CSR ; Inner loop counter as L=3

mpym *AR3+,*CDP+,AC0 ; The first operation

macm *AR3+,*CDP+,AC0 ; The rest MAC iterations

macmr *AR3,*CDP+,AC0

mov T2,CSR

mov hi(AC0),*AR2+

mov *AR0+,*AR3− ; do it only once for the case when D=2

sample_loop2

L2:

popm T3

90

popm T2

popm ST3,55 ; Restore ST1, ST2, and ST3

popm ST2,55

popm ST1,55

mov AR3,T0 ; Return signal buffer index

ret

.end

E.7 hanning.h

/ *
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 * *
 */

/***********************************************************************************/
#define WINDOW_SIZE 1024
#define FREQ_SIZE 513

ushort windex;
DATA output[WINDOW_SIZE];
DATA wsignal[WINDOW_SIZE];

/* window coefficients */
ushort hanning[WINDOW_SIZE]={
1,
2,
6,
10,
15,
22,
30,
39,
50,
62,
74,
89,
104,
121,
138,
157,
178,
199,
222,
246,
271,
298,
325,
354,
384,
415,
448,
481,
516,
553,
590,
628, 668, 709, 751, 795, 839, 885, 932, 980, 1029, 1080, 1132, 1185, 1239, 1294, 1351, 1408, 1467, 1527, 1588, 1651, 1714, 1779, 1845, 1912, 1980, 2049, 2120, 2191, 2264, 2338, 2413, 2489, 2567, 2645, 2725, 2806, 2888, 2971, 3055, 3140, 3226, 3314, 3402, 3492,
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|      | 3957,  |
|      | 4053,  |
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|      | 4861,  |
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|      | 5182,  |
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E.8 hp_filter.asm

; Personnel Detector
; Elliot Ranger
; Master of Science Thesis
; Massachusetts Institute of Technology
; in conjunction with Charles Stark Draper Laboratory
;
; prototype: void hp_filter(DATA *x, ushort nx, DATA *y, previous, DATA *x_previous)
;
; Entry: arg0: AR0 — signal input pointer
; arg1: T0 — number of samples in the input
; arg2: AR1 — pointer to previous output y
; arg3: AR2 — pointer to previous input x
;

.def _hp_filter
.sect .text

_hp_filter
pshm ST1,55 ; Save ST1, ST2, and ST3
pshm ST2,55
pshm ST3,55

or #0x340,mmap(ST1,55); Set FRCT,SMXD,SATD
bset SMUL ; Set SMUL


```
sub #1,T0

mov T0,BRC0 ; Outer loop counter

rptblocal lp1−1

mov *AR0, T2 ; save the input value x[1] in T2

mov *AR1, T1 ; store y[previous] in T1

sub *AR0,*AR2,AC0 ; subtract x[1] − x[previous]

mack T1, #30720, ACO, ACO ; multiply y[previous] × 30720 and accumulate

mov hi(ACO),*AR0 ; store the new output

mov T2, *AR2 ; put the previous x value in AR2

mov *AR0+, *AR1 ; put the previous y value in AR1

lp1

50

popm ST1.55

ret
.
.end
```

---

**E.9 hpi.c**

```c
/
* Personnel Detector
* Elliot Ranger
* Master of Science Thesis
* Massachusetts Institute of Technology
* in conjunction with Charles Stark Draper Laboratory
* 
*/
/**************************************************************************/
10 * FILENAME....... hpi.c
*
* DATE CREATED.. 07/11/2002
```
#include "include.h"

/* print_message: takes a string and packs the bytes to be sent over the HPI
   * then gives the command to the MSP to print the data in the buffer

   The first position is for the length of the string */
   hpi_data_address+=1;

   /* start at the beginning of the message */
   i=0;

   /* takes care of everything but last character */
   while ((message[i] != 0) && (i <= MAX_BUFFER))
   {
       /* load the first character of the word */
       temp_word = (Uint16) (message[i] << 8);
       i++;

       /* load the second character of the word */
       if (message[i] != 0)
       {
           temp_word |= (Uint16) (message[i]);
           i++;
       }
       else
       {
           temp_word |= 0x0000;
           /* do not increment i */
       }

       /* store the word at the address */
       *(Uint16 *)hpi_data_address) = temp_word;
       hpi_data_address++;
   }
/* put a null character in at the end, just in case */
(**(Uint16 *)hpi_data_address) = 0x0000;

/* store the length in bytes at the beginning of the buffer */
(**(Uint16 *)_MSP_DATA) = (Uint16) i;

/* send code to MSP to print the buffer */
MSP_COMMAND_REGISTER = PRINT_MESSAGE;
send_host_interrupt();

void clear_messages(void)
{
   Uint16 hpi_data_address = _MSP_DATA;
    Uint16 i = 0;

    for (i = 0; i < MAX_BUFFER; i++)
    {
        (*(*(Uint16 *)hpi_data_address) = 0x0000;
            hpi_data_address++;
    }
}

80 /***********************************************************************************/
 /* send_host_interrupt: sends an interrupt to the MSP */
 /*******************************************************************************/
 void send_host_interrupt(void)
{
    Uint16 i;

    /* interrupts on the falling edge of HINT */
    ST3_55 &= (~MSP_HINT);

    /* delay */
    for(i = 0; i <= 1000; i++);

    /* release the interrupt pin */
    ST3_55 |= MSP_HINT;
}

80 /***********************************************************************************/
 /* get_command: gets the next command from the MSP */
 /*******************************************************************************/
 100 Uint16 get_command(void)
{

while (new_command == FALSE)
{
    /* Puts the processor in low power mode when it */
    /* is not processing anything */
    ICR |= (CACHE | CPU);
    EXECUTE_IDLE;
}

/* reset new_command to prepare for next command*/
new_command = FALSE;

/* return command */
return (DSP_COMMAND_REGISTER);

/***************************************************************************/
/* send_hpi_command: sends a command to the MSP */
/***************************************************************************/
void send_hpi_command(Uint16 command)
{
    /* writes a command to the register */
    MSP_COMMAND_REGISTER = command;

    /* sends an interrupt to the MSP to look at the register */
    send_host_interrupt();
}

/***************************************************************************/
/* hpi_interrupt: turns on LED1 when an interrupt is received, sets a flag */
/* to indicate there is a new command to process and takes the */
/* system out of low power mode. */
/***************************************************************************/
interrupt void hpi_interrupt(void)
{
    /* turn on LED1 */
    GPIO_DATA |= LED1;

    /* start timer to turn off LED1 */
    start_timer1();

    new_command = TRUE;

    /* take out of low power mode */
    ICR &=(~(CACHE | CPU));
}
E.10  include.h

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 *
 */
/*******************************************************************************************/

#include "vc5509.h"
#include "prototype.h"
#include "define.h"
#include "extern.h"
#include "math.h"

#include "dsplib.h"

E.11  init_sys.c

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 *
 */
/*******************************************************************************************/

FILENAME...... include.h
DATE CREATED.. 07/11/2002
LAST MODIFIED.. 08/07/2002

FILENAME...... init_sys.c
DATE CREATED.. 07/11/2002
LAST MODIFIED.. 08/07/2002
```c
#include "include.h"

/* initialize_system: initialize all the io, interrupts, and low power mode */

void initialize_system(void)
{
    INTR_GLOBAL_DISABLE;

    ST1_55 &= (~C54CM);

    initialize_gpio();

    initialize_intr();

    DSP_COMMAND_REGISTER = 0;
    MSP_COMMAND_REGISTER = 0;

    clear_messages();

    IER0 |= (DSPINT | TINT0);

    IER1 |= TINT1;

    initialize_idle_configuration();

    GPIO_DATA &= (~LED0);
    GPIO_DATA &= (~LED1);
    GPIO_DATA &= (~LED2);

    INTR_GLOBAL_ENABLE;
```
60  /**************************************************************************
   * initialize_gpio: setup GPIO0-7 as inputs, and enable GPIO on the ports
   * with the LEDs.
   /**************************************************************************/
void initialize_gpio(void)
{
    /* setup GPIO0-GPIO7 as inputs */
    IO_DIR = 0x0000;

    /* enable LED GPIO ports */
    GPIO_ENABLE = LED2 | LED1 | LED0;

    /* setup LED GPIO ports as outputs */
    GPIO_DIR = LED2 | LED1 | LED0;

    /* turn off all the LEDs */
    GPIO_DATA &= ~(LED0 | LED1 | LED2);
}

80 /**************************************************************************
   * initialize_intr: initialize interrupts and the interrupt vector table
   **************************************************************************/
void initialize_intr(void)
{
    /* disable interrupt enable register 0 */
    IER0 = 0;    //

    /* disable interrupt enable register 1 */
    IER1 = 0;

    /* clear any pending interrupts on interrupt flag register 0 */
    IFRO = 0xFFFF;

    /* clear any pending interrupts on interrupt flag register 1 */
    IFR1 = 0xFFFF;

    /* Locate DSP Interrupt vectors at byte address 100h */
    IVPD = 1;

    /* Locate Host Interrupt vectors at byte address 100h */
    IVPH = 1;
}
/* initialize_idle_configuration: shutdown all the peripherals not in use */

void initialize_idle_configuration(void)
{
    /* enable the idle domain for the serial ports */
    PCR0 |= McBSP_IDLE_EN;
    PCR1 |= McBSP_IDLE_EN;
    PCR2 |= McBSP_IDLE_EN;

    /* enable the idle domain for the I2C */
    ICMDR |= I2C_IDLE_EN;

    /* enable the idle domain for the multimedia card */
    MMCFCLK |= MMC_IDLE_EN;

    /* load the idle configuration register with the peripheral */
    /* and external memory interface domains to shut them down */
    ICR = (EMIF | PERIPH);

    /* execute the loaded idle configuration */
    EXECUTE_IDLE;
}

E.12 lp_filter.asm

; Filename: ........ lp_filter.asm
; Date Created: 02/12/2003
; Last Modified: 02/20/2003

; void lp_filter(DATA *x, ushort nx, DATA *y_previous);

; Entry: arg0: ARO — signal input pointer
; arg1: T0 — number of samples in the input
; arg2: AR1 — pointer to previous output y

20 ;

.def _lp_filter
.sect .text

.lp_filter

.pshm ST1,55 ; Save ST1, ST2, and ST3
.pshm ST2,55
.pshm ST3,55

30

or #0x340,mmap(ST1,55); Set FRCT,SMMD,SATD

bset SMUL ; Set SMUL

sub #1,T0

mov T0,BRC0 ; Outer loop counter
rptblocal lp1−1

mov *AR1, T1 ; store y[previous] in T1
mov *AR0<<#16,AC0

mpyk #8192,AC0,AC0 ; multiply z[i]=8192

40 mack T1, #24576, AC0, AC0 ; multiply y[previous] * 30720 and accumulate

mov hi(AC0),*AR0 ; store the new output
mov *AR0+, *AR1 ; put the previous y value in AR1

lp1

.popm ST3,55 ; Restore ST1, ST2, and ST3
.popm ST2,55
.popm ST1,55

ret

.end
#include "include.h"
#include "variables.h"

void main(void)
{
    /* initialize the system */
    initialize_system();
    signal_proc_init();

    /* starts timer0 to flash LED0 while the processor is running */
    start_timer0();

    /* send a message to MSP */
    print_message("VC5509: Booted and Running");

    /* infinite loop */
    while(1)
    {
        process_commands();
    }
}
E.14 normalization.h

/∗
∗ Personnel Detector
∗ Elliot Ranger
∗ Master of Science Thesis
∗ Massachusetts Institute of Technology
∗ in conjunction with Charles Stark Draper Laboratory
∗
*/
/**
FILENAME .... normalization.h
DATE CREATED .. 12/14/2002
LAST MODIFIED. 02/08/2003
**************************************************************************/

#define SUMWIDTH 8
#define BLKOUT 4
#define OFFSET 12    /* SUMWIDTH + BLKOUT */
#define THRESHOLD 1
#define SPECTRUM_SIZE 512
#define CENTER_SIZE 9   /* 2*BLKOUT + 1 */
#define SIDES_SIZE 16   /* 2*SUMWIDTH */

/∗ used as a temporary variable for converting to magnitude ∗/
LDATA magtemp[FREQ_SIZE];

/∗ extx and r should be the nx + 2*(offset) ∗/
DATA spectemp[SPECTRUM_SIZE+(2*OFFSET)];
DATA norm_spec[SPECTRUM_SIZE+(2*OFFSET)];

E.15 proc_cmd.c

/∗
∗ Personnel Detector
∗ Elliot Ranger
∗ Master of Science Thesis
∗ Massachusetts Institute of Technology
∗ in conjunction with Charles Stark Draper Laboratory
*/
#include "include.h"

process_commands: processes a command that is received through the hpi

void process_commands(void)
{
    switch(get_command())
    {
        case PROCESS_DATA_BLOCK_1:
            block_memloc=(DATA*)BLOCK1_MEM;
            process_block();
            break;

        case PROCESS_DATA_BLOCK_2:
            block_memloc=(DATA*)BLOCK2_MEM;
            process_block();
            break;

        case CLEAR_PROCESSING_BUFFERS:
            signal_proc_init();
            print_message("VC5509: Buffers Cleared");
            break;

        case GET_VC5509_VERSION:
            print_message(VERSION);
            break;

        case COPY_TO_HPI_WRITE:
            hpi_save_code();
            print_message("VC5509: Code Copied to Buffer");
            break;

        default: break;
    }
}
E.16 prototype.h

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 */
#include "tms320.h"

void initialize_system(void);
void initialize_gpio(void);
void initialize_intr(void);
void initialize_idle_configuration(void);

void LED0_on(void);
void LED0_off(void);
void LED1_on(void);
void LED1_off(void);
void LED2_on(void);
void LED2_off(void);
void LED_test(void);

void send_host_interrupt(void);
interrupt void hpi_interrupt(void);

void start_timer0(void);
void start_timer1(void);
interrupt void timer0_interrupt(void);
interrupt void timer1_interrupt(void);

void process_commands(void);
void print_message (Char *message);
void hpi_save_code(void);

void send_hpi_command(Uint16 command);
void clear_messages(void);

void process_block(void);

void abs_val(DATA *x, ushort nx);
void signal_proc_init(void);
ushort firdecimate(DATA *x, ushort nx, DATA *h, ushort nb, DATA *r, DATA *dbuf, ushort dbufindex, ushort m, ushort outsize);
void convert_to_mag(DATA *x, ushort nx, LDATA *r);
ushort Sqrt32(ulong x);
void spectral_normalization(DATA *x, ushort nx, DATA *extx, DATA *r);
void window(DATA *x, ushort nx, ushort *window, DATA *output);
ushort window_buffer(DATA *x, ushort nx, ushort nb, DATA *output, DATA *signal, ushort index);
void scale_output(DATA *x, ushort nx);
ushort detection_algorithm(DATA *x);
void shift_down(DATA *x, ushort nx, ushort shift_value);
void hp_filter(DATA *x, ushort nx, DATA *y_previous, DATA *x_previous);
void lp_filter(DATA *x, ushort nx, DATA *y_previous);

E.17 signal_proc.c

/*/ 
* Personnel Detector 
* Elliot Ranger 
* Master of Science Thesis 
* Massachusetts Institute of Technology 
* in conjunction with Charles Stark Draper Laboratory 
* 
*/ 

/*********************************************/

#include "include.h"
#include "filters.h"
#include "hanning.h"
#include "normalization.h"

/*********************************************/

#pragma DATA SECTION(h_bp, "iir_coef");
#pragma DATA SECTION(dbuffer_bp, "iir_delay");
#pragma DATA SECTION(h_firdec1, "fir_coef");
#pragma DATA SECTION(h_firdec2, "fir_coef");
#pragma DATA SECTION(dbuffer_firdec1, "fir_delay");
/* signal_proc_init: initializes all the signal processing buffers and
variables. */

void signal_proc_init()
{
  ushort i;

  /* clear buffers for bandpass filters */
  iir_hp_y=0;
  iir_hp_x=0;
  iir_lp_y=0;

  /* clear signal buffers for FIR */
  for (i=0; i<(NH_FIR+1); i++)
  {
    dbuffer_firdec1[i]=0;
    dbuffer_firdec2[i]=0;
  }

  /* clear signal buffer index for FIR */
  dbuffer_index1 =0;
  dbuffer_index2 =0;

  /* clear signal buffers for window */
  for (i=0; i<(WINDOW_SIZE); i++)
  {
    wsignal[i]=0;
    output[i]=0;
  }

  /* clear normalization buffers */
  for (i=0; i<(SPECTRUM_SIZE); i++)
  {
    norm_spec[i]=0;
  }
}
spectemp[i]=0;
}

/* clear index for window */
windex=0;

clear_messages();
}

/* process_block: function called by the MSP after it has loaded a complete block of data into the DSP memory. */
void process_block()
{
    /* take out the DC offset from the incoming data */
    shift_down(block_memloc, NX_IIR, DC_OFFSET);

    /* IIR bandpass filter */
    hp_filter(block_memloc, NX_IIR, &iir_hp_y, &iir_hp_x);
    lp_filter(block_memloc, NX_IIR, &iir_lp_y);

    /* envelope detect */
    abs_val(block_memloc,NX_IIR);

    /* FIR decimation in two stages (5 and 2) */
    dbuffer_index1=firdecimate(block_memloc, NX_FIR1, h_firdec1, NH_FIR, block_memloc, dbuffer_firdec1, dbuffer_index1, D1);
    dbuffer_index2=firdecimate(block_memloc, NX_FIR2, h_firdec2, NH_FIR, block_memloc, dbuffer_firdec2, dbuffer_index2, D2);

    /* window buffer circular buffer that keeps aligning the data correctly for the FFT */
    windex=window_buffer(block_memloc, NX_SIZE, WINDOW_SIZE, output, wsignal, windex);

    /* multiply the data by a hanning window before FFT */
    window(output, WINDOW_SIZE, hanning, output);

    /* FFT routine */
    rfft(output,WINDOW_SIZE,SCALE);

    /* convert output magnitude */
    convert_to_mag(output,WINDOW_SIZE,magtemp);

    /* take out DC component and scale output */
    scale_output(output,SPECTRUM_SIZE);

    /* normalize the spectrum */

    clear_index_for_window;
spectral_normalization(output,SPECTRUM_SIZE, spectemp, norm_spec);

    /* detection algorithm */
if (detection_algorithm(norm_spec)==TRUE)
{
    print_message("VC5509: Footsteps Detected");

    /* turn on LED2 */
    GPIO_DATA |= LED2;
}
else
{
    /* turn off LED2 */
    GPIO_DATA &= (~LED2);
}

/******************************************************************************
 * shift_down: just subtracts out the DC offset from the A/D conversion
 ******************************************************************************/
void shift_down(DATA *x, ushort nx, ushort shift_value)
{
    /* just shift the whole signal down by DC offset */
    ushort i;
    for (i=0;i<nx;i++) x[i] = x[i] - shift_value;
}

/******************************************************************************
 * abs_val: takes the absolute value of all the values
 ******************************************************************************/
void abs_val(DATA *x, ushort nx)
{
    ushort i;
    for (i=0;i<nx;i++) x[i] = abs(x[i]);
}

/******************************************************************************
 * scale_output: removes any DC frequency components by setting all the values
 * to the mean of the next 20 values divided by 2 to account for the fact that
 * the data contains a number of peaks and we want it to be lower. Then scales
 * the whole data set so the peak value is near full scale.
 ******************************************************************************/
void scale_output(DATA *x, ushort nx)
{
ushort i;
ushort xval;
ulong sum=0;

/* take out DC values by setting to the mean/2 of the first values */
for (i=5;i<25;i++) sum = sum + x[i];
xval=sum/40;
for (i=0;i<5;i++) x[i] = xval;

/* scale the data up */
for (i=0;i<nx;i++) x[i] = x[i]<<7;

/******************************
* convert_to_mag: takes the real and imaginary data that is outputed from
* the FFT routine and converts it to a magnitude.
*******************************/
void convert_to_mag(DATA *x, ushort nx, LDATA *r)
{
    ushort i,j;
    ushort temp;

    /* take absolute value first */
    for (i=0;i<nx;i++) x[i] = abs(x[i]);

    /* first two values are DC and Nyquist */
    temp = x[1];
    j=1;
    for (i=2;i<(nx/2-1);i=i+2)
    {
        x[j]=(ulong)x[i]*x[i]+(ulong)x[i+1]*x[i+1];
        x[j]=Sqrt32(r[j]);
        j++;
    }

    /* store Nyquist */
    x[j] = temp;
}

/******************************
* Sqrt32: fixed point square-root function. This algorithm was provided
*******************************/
ushort Sqrt32(unsigned long x)
{
    register unsigned long root, remHi, remLo, testDiv, count;

    /* Clear root */
    root = 0;

    /* Clear high part of partial remainder */
    remHi = 0;

    /* Get argument into low part of partial remainder */
    remLo = x;

    /* Loop counter */
    count = 15;

    do
    {
        /* get 2 bits of arg */
        remHi = (remHi<<2)|(remLo>>30); remLo <<=2;

        /* get ready for the next bit in the root */
        root <<= 1;

        /* Test radical */
        testDiv = (root <<1) + 1;
        if (remHi >= testDiv)
        {
            remHi-=testDiv;
            root++;
        }
    } while (count-- != 0);

    return(root);
}

/**********************************************************\
 * spectral_normalization: 2 pass normalization function which normalizes
 * the peaks to the noise floor.
\**********************************************************/
void spectral_normalization(DATA *x, ushort nx, DATA *extx, DATA *r)
{
    ushort i,j,lbeg,lend,rbeg,rend;

    ulong lsum=0,rsum=0,censum=0,cmpsum=0;

    /*...*/
/ mirror data to left side and calculate the sum */
j=OFFSET−1;
for (i=0;i<OFFSET;i++)
{
    r[j]=x[i];
    if (i>=BLKOUT) lsum=lsum+x[i];
    j--;
}

/* copy over the data */
j=OFFSET;
for (i=0;i<nx;i++)
{
    r[j]=x[i];
    j++;  
}

/* mirror data to right */
j=nx+OFFSET;
for (i=nx−1;i>(nx−OFFSET);i--)
{
    r[j]=x[i];
    j++;
}

/* get the sum for the right side */
for (i=(OFFSET+BLKOUT+1);i<=(2∗OFFSET);i++) rsum=rsum+r[i];

/* get the sum for the center */
for (i=(OFFSET−BLKOUT);i<=(OFFSET+BLKOUT);i++) censum=censum+r[i];

/* store value of first point */
extx[OFFSET]=censum/CENTER_SIZE;
cmpsum=(lsum+rsum)/SIDES_SIZE;

/* replace with lower value */
if (((extx[OFFSET]/THRESHOLD) > cmpsum) extx[OFFSET]=cmpsum;

lbeg=0;
lend=OFFSET−BLKOUT;
rbeg=OFFSET+BLKOUT+1;
rend=2∗OFFSET+1;

/* first pass */
for (i=OFFSET+1;i<(nx+OFFSET);i++)
{  
    /* move everything over by one */  
    lsum=lsum-r[lbeg];
    lsum=lsum+r[lend];
    rsum=rsum-r[rbeg];
    rsum=rsum+r[rend];

    /* get the new sum for the center */  
    censum=censum-r[lend];
    censum=censum+r[rbeg];

    lbeg++;
    lend++;
    rbeg++;
    rend++;

    /* store value of next point */  
    extx[i]=censum/CENTER_SIZE;
    cmpsum=(lsum+rsum)/SIDES_SIZE;

    if ((extx[i]/THRESHOLD) > cmpsum) extx[i]=cmpsum;
}

/* reset all the values */  
    lsum=0; rsum=0; censum=0; cmpsum=0;

/* mirror the data back around the sides */  
    j=OFFSET−1;
    for (i=OFFSET; i<(2 OFFSET); i++)
    {
        extx[j]=extx[i];
        if (i>(OFFSET+BLKOUT)) lsum=lsum+extx[i];
        j--;
    }

    j=nx+OFFSET;
    for (i=nx+OFFSET−1; i>=nx; i--)
    {
        extx[j]=extx[i];
        j++;
    }

    /* get the sum for the right side */  
    for (i=(OFFSET+BLKOUT+1); i<=(2 OFFSET); i++) rsum=rsum+extx[i];

}
/* get the sum for the center */
for (i=(OFFSET-BLKOUT);i<=(OFFSET+BLKOUT);i++)
censum=censum+extx[i];

/* store value of first point */
r[0]=censum/CENTER_SIZE;
cmpsum=(lsum+rsum)/SIDES_SIZE;

/* replace with lower value */
if ((r[0]/THRESHOLD) > cmpsum) r[0]=cmpsum;

lbeg=0;
lend=OFFSET-BLKOUT;
rbeg=OFFSET+BLKOUT+1;
rend=2*OFFSET+1;

/* second pass */
for (i=1;i<nx;i++)
{
    /* move everything over by one */
lsum=lsum-extx[lbeg];
lsum=lsum+extx[lend];
rsum=rsum-extx[rbeg];
rsum=rsum+extx[rend];

    /* get the new sum for the center */
censum=censum-extx[lend];
censum=censum+extx[rbeg];

    lbeg++;
lend++;
rbeg++;
rend++;

    /* store value of first point */
r[i]=censum/CENTER_SIZE;
cmpsum=(lsum+rsum)/SIDES_SIZE;

    if ((r[i]/THRESHOLD) > cmpsum) r[i]=cmpsum;
}

/* divide the normalized spectrum by 64 otherwise the */
/* results from the integer division are too low */
/* want to find peaks that are twice as big as background */
for (i=0;i<nx;i++) r[i] = r[i]<<1;
/ all that is left is to subtract the background from */
/* the original spectrum */
for (i=0;i<nx;i++)
    r[i]=x[i]-r[i];
}

('*', 'detection_algorithm: actual algorithm that classifies whether it is a person
looks at frequency and threshold of the first harmonic and if
there is a second or third harmonic present as well which is above
a certain threshold.

ushort detection_algorithm2(DATA *x)
{
    ushort i;
    ushort peak1=0;
    ushort index_peak1;
    ushort second_harmonic=FALSE;
    ushort third_harmonic=FALSE;

    /* first check and see if there is a peak within the */
    /* range of 1-3 Hz above the threshold (each bin is .098 Hz) */
    for (i=10;i<=31;i++)
    {
        if (x[i] > peak1)
        {
            peak1=x[i];
            index_peak1=i;
        }
    }
    if (peak1 < FIRST_THRESHOLD) return FALSE;

    /* now check to see if there is a second or third harmonic */
    /* that is above the threshold */
    for (i=(index_peak1*2)-PEAK_WIDTH;i<=(index_peak1*2)+PEAK_WIDTH;i++)
    {
        if (x[i] > SECOND_THRESHOLD) second_harmonic=TRUE;
    }
    for (i=(index_peak1*3)-PEAK_WIDTH;i<=(index_peak1*3)+PEAK_WIDTH;i++)
    {
        if (x[i] > THIRD_THRESHOLD) third_harmonic=TRUE;
    }
if (second_harmonic==TRUE || third_harmonic==TRUE) return TRUE;

return FALSE;
}

ushort detection_algorithm(DATA *x)
{
    ushort i,j;
    DATA peaks[5];
    ushort index_peaks[5];

    /* clear out values */
    for (i=0;i<5;i++)
    {
        peaks[i]=0;
        index_peaks[i]=0;
    }

    /* find first 5 peaks */
    for (i=0;i<5;i++)
    {
        for (j=10;j<100;j++)
        {
            if (x[j] > peaks[i])
            {
                peaks[i]=x[j];
                index_peaks[i]=j;
            }
        }
    }

    /* make peak negative so it isn't included again */
    for (j=index_peaks[i]-PEAK_WIDTH;j<=index_peaks[i]+PEAK_WIDTH;j++)
    {
        /* only flip down positive values */
        if (x[j] > 0) x[j]=−x[j];
    }

    for (i=0;i<5;i++)
    {
        /* first check and see if there is a peak within the */
        /* range of 1-3 Hz above the threshold (each bin is .098 Hz) */
        if ((index_peaks[i] >= 10) &&
(index_peaks[i] <= 31) &&
(peaks[i] >= FIRST_THRESHOLD))
{
    /* this is a possible first harmonic */
    /* check and see if there is a second or third harmonic */
    /* which is above the threshold */
    for (j=0;j<5;j++)
    {
        /* do not want to check against itself */
        if (j!=i)
        {
            if ((index_peaks[j] >= (index_peaks[i]∗2−PEAK_WIDTH)) &&
                (index_peaks[j] <= (index_peaks[i]∗2+PEAK_WIDTH)) &&
                (peaks[j] >= SECOND_THRESHOLD)) return TRUE;

            if ((index_peaks[j] >= (index_peaks[i]∗3−PEAK_WIDTH)) &&
                (index_peaks[j] <= (index_peaks[i]∗3+PEAK_WIDTH)) &&
                (peaks[j] >= THIRD_THRESHOLD)) return TRUE;
        }
    }
}

return FALSE;


E.18  timer.c

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 *
*/

*******************************************************************************/

FILENAME. . . . . timer.c
DATE CREATED.. 07/11/2002
LAST MODIFIED. 08/07/2002
*******************************************************************************/
#include "include.h"

//************************************************************************************
* start_timer0: timer 0 is used to flash the LED when the VC5509 is booted
* up and running code.
************************************************************************************
void start_timer0(void)
{
    /* make sure Timer 0 is stopped */
    TCR0 |= TSS;

    /* enable timer loading */
    TCR0 |= TLB;

    /* do not stop timer for breakpoints */
    TCR0 |= FREE;

    /* automatically reload the timer */
    TCR0 |= ARB;

    /* TDDR = F in PRSC0 divide the main clock by 15 */
    PRSC0 = 0x000F;

    /* period register which is loaded into TIM0 */
    PRD0 = 0xFFFF;

    /* disable further loading of register */
    TCR0 &= ~TLB;

    /* start Timer 0 */
    TCR0 &= ~TSS;
}

//************************************************************************************
* start_timer1: timer 1 is used to flash the LED when the VC5509 receives
* an hpi command from the MSP.
************************************************************************************
void start_timer1(void)
{
    /* make sure Timer 1 is stopped */
    TCR1 |= TSS;

    /* enable timer loading */
    TCR1 |= TLB;
/* do not stop timer for breakpoints */
TCR1 |= FREE;

/* TDDR = F in PRSC0 divide the main clock by 15 */
PRSC1 = 0x000F;

/* period register which is loaded into TIM1 */
PRD1 = 0xFFFF;

/* disable further loading of register */
TCR1 &= (~TLB);

/* start Timer 1 */
TCR1 &= (~TSS);

}/* *******************************************************************/
/* timer0_interrupt: only turn LED0 on after the timer counts down 25 times */
interrupt void timer0_interrupt(void)
{
if ((GPIO_DATA & LED0) == LED0) /* LED0 is on */
{
    /* turn off LED0 */
    GPIO_DATA &= (~LED0);
    timer0_counter=0;
}
else /* LED0 is off */
{
timer0_counter++;

    if (timer0_counter >= 25 )
    {
        /* turn on LED0 */
        GPIO_DATA |= LED0;
    }
}
}/* *******************************************************************/
/* timer1_interrupt: turn LED1 off and stop the timer */
interrupt void timer1_interrupt(void)
{  
  /* turn off LED1 */  
  GPIO_DATA &= ~LED1;  
  TCR1 |= TSS;  
  // make sure Timer 0 is stopped  
}

E.19 variables.h

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 */

/****************************Nguồn*ToLocal указаный*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*ливрый*liv}

FILENAME........variables.h
* DATE CREATED..07/11/2002
* LAST MODIFIED.08/07/2002
\**********************************************************************/

/* global variables */
Uint16 timer0_counter=0;
Uint16 new_command=0;

DATA= block_memloc;  /* stores the location of where to begin processing */

E.20 vc5509.h

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 */
typedef declarations

typedef unsigned char Uchar;
typedef char Char;
typedef unsigned short Uint16;
typedef unsigned long Uint32;
typedef short Int16;
typedef long Int32;

helper functions

#define PREG16(addr) (*((volatile ioport Uint16 *)(addr))
#define REG16(addr) (*((volatile Uint16 *)(addr))

LED declarations

#define LED0 0x0002u /* GPIO 9 */
#define LED1 0x0004u /* GPIO 10 */
#define LED2 0x0020u /* GPIO 13 */

I/O registers

#define IO_DIR PREG16(0x3400u) /* GPIO0-GPIO7 Dir Register */
#define IO_DATA PREG16(0x3401u) /* GPIO0-GPIO7 Data Register */
#define GPIO_ENABLE PREG16(0x4403u) /* GPIO8-GPIO15 Enable Register */
#define GPIO_DIR PREG16(0x4404u) /* GPIO8-GPIO15 Dir Register */
#define GPIO_DATA PREG16(0x4405u) /* GPIO8-GPIO15 Data Register */

Idle registers

#define ICR PREG16(0x0001u) /* Idle Configuration Register */
#define ISRT PREG16(0x0002u)  /* Idle Status Register */
#define PCR0 PREG16(0x2812u) /* Pin Control Register for McBSP0 */
#define PCR1 PREG16(0x2C12u) /* Pin Control Register for McBSP0 */
#define PCR2 PREG16(0x3012u) /* Pin Control Register for McBSP0 */
#define ICMDR PREG16(0x3C09u) /* I2C Control Register */
#define MMCFCCLK PREG16(0x4800u) /* Multi-Media Card Clock Control */

/**************************************************************************
  * Idle declarations
**************************************************************************/
#define CPU 0x0001u  /* for shutting down the CPU */
#define DMA 0x0002u  /* for shutting down the DMA */
#define CACHE 0x0004u /* for shutting down the CACHE */
#define PERIPH 0x0008u /* for shutting down the PERIPHERALS */
#define CLKGEN 0x0010u /* for shutting down the CLKGEN */
#define EMIF 0x0020u /* for shutting down the External Memory Interface */
#define McBSP_IDLE_EN 0x0040u /* Idle enable bit for McBSP ports */
#define I2C_IDLE_EN 0x1000u /* Idle enable bit for I2C port */
#define MMC_IDLE_EN 0x0100u /* Idle enable bit for MMC port */

/**************************************************************************
  * Timer registers
**************************************************************************/
#define TIM0 PREG16(0x1000u) /* Timer Count Register, Timer #0 */
#define PRD0 PREG16(0x1001u) /* Period Register, Timer #0 */
#define TCR0 PREG16(0x1002u) /* Timer Control Register, Timer #0 */
#define PRSC0 PREG16(0x1003u) /* Timer Prescaler Register, Timer #0 */
#define TIM1 PREG16(0x2400u) /* Timer Count Register, Timer #1 */
#define PRD1 PREG16(0x2401u) /* Period Register, Timer #1 */
#define TCR1 PREG16(0x2402u) /* Timer Control Register, Timer #1 */
#define PRSC1 PREG16(0x2403u) /* Timer Prescaler Register, Timer #1 */

/**************************************************************************
  * Timer declarations
**************************************************************************/
#define TSS 0x0010u /* Timer Start/Stop Bit */
#define TLB 0x0400u /* Timer Load Bit */
#define FREE 0x0100u /* Free running */
#define ARB 0x0020u /* Automatic Reload of Timer */

/**************************************************************************
  * CPU registers
**************************************************************************/
#define ST0_55 PREG16(0x0002u) /* Status Register 0 */
```c
#define ST1_REG16(0x0003u) /* Status Register 1 */
#define ST3_REG16(0x0004u) /* Status Register 3 */
#define IER0_REG16(0x0000u) /* Interrupt Enable Register 0 */
#define IFR0_REG16(0x0001u) /* Interrupt Flag Register 0 */
#define IER1_REG16(0x0045u) /* Interrupt Enable Register 1 */
#define IFR1_REG16(0x0046u) /* Interrupt Flag Register 1 */
#define IVPD_REG16(0x0049u) /* Interrupt Vector Pointer for DSP */
#define IVPH_REG16(0x004Au) /* Interrupt Vector Pointer for Host */

/*--------------------------------------------------------------------------
 CPU declarations
 */
#define INTM 0x0800u /* Global Interrupts */
#define MSP_HINT 0x1000u /* HPI Interrupt bit */
#define DSPINT 0x0400u /* DSP Interrupt bit */
#define TINT0 0x0010u /* Timer 0 Interrupt bit */
#define TINT1 0x0040u /* Timer 1 Interrupt bit */
#define C54CM 0x0020u /* C54 Compatibility mode */

/*--------------------------------------------------------------------------
 HPI declarations
 */
#define DSP_COMMAND_REGISTER_REG16(0x0100u) /* Location to Read commands from MSP */
#define MSP_COMMAND_REGISTER_REG16(0x0101u) /* Location to Write commands to the MSP */
#define _MSP_DATA 0x0102u /* Memory location */
#define MSP_DATA REG16(0x0102u) /* Location to Write data for the MSP */
#define DSP_HPI_WRITE REG16(0x0A00u) /* Location to read data from the MSP */

 /*--------------------------------------------------------------------------
 */
/* INTR_ENABLE - enables all masked interrupts by resetting INTM */
/* bit in Status Register 1 */
/*--------------------------------------------------------------------------
#define INTR_GLOBAL_ENABLE \
  asm("\t RSBX\t INTM"); \
  asm("\tNOP");

 /*--------------------------------------------------------------------------
 */
/* INTR_DISABLE - disables all masked interrupts by setting INTM */
/* bit in Status Register 1 */
 /*--------------------------------------------------------------------------
#define INTRGLOBAL_DISABLE \
  asm("\t SSBX\t INTM"); \
  asm("\tNOP");

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```
EXECUTE_IDLE - tells the processor to execute the current idle configuration held in ICR

#define EXECUTE_IDLE
    asm("t Idle	"); 

E.21 vectors.asm

; Personnel Detector
; Elliot Ranger
; Master of Science Thesis
; Massachusetts Institute of Technology
; in conjunction with Charles Stark Draper Laboratory
;
;
;******************************************************************************

; FILENAME. .... vectors.asm
; DATE CREATED. . 07/11/2002
; LAST MODIFIED. 08/07/2002
;******************************************************************************

.ref _hpi_interrupt, _timer0_interrupt, _timer1_interrupt
.def rsv, no_isr ; symbols defined in this file

.sect "vectors"  ; interrupt vectors
rsv .ivec no_isr

20 nmi .ivec no_isr  ; non-maskable interrupt
int0 .ivec no_isr ; External interrupt #0
int2 .ivec no_isr ; External interrupt #2
tint0 .ivec _timer0_interrupt ; Timer 0
rint0 .ivec no_isr ; McBSP #0 receive
rint1 .ivec no_isr ; McBSP #1 receive
xint1 .ivec no_isr ; McBSP #1 transmit
usb .ivec no_isr ; USB interrupt
dmac1 .ivec no_isr ; DMA Channel #1

dspint .ivec _hpi_interrupt ; Interrupt from host

30 int3 .ivec no_isr ; External interrupt #3

rint2 .ivec no_isr ; McBSP #2 receive

xint2 .ivec no_isr ; McBSP #2 transmit

dmac4 .ivec no_isr ; DMA Channel #4

int1 .ivec no_isr ; External interrupt #1

xint0 .ivec no_isr ; McBSP #0 transmit

dmac0 .ivec no_isr ; DMA Channel #0

int4 .ivec no_isr ; External interrupt #4

int1 .ivec _timer1_interrupt ; Timer 1

int5 .ivec no_isr ; External interrupt #5

berr .ivec no_isr ; Bus error interrupt

dlog .ivec no_isr ; Data log interrupt

rtos .ivec no_isr ; Real-time operating system interrupt

sint27 .ivec no_isr ; Software interrupt #27

sint28 .ivec no_isr ; Software interrupt #28

sint29 .ivec no_isr ; Software interrupt #29

sint30 .ivec no_isr ; Software interrupt #30

sint31 .ivec no_isr ; Software interrupt #31

; Interrupt service routine:

.text

no_isr: B no_isr ; default ISR
E.22 wbuffer.asm

;
; Personnel Detector
; Elliot Ranger
; Master of Science Thesis
; Massachusetts Institute of Technology
; in conjunction with Charles Stark Draper Laboratory
;
;******************************************************************************

; FILENAME. . . . . wbuffer.asm
; DATE CREATED. . 08/23/2002
; LAST MODIFIED. 01/15/2003
;******************************************************************************

window_buffer.asm

prototype: ushort window_buffer(DATA *x, ushort nx, ushort nb,
DATA *output, DATA *signal, ushort index);

; Entry: arg0: AR0 – signal input buffer pointer
; arg1: T0 – number of samples in the input
; arg2: T1 – buffer size
; arg3: AR1 – output
; arg4: AR2 – signal buffer pointer
; arg5: AR3 – signal buffer index
;
; Return: T0 = signal buffer index
;
.def _window_buffer
.sect .text

_window_buffer
    pshm ST1.55 ; Save ST1, ST2, and ST3
    pshm ST2.55
    pshm ST3.55

    or   #0x340,mmap(ST1.55); Set FRCT,SMND,SATD
    bset SMUL ; Set SMUL

    mov mmap(AR2),BSA23 ; Set base address for AR2
    mov mmap(T1),BK03 ; Set signal buffer size

164
mov AR3,AR2 ; AR2 signal buffer index

or #0x4,mmap(ST2,55) ; AR2 circular pointer

; First block equal to size of input so we can save
; the starting point for the next we run
mov T0,T3
sub #1,T0
mov T0,BRC0 ; Outer loop counter

50 rptblocal lp1-1
mov *AR2+,*AR1+ ; load first part

lp1

mov AR2,T0 ; save next starting point

; Do all other calculations which don't have the new
; input values

sub T3,T1 ; subtract beginning and ending
sub T3,T1 ; samples

60 sub #1,T1
mov T1,BRC0 ; Outer loop counter
rptblocal lp2-1
mov *AR2+,*AR1+ ; load other values

lp2

; Lastly add new data to the end of the signal buffer
; and do the calculations

sub #1,T3
mov T3,BRC0

70 rptblocal lp3-1
mov *AR0+,*AR2 ; Put new samples into signal buffer
mov  *AR2+,*AR1+  ; create array

popm ST3_55  ; Restore ST1, ST2, and ST3
popm ST2_55
popm ST1_55
ret
.end

---

E.23  window.asm

; Personnel Detector
; Elliot Ranger
; Master of Science Thesis
; Massachusetts Institute of Technology
; in conjunction with Charles Stark Draper Laboratory
;
******************************************************************************

FILENAME. . . . . . window.asm
DATE CREATED. . 07/11/2002
LAST MODIFIED. 01/15/2003
******************************************************************************

window.asm

prototype: void window(DATA *x, ushort nx, ushort *window, DATA *output);

Entry: arg0: AR0 - signal input buffer pointer
arg1: T0 - number of samples in the input buffer
arg2: AR1 - window array pointer
arg3: AR2 - output

.def  _window
.sect  .text
.window

30 pshm ST1_55 ; Save ST1, ST2, and ST3
pshm ST2_55
pshm ST3_55

or #0x340,mmap(ST1_55); Set FRCT,SXMD,SATD
bset SMUL ; Set SMUL

; just multiply the window by the input buffer and store the output
sub #1,T0

40 mov T0,BRC0 ; Outer loop counter
rptblocal lp1-1
mpym uns(*AR1+),*AR0+,AC0 ; multiply the beginning values
mov h1(AC0),*AR2+
lp1

popm ST3_55 ; Restore ST1, ST2, and ST3
popm ST2_55
popm ST1_55

50 ret
.end
Appendix F

MSP430F149 Source Code

F.1 boot_dsp.c

/*------------------------------------------------*/
/* Personnel Detector
* Elliot Ranger
* Master of Science Thesis
* Massachusetts Institute of Technology
* in conjunction with Charles Stark Draper Laboratory
*/
/* FILENAME..... boot_dsp.c
* DATE CREATED.. 07/29/2002
* LAST MODIFIED. 08/06/2002

#include "include.h"

/*@boot_dsp: copies the VC5509 boot code and program code that was stored in the MSP flash to the VC5509 and then instructs the processor where to start loading code from.*/

void boot_dsp(void)
{
    Uint16 flash_data;
    Uint16 flash_memory_address;

    enable_hpi();
}
/* Load Boot Code */
/* VC5509 memory location 0x0180 - 0x0200 (word addressing) */
/* MSP Flash memory 0x6000 - 0x6100 (byte addressing) */
write_hpi_address_register(0x0180);

for (flash_memory_address = 0x0000;
    flash_memory_address < 0x6100;
    flash_memory_address+=0x0002)
{
    flash_data = read_flash(flash_memory_address);
    write_hpi_data_word(flash_data,TRUE);
}

/* Load Program Code */
/* VC5509 memory location 0x0A00 - 0x1A80 (word addressing) */
/* MSP Flash memory 0x6100 - 0x8200 (byte addressing) */
write_hpi_address_register(0x0D00);

for (flash_memory_address = 0x0100;
    flash_memory_address <= 0xC600;
    flash_memory_address+=0x0002)
{
    flash_data = read_flash(flash_memory_address);
    write_hpi_data_word(flash_data,TRUE);
}

/* VC5509 location to start executing boot code */
/* The VC5509 uses byte addressing for the program code */
write_hpi_address_register(0x0061);
write_hpi_data_word(0x0300,FALSE);
write_hpi_address_register(0x0060);
write_hpi_data_word(0xFF00,FALSE);
}

/**********************************************************
 * copy_dsp_code_to_flash: first erases the flash memory used to store the
 * VC5509 code. Then copies all the code from the HPI Write section
 * of the VC5509's memory to the MSP's flash.
/**********************************************************/
void copy_dsp_code_to_flash(void)
{
    Uint16 flash_memory_address;
    Uint16 flash_data;
/* Disable global interrupts */
_disable();

/* Erase flash memory used to store VC5509 code */
for (flash_memory_address = 0x6000;
     flash_memory_address <= 0xC600;
     flash_memory_address+=0x0100)
{
    erase_flash(flash_memory_address);
}

/* Save VC5509 boot code and program code to MSP flash */
/* VC5509 memory location 0x0D00 - 0x4000 (word addressing) */
/* MSP Flash memory 0x6000 - 0xC600 (byte addressing) */
write_hpi_address_register(0x0D00);
for (flash_memory_address = 0x6000;
     flash_memory_address <= 0xC600;
     flash_memory_address+=0x0002)
{
    flash_data = read_hpi_data_word(TRUE);
    write_flash(flash_memory_address, flash_data);
}

/* Enable global interrupts */
_enable();

/*******************************************************
* verify_dsp_code: compares the code stored in MSP flash to the data in
* VC5509 HPI Write section and checks for any differences.
*******************************************************/
void verify_dsp_code(void)
{
    Uint16 vc55_data;
    Uint16 flash_data;
    Uint16 flash_memory_address;
    Uchar buffer[MAX_LINE_LENGTH];
    Uint16 compare=0;

    /* Set address to beginning of HPI Write Section of VC5509 memory */
    write_hpi_address_register(0x0D00);
/* Compare flash memory contents with VC5509 HPI write */
/* section and increment compare if they are not equal */
for (flash_memory_address = 0x6000;
     flash_memory_address <= 0xC600;
     flash_memory_address+=0x0002)
{
    vc55_data = read_hpi_data_word(TRUE);
    flash_data = read_flash(flash_memory_address);
    if (flash_data != vc55_data)
    {
        compare++;
    }
}

/* Print a message displaying the results */
if (compare > 0)
{
    sprintf(buffer, ">>> \%d Errors in compare of memory", compare);
    add_message_to_display(buffer);
}
else add_message_to_display("Memory verified correctly");

F.2 comms.c

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 * /

/*******************************************************************************/

/* FILENAME. . . . comms.c
 * DATE CREATED. . 04/18/2002
 * LAST MODIFIED. 08/06/2002

*******************************************************************************/

#include "include.h"
/*******************************
* print_message: outputs a message to the RS232 port and the RF port if
* RF is enabled.
*******************************

void print_message(Uchar *message)
{
    RF_CONTROL_TYPE rf_in;
    Uint16 i=0;
    Uint16 start_timer;

    /* turn on RS232 transmitter */
    msp_port5.byte = P5OUT;
    msp_port5.bit.rs232_enable = 1;
    P5OUT = msp_port5.byte;

    /* use timer A to make sure the transmitter is out of shutdown */
    start_timer = TAR;
    while (((TAR - start_timer) & TIMER_MASK) < 50);

    i = 0;
    while (message[i] != 0)
    {
        /* wait for TX ready on RS232 */
        while ((IFG1 & UTXIFG0) != UTXIFG0);

        /* Transmit character on RS232 */
        U0TXBUF = message[i];

        if (rf_ena == TRUE)
        {
            /* wait for TX ready on RF */
            while ((IFG2 & UTXIFG1) != UTXIFG1);

            /* wait for CTS on RF */
            rf_in.byte = P3IN;
            while (rf_in.bit.rf_cts) rf_in.byte=P3IN;

            /* Transmit character on RF */
            U1TXBUF = message[i];
        }
        i++;
    }

    #if LOW_POWER_MODE==TRUE

    173
/∗ use timer A to make sure all the characters get sent out ∗/

start_timer = TAR;
while (((TAR - start_timer) & TIMER_MASK) < 50);

/* turn off RS232 transmitter */
msp_port5.byte = PSOUT;
msp_port5.bit.rs232_enable = 0;
PSOUT = msp_port5.byte;
#endif

/******************************
∗ rcv1_handler: interrupt handler when a character is received on RS232
∗ places the character in a buffer and then takes the system out
∗ of low power mode if enabled
\******************************/
interrupt [UART0RX_VECTOR] void rcv1_handler(void)
{
    in_buffer[buffer_write_pos] = U0RXBUF;
    buffer_write_pos++;

    /* loops to beginning of buffer */
    if (buffer_write_pos >= MAX_BUFFER) buffer_write_pos=0;

#if LOW_POWER_MODE==TRUE
    clear_low_power_mode(LPM1_bits);
#endif
}

/******************************
∗ rcv2_handler: interrupt handler when a character is received on RF
∗ places the character in a buffer and then takes the system out
∗ of low power mode if enabled
\******************************/
interrupt [UART1RX_VECTOR] void rcv2_handler(void)
{
    in_buffer[buffer_write_pos] = U1RXBUF;
    buffer_write_pos++;

    /* loops to beginning of buffer */
    if (buffer_write_pos >= MAX_BUFFER) buffer_write_pos=0;

#if LOW_POWER_MODE==TRUE
    clear_low_power_mode(LPM1_bits);
#endif

F.3 define.h

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 * 
 */

#define VERSION "MSP430F149 VERSION 1.04 3/04/2003"

/* get_char: returns the next character in the buffer. Puts system in low power mode while waiting for the next character, if enabled. */
Uchar get_char(void)
{
    Uchar byte;

    #if LOW_POWER_MODE==TRUE
        while (buffer_write_pos == buffer_read_pos) LPM1;
    #else
        while (buffer_write_pos == buffer_read_pos);
    #endif

    byte = in_buffer[buffer_read_pos];
    buffer_read_pos++;

    /* loops to beginning of buffer */
    if (buffer_read_pos >= MAX_BUFFER) buffer_read_pos = 0;

    return (byte);
}

#define VERSION "MSP430F149 VERSION 1.04 3/04/2003"
#define TRUE 1
#define FALSE 0

#define CR 0x0D
#define LF 0x0A
#define ESC 0x1B
#define BS 0x08
#define DEL 0x7F

#define MAX_LINE_LENGTH 64
#define MAX_DISPLAY_LINES 3
#define MAX_BUFFER 64
#define TIMER_MASK 0x07FF

/* set to true to enable low power modes, */
/* set to falsh to disable low power modes */
#define LOW_POWER_MODE TRUE

/* controls the sampling rate of ADC with timer B */
/* 0x0021 is approx 1 KHz, 0x0042 is approx 500 Hz */
#define SAMPLING_RATE 0x0021;

/* VC5509 memory location to read commands */
#define DSP_COMMAND_REGISTER 0x0100
#define MSP_COMMAND_REGISTER 0x0101
#define DSP_HPI_WRITE_1 0x1000
#define DSP_HPI_WRITE_2 0x1500
#define DATA_BLOCK_1 0x0001
#define DATA_BLOCK_2 0x0002

/* MSP Command Codes */
#define PRINT_MESSAGE 0x0100
#define STOP_PROCESSING 0x0200

/* VC5509 Command Codes */
#define PROCESS_DATA_BLOCK_1 0x0100
#define PROCESS_DATA_BLOCK_2 0x0200
#define CLEAR_PROCESSING_BUFFERS 0x0300
#define GET_VC5509_VERSION 0x0900
#define COPY_TO_HPI_WRITE 0x0999
F.4 display.c

#include "include.h"

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 *
*/

#include "include.h"

/*
 * add_message_to_display: adds a message to the display area of the screen
*/

void add_message_to_display(Uchar *message)
{
    Uint16 i = 0, display_pos = 0;
    Uint16 done = FALSE;

    do
    {
        switch(message[i])
        {
            case 0: /* take care of the null by putting a new line at the end */
                display_lines[display_current_line][display_pos] = CR;
                display_pos++;
                display_lines[display_current_line][display_pos] = LF;
                display_pos++;
                display_lines[display_current_line][display_pos] = 0;

                /* increment current line for the next write */
                display_current_line++;

                /* loop around if reach maximum number of lines */
                if (display_current_line == MAX_DISPLAY_LINES) display_current_line = 0;

                done = TRUE;
                break;
        }
    }
    while (!done);
case CR: /* check and see if next character is a line feed */
    if (message[i+1] == LF )
    {
        /* put the line feed at the end of the line */
        display_lines[display_current_line][display_pos] = CR;
        display_pos++;
        i++;
        display_lines[display_current_line][display_pos] = LF;
        display_pos++;
        i++;
        display_lines[display_current_line][display_pos] = 0;
        /* increment current line */
        display_current_line++;
        /* loop around if reach maximum number of lines */
        if (display_current_line == MAX_DISPLAY_LINES) display_current_line = 0;
        /* start at the beginning of the next line */
        display_pos = 0;
    }
    else
    {
        /* just copy the letter */
        display_lines[display_current_line][display_pos] = message[i];
        display_pos++;
        i++;
    }
    break;

    default: /* just copy the letter */
        display_lines[display_current_line][display_pos] = message[i];
        display_pos++;
        i++;
        break;

} while ((done == FALSE) && (display_pos < MAX_LINE_LENGTH));

if (display_pos == MAX_LINE_LENGTH)
{
    display_lines[display_current_line][MAX_LINE_LENGTH-3] = CR;
    display_lines[display_current_line][MAX_LINE_LENGTH-2] = LF;
    display_lines[display_current_line][MAX_LINE_LENGTH-1] = 0;
}
void clear_display_area(void)
{
    Uint16 i;

    /* do for each display line */
    for (i=0; i<MAX_DISPLAY_LINES; i++)
    {
        display_lines[i][0] = CR;
        display_lines[i][1] = LF;
        display_lines[i][2] = 0;
    }

    display_current_line = 0;
}

void print_display_area(void)
{
    Uint16 line_to_print;

    line_to_print = display_current_line;

    do
    {
        print_message(display_lines[line_to_print]);
        line_to_print++;

        /* start at the beginning when line_to_print reaches the last line */
        if (line_to_print == MAX_DISPLAY_LINES) line_to_print = 0;
    } while (line_to_print != display_current_line);
}
F.5    extern.h

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 *
*/

extern MSP_PORT3_TYPE msp_port3;
extern MSP_PORT5_TYPE msp_port5;
extern HPIC_CONTROL_TYPE hpic;
extern Uint32 time;
extern Uint16 seconds;
extern Uint16 minutes;
extern Uint16 hours;
extern Uchar in_buffer[MAX_BUFFER];
extern Uint16 buffer_write_pos;
extern Uint16 buffer_read_pos;
extern Uint16 rf_ena;
extern Uchar display_lines[MAX_DISPLAY_LINES][MAX_LINE_LENGTH];
extern Uint16 display_current_line;
extern Uint16 dsp_data_address;
extern Uint16 dsp_memory_block;

F.6    flash.c

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 *
*/
/**
 * Filename: flash.c
 * Date Created: 07/17/2002
 * Last Modified: 08/06/2002
 */

#include "include.h"

/**
 * erase_flash: erases one segment of flash memory
 */

void erase_flash(Uint16 address)
{
  /* wait for busy to be reset */
  while ((FCTL3 & BUSY) == BUSY);

  /* clear lock bit */
  FCTL3 = FWKEY;

  /* enable erase from flash */
  FCTL1 = (FWKEY | ERASE);

  /* address to erase */
  *((unsigned short *)address) = 0x0000;

  /* wait for busy to be reset */
  while ((FCTL3 & BUSY) == BUSY);

  /* reset write bit */
  FCTL1 = FWKEY;

  /* change lock bit */
  FCTL3 ^= (FXKEY | LOCK);
}

/**
 * write_flash: writes one word of data to flash memory
 */

void write_flash(unsigned short address, unsigned short data)
{
  /* wait for busy to be reset */
  while ((FCTL3 & BUSY) == BUSY);

  /* Clear lock bit */
  FCTL3 = FWKEY;
/* enable write to flash */
FCTL1 = (FWKEY | WRT);

/* data to write to flash */
(∗(Uint16 ∗)address) = data;

/* wait for busy to be reset */
while ((FCTL3 & BUSY) == BUSY);

/* reset write bit */
FCTL1 = FWKEY;

/* change lock bit */
FCTL3 ^= (FXKEY | LOCK);
}

/***********************************************************/
* read_flash: returns the memory contents of the address
/***********************************************************/
Uint16 read_flash(Uint16 address)
{
  return(∗(Uint16 ∗)address);
}

F.7 hpi.c

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 *
 */
/***********************************************************/

#include "include.h"
/******************************************************************************************
* enable_hpi: sets up MSP ports for HPI use, and enables host port interrupt
******************************************************************************************

void enable_hpi(void)
{
    HPI_CONTROL_TYPE hpi_ctl_out;

    /* Reset the HPIC register values */
    hpic.byte = 0;
    hpic.bit.reset = 1;
    write_hpi_control_register(hpic.byte);

    /* Enable HPI interrupt on the falling edge*/
    P1IES = 1;
    P1IFG = 0;
    P1IE = 1;

    /* hold the host data strobe line high */
    hpi_ctl_out.byte = 0;
    hpi_ctl_out.bit.hds = 1;
    P1OUT = hpi_ctl_out.byte;
}

/* disable_hpi: disables host port interrupt and sets hpi port as output
******************************************************************************************

void disable_hpi(void)
{
    HPI_CONTROL_TYPE hpi_ctl_out;

    /* disable HPI interrupt and clear interrupt flag */
    P1IE = 0;
    P1IFG = 0;
    P1IES = 0;

    /* Clear all lines on the control port */
    hpi_ctl_out.byte = 0;
    P1OUT = hpi_ctl_out.byte;

    /* reset the data lines */
    P2DIR = 0xFF;
    P4DIR = 0xFF;
    P2OUT = 0x0;
    P4OUT = 0x0;
}
void write_hpi_control_register(Uint16 data)
{
    Uint16 i;

    HPI_CONTROL_TYPE hpi_ctl_out;
    HPI_CONTROL_TYPE hpi_ctl_in;

    /* Configure PORT2 and PORT4 as outputs */
    P2DIR = 0xFF;
    P4DIR = 0xFF;

    /* Initialize hpi_ctl_out */
    hpi_ctl_out.byte = P1OUT;

    /* Set to write mode, word addressing, HPIC register */
    hpi_ctl_out.bit.rd_wr = 0;
    hpi_ctl_out.bit.control = 0;
    hpi_ctl_out.bit.byte_en = 0;
    hpi_ctl_out.bit.hds = 1;
    P1OUT = hpi_ctl_out.byte;

    /* wait for ready from VC5509 */
    hpi_ctl_in.byte = P1IN;
    while (!hpi_ctl_in.bit.ready) hpi_ctl_in.byte = P1IN;

    /* Assert the data strobe low */
    hpi_ctl_out.bit.hds = 0;
    P1OUT = hpi_ctl_out.byte;

    /* Write the LSB of the HPIC data register */
    P2OUT = (char) data;

    /* Write the MSB of the HPIC data register */
    P4OUT = (char) (data >> 8);

    /* small loop to make sure the data lines are stable */
    for(i=0;i<2;i++)

    /* Release the data strobe */
    hpi_ctl_out.bit.hds = 1;
P1OUT = hpi_ctl_out.byte;
}

/***************************************************************************/
/* write_hpi_address_register: writes a word to the HPI address register  */
/* in the VC5509.                                                          */
/***************************************************************************/
void write_hpi_address_register(Uint16 data)
{
    Uint16 i;
    HPI_CONTROL_TYPE hpi_ctl_out;
    HPI_CONTROL_TYPE hpi_ctl_in;

    /* Configure PORT2 and PORT4 as outputs */
    P2DIR = 0xFF;
P4DIR = 0xFF;

    /* Initialize hpi_ctl_out */
hpi_ctl_out.byte = P1OUT;

    /* Set to write mode, word addressing, HPIA register */
hpi_ctl_out.bit.rd_wr = 0;
hpi_ctl_out.bit.control = 2;
hpi_ctl_out.bit.byte_en = 0;
hpi_ctl_out.bit.hds = 1;
P1OUT = hpi_ctl_out.byte;

    /* wait for ready from VC5509 */
hpi_ctl_in.byte = P1IN;
while (!hpi_ctl_in.bit.ready) hpi_ctl_in.byte = P1IN;

    /* Assert the data strobe low */
hpi_ctl_out.bit.hds = 0;
P1OUT = hpi_ctl_out.byte;

    /* Write the LSB of the address */
P2OUT = (char) data;

    /* Write the MSB of the address */
P4OUT = (char) (data >> 8);

    /* small loop to make sure the data lines are stable */
    for(i=0;i<=2;i++);
/ * Release the data strobe */
    hpi_ctl_out.bit.hds = 1;
    P1OUT = hpi_ctl_out.byte;
}


/* write_hpi_data_word: writes a data word to the address location stored
 in the HPI address register. Increments the address register
 if auto_incr is true. */

void write_hpi_data_word(Uint16 data, Uint16 auto_incr)
{
    Uint16 i;
    HPI_CONTROL_TYPE hpi_ctl_out;
    HPI_CONTROL_TYPE hpi_ctl_in;

    /* Configure PORT2 and PORT4 as outputs */
    P2DIR = 0xFF;
    P4DIR = 0xFF;

    /* Initialize hpi_ctl_out */
    hpi_ctl_out.byte = P1OUT;

    /* Set to write mode, word addressing, HPID register */
    hpi_ctl_out.bit.rd_wr = 0;
    hpi_ctl_out.bit.byte_en = 0;
    hpi_ctl_out.bit.hds = 1;

    if (auto_incr == TRUE)
    {
        hpi_ctl_out.bit.control = 1;
    }
    else
    {
        hpi_ctl_out.bit.control = 3;
    }
    P1OUT = hpi_ctl_out.byte;

    /* wait for ready from VC5509*/
    hpi_ctl_in.byte = P1IN;
    while (!hpi_ctl_in.bit.ready) hpi_ctl_in.byte = P1IN;

    /* Assert the data strobe low */
    hpi_ctl_out.bit.hds = 0;
P1OUT = hpi_ctl_out.byte;

/* Write the LSB of the data */
P2OUT = (char)data;

/* Write the MSB of the data */
P4OUT = (char)(data >> 8);

/* small loop to make sure the data lines are stable */
for(i=0; i<=2; i++);

/* Release the data strobe */
hipi_ctl_out.bit.hds = 1;
P1OUT = hpi_ctl_out.byte;

210 }

/*************************************************************\
* read_hpi_data_word: reads the data word at the address location stored
* in the HPI address register. Increments the address register
* if autoincr is true.
\*********************************************************************/
Uint16 read_hpi_data_word(Uint16 auto_incr)
{
    Uint16 i,hipi_data;
    HPI_CONTROL_TYPE hpi_ctl_out;
    HPI_CONTROL_TYPE hpi_ctl_in;

    /* Configure PORT2 and PORT4 as inputs */
P2DIR = 0x0;
P4DIR = 0x0;

    /* Initialize hpi_ctl_out */
    hpi_ctl_out.byte = P1OUT;

    230 /* Set to read mode, word addressing, HPID register */
    hpi_ctl_out.bit.rd_wr = 1;
    hpi_ctl_out.bit.byte_en = 0;
    hpi_ctl_out.bit.hds = 1;

    if (auto_incr == TRUE)
    {
        hpi_ctl_out.bit.control = 1;
    }
else
    {
hpi_ctl_out.bit.control = 3;
}  
P1OUT = hpi_ctl_out.byte;

/* wait for ready from VC5509 */
hpi_ctl_in.byte = P1IN;
while ((hpi_ctl_in.bit.ready) hpi_ctl_in.byte = P1IN;

/* Assert the data strobe low */
hpi_ctl_out.bit.hds = 0;
P1OUT = hpi_ctl_out.byte;

/* loop to make sure the data lines are stable */
for (i=0; i<10; i++);

/* Read the MSB */
hpi_data = (((unsigned short)P4IN) << 8);

/* Read the LSB */
hpi_data |= ((unsigned short)(P2IN));

/* Release the data strobe */
hpi_ctl_out.bit.hds = 1;
P1OUT = hpi_ctl_out.byte;

return (hpi_data);
}

/******************************************************************************/

/* send_dsp_interrupt: sends an interrupt to the VC5509 by asserting the
   dsp interrupt bit in the control register. */

/*****************************************************************************/
void send_dsp_interrupt(void)
{
    hpic.byte = 0;
    hpic.bit.dsp_int = 1;
    write_hpi_control_register(hpic.byte);
    hpic.bit.dsp_int = 0;
    write_hpi_control_register(hpic.byte);

}  

/******************************************************************************/

/* send_dsp_command: writes a command code to the VC5509's memory and then
   sends an interrupt to the VC5509 to look at the command. */

******************************************************************************/
void send_dsp_command(Uint16 command)
{
    write_hpi_address_register(DSP_COMMAND_REGISTER);
    write_hpi_data_word(command,FALSE);
    send_dsp_interrupt();
}

/***********************************************/
/* print_hpi_message: prints messages received from the VC5509 to the display */
/* area. The characters are sent in a packed array. */
/***********************************************/
void print_hpi_message(void)
{
    Uint16 read_buffer, i, str_len;
    Uchar read_msg[MAX_LINE_LENGTH];

    /* print_hpi_message is always called from the hpi interrupt handler */
    /* so the next memory location in the address register is the length */
    str_len = read_hpi_data_word(TRUE);

    i=0;
    while ((i < str_len) && (i < (MAX_LINE_LENGTH-3)))
    {
        /* get next character */
        read_buffer = read_hpi_data_word(TRUE);

        /* put the MSB in first */
        read_msg[i] = (char)(read_buffer >> 8);
        i++;

        /* then the LSB */
        read_msg[i] = (char) (read_buffer);
        i++;
    }

    /* null terminate the string */
    read_msg[i] = 0;

    add_message_to_display(read_msg);
}

/***********************************************/
/* hpi_handler: processes any commands that are received from the VC5509 */
/***********************************************/
interrupt [PORT1 VECTOR] void hpi_handler(void)


```c
{
    Uint16 read_buffer;
    Uint16 refresh=FALSE;

    /* get the command */
    write_hpi_address_register(MSP_COMMAND_REGISTER);
    read_buffer = read_hpi_data_word(TRUE);

    switch(read_buffer)
    {
        case PRINT_MESSAGE:
            print_hpi_message();
            refresh=TRUE;
            break;

        case STOP_PROCESSING:
            stop_signal_processing();
            refresh=TRUE;
            break;

        default: break;
    }

    if (refresh)
    {
        /* simulates typing a dummy character to refresh the screen */
        in_buffer[buffer_write_pos] = '\'';
        buffer_write_pos++;

        /* loop back to the beginning if at the end of the buffer */
        if (buffer_write_pos >= MAX_BUFFER) buffer_write_pos = 0;

        #if LOW_POWER_MODE==TRUE
            clear_hpi_low_power(LPM1_bits);
        #endif
    }

    /* Clear the interrupt flag */
    P1IFG = 0;
```

190
F.8  include.h

@Path

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*
*/

#include <stdio.h>
#include <string.h>
#include "msp430x14x.h"
#include "typedef.h"
#include "prototype.h"
#include "define.h"
#include "extern.h"

F.9  init_sys.h

@Path

#include "include.h"

Path initialize system: all the setting to initialize the system
```c
// initialize system
void initialize_system(void)
{
    disable_watch_dog_timer();
    initialize_ports();
    initialize_serial_interface();
    initialize_adc();
    initialize_timers();
    clear_display_area();

    // only temporary for debugging
    dsp_data_address = DSP_HPI_WRITE_1;
    dsp_memory_block = DATA_BLOCK_1;

    /* enable global interrupts */
    _EINT();
}

// initialize serial interface
void initialize_serial_interface(void)
{
    /* select the uarts as special function ports */
    P3SEL |= (BIT4 | BIT5 | BIT6 | BIT7);

    /* set RS232 to 8-bits per character */
    U0CTL = CHAR;

    /* select the SMCLK for the transmit and receive baud rate generator for RS232 */
    U0TCTL = SSEL1 | SSEL0;
    U0RCTL = SSEL1 | SSEL0;

    /* enable the RS232 receiver */
    U0RCTL |= URXEIE;

    /* program the RS232 baud rate to 19.2kbs */
    U0BR1 = 0;
    U0BR0 = 64;
    U0MCTL = 0;

    /* enable the RS232 transmitter and receiver */
    ME1 = UTXE0 | URXE0;
}```
/* enable the receive interrupt for RS232 */
IE1 = URXIE0;

/* set RF to 8-bits per character */
U1CTL = CHAR;

/* select the SMCLK for the transmit and receive baud rate generator for RF */
U1TCTL = SSEL1 | SSELO;
U1RCTL = SSEL1 | SSELO;

/* enable the RF receiver */
U1RCTL |= URXEIE;

/* program the RF baud rate to 19.2kbs */
U1BR1 = 0;
U1BR0 = 64;
U1MCTL = 0;

/**************************************************************************/
/* initialize_adc: sets up the A/D converter                             
\**************************************************************************/
void initialize_adc(void)
{
    /* Reset before changing the settings */
    ADC12CTL0 = 0x0000;
    ADC12CTL1 = 0x0000;

    /* Ref = Vref+, Vref-, input = ADC2 (Geo A) */
    ADC12MCTL0 = (SREF_7 | INCH_2);

    /* Ref = Vref+, Vref-, input = ADC3 (Geo B) */
    ADC12MCTL1 = (SREF_7 | INCH_3);

    /* Ref = Vref+, Vref-, input = ADC4 (Geo C) */
    ADC12MCTL2 = (EDS | SREF_7 | INCH_4);

    /* Ref = Vref+, Vref-, input = ADC5 (Test 1) */
    ADC12MCTL3 = (SREF_7 | INCH_5);

    /* Ref = Vref+, Vref-, input = ADC6 (Test 2) */
    ADC12MCTL4 = (SREF_7 | INCH_6);

    /* Ref = Vref+, Vref-, input = ADC7 (Test 3) */
    ADC12MCTL5 = (EDS | SREF_7 | INCH_7);
110 /* Ref = VREF+, AVss, Input = ADC10 (Temperature) */
ADC12MCTL6 = (EOS | SREF_1 | INCH_10);

/* Ref = VREF+, AVss, Input = ADC11 (Power Supply Volatge) */
ADC12MCTL7 = (EOS | SREF_1 | INCH_11);

/* used to buffer the conversions for signal processing */
/* Ref = VeRef+, VeRef-, Input = ADC2 (Geo A) */
ADC12MCTL8 = (SREF_7 | INCH_2);
ADC12MCTL9 = (SREF_7 | INCH_2);
ADC12MCTL10 = (SREF_7 | INCH_2);
ADC12MCTL11 = (SREF_7 | INCH_2);
ADC12MCTL12 = (SREF_7 | INCH_2);
ADC12MCTL13 = (SREF_7 | INCH_2);
ADC12MCTL14 = (SREF_7 | INCH_2);
ADC12MCTL15 = (EOS | SREF_7 | INCH_2);
}

/***************************************************************************/
/* initialize ports: sets up the I/O ports */
void initialize_ports(void)
{

/* ---- Port 1 Settings ---- */
/* use as a port */
P1SEL = 0x00;

/* HINT and HRDY are inputs, the rest are outputs 0x7E */
P1DIR = (BIT6 | BIT5 | BIT4 | BIT3 | BIT2 | BIT1);

/* force all outputs to 0 */
P1OUT = 0x00;

/* disable all interrupts */
P1IE = 0x00;

/* when interrupts are enabled, interrupt on a low to high transition */
P1IES = 0x00;

/* ---- Port 2 Settings ---- */
/* use as a port */
P2SEL = 0x00;

/* all bits are inputs */
P2DIR = 0x00;  //

/* force all output bits to 0 */
P2OUT = 0x00;

/* disable all interrupts */
P2IE = 0x00;

/* When interrupts are enabled, interrupt on a low to high transition */
P2IES = 0x00;

/* ---- Port 3 Settings ---- */
/* use bits 0 to 3 as a port, use bits 4 to 7 as UARTs */
P3SEL = (BIT7 | BIT6 | BIT5 | BIT4);

/* CTS is an input, bits 0 to 2 are outputs */
P3DIR = (BIT2 | BIT1 | BIT0);

/* force VC55_ENA and GEO_ENA to 1 and all other output bits to 0 */
P3OUT = (BIT1 | BIT0);

/* ---- Port 4 Settings ---- */
/* Use as a port */
P4SEL = 0x00;

/* all bits are inputs */
P4DIR = 0x00;

/* force all output bits to 0 */
P4OUT = 0x00;

/* ---- Port 5 Settings ---- */
/* enable ACLK, and MCLK */
P5SEL = (BIT6 | BIT4);

/* all bits are outputs */
P5DIR = (BIT7 | BIT6 | BIT5 | BIT4 | BIT3 | BIT2 | BIT1 | BIT0);

/* force RS232 enable high, all other outputs 0 */
P5OUT = BIT5;

/* ---- Port 6 Settings ---- */
/* use as special function for ADC */
P6SEL = (BIT7 | BIT6 | BIT5 | BIT4 | BIT3 | BIT2 | BIT1 | BIT0);
/* all inputs */

P6DIR = 0x00;

} /***************************************************************************/ /* initialize_timers: initializes the clock crystals and sets up the timers */

#include <avr/io.h>

void initialize_timers(void)
{
    Uint16 i, j;

    /* select 1.3 MHz for the DCOC just in case */
    BCSCTL1 |= RSEL2 | RSEL0;

    /* clear the XTS bit */
    BCSCTL1 &= (~XTS);

    /* clear the OSCOFF flag in the Status Register */
    _BIC_SR(OSCOFF);

    /* turn on XT2 oscillator */
    BCSCTL1 &= (~XTOFF);

    /* test to see if it was able lock onto X2 */
    for (i=15; i > 0; i--)
    {
        IFG1 &= (~OFIFG);
        for (j=0; j<1000; j++);
        if (IFG1 && OFIFG == 0) break;
    }

    /* set MCLK and SMCLK to XT2 with a divide by 4 */
    BCSCTL2 |= SELM1 | DIVM1 | SELS | DIVS1;

    /* setup timer A to keep the running time */
    /* reset the timer */
    TACTL = TACLR;

    /* start in up mode with ACLK as source */
    TACTL = TASSEL_1 | MC_1 | ID_0;

    /* interrupt produces a toggle of OUT */
    CCTL0 = OUTMOD_4 | CCIE;

    /* set CCR0 register to 32768 ticks for one second */
CCR0 = 0x8000;

/* shut off CC1 and CC2 */
CCTL1 = 0;
CCTL2 = 0;
CCR1 = 0x0000;
CCR2 = 0x0000;

/* setup timer B to keep the sampling rate for ADC */
/* reset the timer */
TBCTL = TBCLR;

/* pulse OUT when it reaches the register */
TBCCTL0 = OUTMOD_3;

/* sets the sampling rate of the ADC */
TBCCR0 = SAMPLING_RATE;

/* shut off all the other CCTL registers */
TBCCTL1 = 0;
TBCCTL2 = 0;
TBCCTL3 = 0;
TBCCTL4 = 0;
TBCCTL5 = 0;
TBCCTL6 = 0;
TBCCR1 = 0x0000;
TBCCR2 = 0x0000;
TBCCR3 = 0x0000;
TBCCR4 = 0x0000;
TBCCR5 = 0x0000;
TBCCR6 = 0x0000;
}

/***************************************************************************/
* disable_watch_dog_timer: disables the watch dog timer

/***************************************************************************/

void disable_watch_dog_timer(void)
{
    WDTCTL = WDTPW | WDTHOLD;
}
F.10  low_power.s43

;
;  Personnel Detector
;  Elliot Ranger
;  Master of Science Thesis
;  Massachusetts Institute of Technology
;  in conjunction with Charles Stark Draper Laboratory
;
;
;******************************************************************************
10  ; FILENAME.    . . low_power.s43
; DATE CREATED.  .04/18/2002
; LAST MODIFIED. 08/06/2002
;******************************************************************************

NAME   low_power(16)
BSEG   CODE(1)
PUBLIC clear_low_power_mode
PUBLIC clear_hpi_low_power
EXTERN ?CL430_1_23_L08

NAME   low_power
PUBLIC clear_low_power_mode
PUBLIC clear_hpi_low_power
EXTERN ?CL430_1_23_L08

20  NAME   low_power
BSEG   CODE

clear_low_power_mode:
  BIC.W R12,11(SP)
  RET

clear_hpi_low_power:
  BIC.W R12,12(SP)
  RET
  END

F.11  main.c

/*
  * Personnel Detector
  * Elliot Ranger
  * Master of Science Thesis
  * Massachusetts Institute of Technology
  * in conjunction with Charles Stark Draper Laboratory
  *
  */

/******************************************************************************
10  * FILENAME.    . . main.c
* DATE CREATED.  .04/18/2002

198
/* LAST MODIFIED. 08/06/2002
 */

#include "include.h"
#include "variables.h"

/* main: initializes the system and then processes commands indefinitely. */

void main(void)
{
    initialize_system();

    /* infinite loop */
    while (TRUE)
    {
        process_commands();
    }
}

F.12 menu.c

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 */

/* FILENAME. . . . menu.c
 * DATE CREATED. . 04/18/2002
 * LAST MODIFIED. 08/06/2002
 */

#include "include.h"

/* cls: ansi ESC character sequence to clear the screen. */

void cls(void)
{
}
unsigned char buffer[10];
sprintf(buffer, "\%c[2J", ESC);
print_message(buffer);
}

/****************************************************************************
 * display_header: prints out the header at the top of each menu then calls
 * print_display_area to print out the messages.
******************************************************************************/
void display_header(void)
{
    cls(); // clear the screen
    print_message("Personnel Detector\n");
    print_message("Master's Thesis Project\n");
    print_message("Elliot Ranger\n");
    print_message(VERSION);
    print_message("\n\n");
    // call function to display messages
    print_display_area();
    print_message("\n\n");
}

/****************************************************************************
 * display_footer: prints out the footer at the bottom of each menu screen.
******************************************************************************/
void display_footer(void)
{
    print_message("\nSelect: ");
}

/****************************************************************************
 * display_main_menu: prints the main menu screen.
******************************************************************************/
void display_main_menu(void)
{
    display_header();
    print_message("Main Menu\n");
    print_message("\n");
    print_message("a. VC5509 Menu\n");
    print_message("b. Geophone Menu\n");
    print_message("c. RF Menu\n");
    print_message("d. RS232 Menu\n");
    print_message("e. ADC Test\n");
    print_message("f. Host Port Interface\n");
print_message("g. Flash Menu\n");
print_message("h. Misc Menu\n");
display_footer();

70 }

/***************************************************************
* display_vc55_menu: prints the VC5509 menu screen.  
/***************************************************************
void display_vc55_menu(void)
{

display_header();
print_message("VC5509 Menu\n");
print_message("\n");
print_message("a. Power ON\n");
print_message("b. Power OFF\n");
print_message("c. Boot DSP\n");
print_message("d. Copy DSP Code to Buffer\n");
print_message("e. Copy Buffer to Flash\n");
print_message("f. Start Signal Processing\n");
print_message("g. Stop Signal Processing\n");
print_message("h. Clear Signal Processing Buffers\n");
print_message("i. VC5509 Code Version\n");
display_footer();

90 }

/***************************************************************
* display_geophone_menu: prints the geophone menu screen.  
/***************************************************************
void display_geophone_menu(void)
{

display_header();
print_message("Geophone Menu\n");
print_message("\n");
print_message("a. Power ON\n");
print_message("b. Power OFF\n");
print_message("c. Channel A Gain 40dB\n");
print_message("d. Channel A Gain 60dB\n");
print_message("e. Channel B Gain 40dB\n");
print_message("f. Channel B Gain 60dB\n");
print_message("g. Channel C Gain 40dB\n");
print_message("h. Channel C Gain 60dB\n");
display_footer();

100 }

/***************************************************************

201
/* display_rf_menu: prints the RF menu screen. */
void display_rf_menu(void)
{
    display_header();
    print_message("RF Menu\r\n");
    print_message("\r\n");
    print_message("a. Power ON\r\n");
    print_message("b. Power OFF\r\n");
    print_message("a. Shutdown ON\r\n");
    print_message("b. Shutdown OFF\r\n");
    display_footer();
}

/* display_rs232_menu: prints the RS232 menu screen. */
void display_rs232_menu(void)
{
    display_header();
    print_message("RS232 Menu\r\n");
    print_message("\r\n");
    print_message("a. Shutdown ON\r\n");
    print_message("b. Shutdown OFF\r\n");
    display_footer();
}

/* display_adc_menu: prints the A/D converter menu screen. */
void display_adc_menu(void)
{
    display_header();
    print_message("ADC Menu\r\n");
    print_message("\r\n");
    print_message("a. Geophone Channels\r\n");
    print_message("b. Test Input Channels\r\n");
    print_message("c. Temperature Sensor\r\n");
    print_message("d. Power Supply Voltage\r\n");
    display_footer();
}

/* display_hpi_menu: prints the host port interface menu screen. */
void display_hpimenu(void)
{
    display_header();
    print_message("Host Port Interface\r\n");
    print_message("\r\n");
    print_message("a. Enable HPI\r\n");
    print_message("b. Disable HPI\r\n");
    print_message("c. Write 0x1234 (4660 Decimal) to 0x0A00\r\n");
    print_message("d. Read Memory Location 0x0A00\r\n");
    print_message("e. Send HPI Interrupt\r\n");
    display_footer();
}

void display_flashmenu(void)
{
    display_header();
    print_message("Flash Menu\r\n");
    print_message("\r\n");
    print_message("a. Write to address 0x6000\r\n");
    print_message("b. Erase address 0x6000\r\n");
    print_message("c. Read address 0x6000\r\n");
    display_footer();
}

void display_miscmenu(void)
{
    display_header();
    print_message("Misc Menu\r\n");
    print_message("\r\n");
    print_message("a. Display Running Time\r\n");
    print_message("b. MSP Power Supply Voltage\r\n");
    print_message("c. MSP Temperature\r\n");
    print_message("d. Clear Message Display Area\r\n");
    display_footer();
}
F.13 proc_adc.c

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 *
 */

#include "include.h"

/**
 * process_adc: gets a character from the process_commands function and allows
 * the user to keep sampling one of the A/D converter channels
 *
 * until ESC is pressed.
 */

void process_adc(Char channel)
{
    Char buffer[MAX_LINE_LENGTH];
    Uint16 start_timer;

    switch(channel)
    {
        case 'a': /* Geophone Channels */
        {
            /* make sure control register is cleared out */
            ADC12CTL1 = 0x0000;

            /* turn on ADC core */
            ADC12CTL0 |= ADC12ON;

            /* perform the conversion on a single channel at address 0 - Geo A */
            ADC12CTL1 = (CONSEQ_0 | ADC12SSEL_2 | SHP | CSTARTADD_0);

            /* single NOP to make sure ADC core is on */
            ;

            /* start sampling */
        }
    }

FILENAME: proc_adc.c
DATE CREATED: 04/18/2002
LAST MODIFIED: 08/06/2002

#*****************************************************************************

*****************************************************************************

#include "include.h"

*****************************************************************************

*****************************************************************************

process_adc: gets a character from the process_commands function and allows
the user to keep sampling one of the A/D converter channels

until ESC is pressed.

*****************************************************************************

*****************************************************************************
ADC12CTL0 |= (ENC | ADC12SC);

/* wait for conversion to complete */
while ((ADC12CTL1 & ADC12BUSY) == ADC12BUSY);

/* turn off enable conversion */
ADC12CTL0 &= (~ENC); //

/* perform the conversion on a single channel at address 1 - Geo B */
ADC12CTL1 = (CONSEQ_0 | ADC12SSEL_2 | SHP | CSTARTADD_1);

/* single NOP to make sure ADC core is on */
;

/* start sampling */
ADC12CTL0 |= (ENC | ADC12SC);

/* wait for conversion to complete */
while ((ADC12CTL1 & ADC12BUSY) == ADC12BUSY);

/* turn off enable conversion */
ADC12CTL0 &= (~ENC);

/* perform the conversion on a single channel at address 2 - Geo C */
ADC12CTL1 = (CONSEQ_0 | ADC12SSEL_2 | SHP | CSTARTADD_2);

/* single NOP to make sure ADC core is on */
;

/* start sampling */
ADC12CTL0 |= (ENC | ADC12SC);

/* wait for conversion to complete */
while ((ADC12CTL1 & ADC12BUSY) == ADC12BUSY);

/* turn off enable conversion */
ADC12CTL0 &= (~ENC);

/* turn off adc */
ADC12CTL0 &= (~ADC12ON);

/* print results to display area */
sprintf(buffer,"Geophone A: %6.4f",((double)ADC12MEM[0]/4096.0)*3.00);
add_message_to_display(buffer);
sprintf(buffer,"Geophone B: %6.4f",((double)ADC12MEM[1]/4096.0)*3.00);
add_message_to_display(buffer);
90 sprintf(buffer,"Geophone C: %6.4f",((double)ADC12MEM[2]/4096.0)*3.00);
add_message_to_display(buffer);
}
break;

case 'b' : /* Test Input */
{
    /* make sure control register is cleared out */
    ADC12CTL1 = 0x0000;

    /* turn on ADC core */
    ADC12CTL0 |= ADC12ON;

    /* perform the conversion on a single channel at address 3 - Test 1 */
    ADC12CTL1 = (CONSEQ_0 | ADC12SSEL_2 | SHP | CSTARTADD_3);

    /* single NOP to make sure ADC core is on */
    ;

    /* start sampling */
    ADC12CTL0 |= (ENC | ADC12SC);

    /* wait for conversion to complete */
    while ((ADC12CTL1 & ADC12BUSY) == ADC12BUSY);

    /* turn off enable conversion */
    ADC12CTL0 &= (~ENC);

    /* perform the conversion on a single channel at address 4 - Test 2 */
    ADC12CTL1 = (CONSEQ_0 | ADC12SSEL_2 | SHP | CSTARTADD_4);

    /* single NOP to make sure ADC core is on */
    ;

    /* start sampling */
    ADC12CTL0 |= (ENC | ADC12SC);

    /* wait for conversion to complete */
    while ((ADC12CTL1 & ADC12BUSY) == ADC12BUSY);

    /* turn off enable conversion */
    ADC12CTL0 &= (~ENC);

    /* perform the conversion on a single channel at address 5 - Test 3 */

ADC12CTL1 = (CONSEQ_0 | ADC12SSEL_2 | SHP | CSTARTADD_5);

/* single NOP to make sure ADC core is on */

/* start sampling */

140 ADC12CTL0 |= (ENC | ADC12SC);

/* wait for conversion to complete */
while ((ADC12CTL1 & ADC12BUSY) == ADC12BUSY);

/* turn off enable conversion */
ADC12CTL0 &= (~ENC);

/* turn off adc */
ADC12CTL0 &= (~ADC12ON);

150 /* print results to display area */
sprintf(buffer,"Test Input 1: %6.4f",((double)ADC12MEM[3]/4096.0)*3.00);
add_message_to_display(buffer);
sprintf(buffer,"Test Input 2: %6.4f",((double)ADC12MEM[4]/4096.0)*3.00);
add_message_to_display(buffer);
sprintf(buffer,"Test Input 3: %6.4f",((double)ADC12MEM[5]/4096.0)*3.00);
add_message_to_display(buffer);
}
break;

160 case 'c' : /* Temperature Sensor */
{
    /* make sure control register is cleared out */
ADC12CTL1 = 0x0000;

    /* perform the conversion on a single channel at address 6 - Temperature Sensor */
ADC12CTL1 = (CONSEQ_0 | ADC12SSEL_2 | ADC12DIV_7 | SHP | CSTARTADD_6);

    /* turn on core and reference voltage to 2.5 V */
ADC12CTL0 |= (ADC12ON | REFON | REF2_5V);

    /* make sure reference voltages are stable */
start_timer = TAR;
while (((TAR - start_timer) & TIMER_MASK) < 15);

    /* start sampling */
ADC12CTL0 |= (ENC | ADC12SC);

207
while ((ADC12CTL1 & ADC12BUSY) == ADC12BUSY);

/* turn off enable conversion */
ADC12CTL0 &= (~ENC);

/* turn off reference voltages */
ADC12CTL0 &= ~(ADC12ON | REFON | REF2_5V);

/* print results to display area */
sprintf(buffer,"Temperature Sensor: %6.2f C",((double) ADC12MEM[6]*2.50/4096.0)/3.55e-3) - 273.15);
add_message_to_display(buffer);
}
break;

case 'd': /* Power Supply Voltage */
{
    /* make sure control register is cleared out */
    ADC12CTL1 = 0x0000;

    /* perform the conversion on a single channel at address 7 - Power Supply Voltage */
    ADC12CTL1 = (CONSEQ_0 | ADC12SEL_2 | ADC12DIV_7 | SHP | CSTARTADD_7); // Using master clock, single channel

    /* turn on core and reference voltage to 2.5 V */
    ADC12CTL0 |= (ADC12ON | REFON | REF2_5V);

    /* make sure reference voltages are stable */
    start_timer = TAR;
    while (((TAR - start_timer) & TIMER_MASK) < 15);

    /* start sampling */
    ADC12CTL0 |= (ENC | ADC12SC);

    /* wait for conversion to complete */
    while ((ADC12CTL1 & ADC12BUSY) == ADC12BUSY);

    /* turn off enable conversion */
    ADC12CTL0 &= (~ENC);

    /* turn off reference voltages */
    ADC12CTL0 &= ~(ADC12ON | REFON | REF2_5V)); // turn off reference voltages

    /* print results to display area */
    sprintf(buffer,"Power Supply Voltage: %6.4f",(((double) ADC12MEM[7])*2.50/4096.0)/5));
    add_message_to_display(buffer);}
F.14 proc_cmd.c

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 *
 */
/*****************************
 FILENAME...... proc_cmd.c
 DATE CREATED. 04/18/2002
 LAST MODIFIED. 08/06/2002
 ***************************/

#include "include.h"

/*****************************
 * process_commands: main function that continually processes any key typed
 * and executes the associated function.
 *****************************

void process_commands(void)
{
    Uint16 done = FALSE;
    Uchar key;
    Uint16 read_data;
    Uchar buffer[MAX_LINE_LENGTH];

    display_main_menu();
    switch(get_char())
    {
        case 'a': /* VC5509 Menu */
        { }


```c

{
    done = FALSE;
    display_vc55_menu();
    switch (get_char())
    {
        case 'a': /* turn on VC5509 and enable hpi */
            msp_port3.byte = P3OUT;
            msp_port3.bit.vc55_enable = 0;
            P3OUT = msp_port3.byte;
            enable_hpi();
            done = TRUE;
            break;
        case 'b': /* disable hpi and turn off VC5509 */
            disable_hpi();
            msp_port3.byte = P3OUT;
            msp_port3.bit.vc55_enable = 1;
            P3OUT = msp_port3.byte;
            done = TRUE;
            break;
        case 'c': /* downloads the code from flash and boots VC5509 */
            boot_dsp();
            done = TRUE;
            break;
        case 'd': /* tells VC5509 to copy its program code to HPI Write */
            send_dsp_command(COPY_TO_HPI_WRITE);
            done = TRUE;
            break;
        case 'e': /* copy VC5509 code to flash and verify that the memory is the same */
            cls();
            print_message("\r\n\nCopying VC5509 Code to Flash, Please Wait...\r\n");
            copy_dsp_code_to_flash();
            verify_dsp_code();
            done = TRUE;
            break;
        case 'f': /* begins signal processing */
            add_message_to_display("MSP: Starting Signal Processing");

            /* turn on geophone power */
            msp_port3.byte = P3OUT;
            msp_port3.bit.geo_enable = 0;
    }
```
P3OUT = msp_port3.byte;
start_signal_processing();
done = TRUE;
break;

case 'g' : /* stops signal processing */
    add_message_to_display("MSP: Stopping Signal Processing");
    stop_signal_processing();
    done = TRUE;
    break;

case 'h' : /* clear signal processing buffers*/
    send_dsp_command(CLEAR_PROCESSING_BUFFERS);
    done = TRUE;
    break;

case 'i' : /* tells VC5509 to print out its code version */
    send_dsp_command(GET_VC5509_VERSION);
    done = TRUE;
    break;

default : break;
}
} while (!done);
} break;

case 'b' : /* Geophone Menu */
{
    do
        {
            done = FALSE;
            display_geophone_menu();
            switch (get_char())
            {
                case 'a' : /* turn on geophone power */
                    msp_port3.byte = P3OUT;
                    msp_port3.bit.geo_enable = 0;
                    P3OUT = msp_port3.byte;
                    done = TRUE;
                    break;

                case 'b' : /* turn off geophone power */
                    msp_port3.byte = P3OUT;
                    msp_port3.bit.geo_enable = 1;

    


P3OUT = msp_port3.byte;
done = TRUE;
break;

case 'c' : /* set Geo A to 40 dB */
        msp_port5.byte = P5OUT;
        msp_port5.bit.geo_A_sel = 0;
        P5OUT = msp_port5.byte;
        done = TRUE;
        break;

        case 'd' : /* set Geo A to 60 dB */
        msp_port5.byte = P5OUT;
        msp_port5.bit.geo_A_sel = 1;
        P5OUT = msp_port5.byte;
        done = TRUE;
        break;

        case 'e' : /* set Geo B to 40 dB */
        msp_port5.byte = P5OUT;
        msp_port5.bit.geo_B_sel = 0;
        P5OUT = msp_port5.byte;
        done = TRUE;
        break;

        case 'f' : /* set Geo B to 60 dB */
        msp_port5.byte = P5OUT;
        msp_port5.bit.geo_B_sel = 1;
        P5OUT = msp_port5.byte;
        done = TRUE;
        break;

        case 'g' : /* set Geo C to 40 dB */
        msp_port5.byte = P5OUT;
        msp_port5.bit.geo_C_sel = 0;
        P5OUT = msp_port5.byte;
        done = TRUE;
        break;

        case 'h' : /* set Geo C to 60 dB */
        msp_port5.byte = P5OUT;
        msp_port5.bit.geo_C_sel = 1;
        P5OUT = msp_port5.byte;
        done = TRUE;
        break;
default : break;
}
} while (!done);
}
break;

case 'c' : /* RF Menu */
{
    do
    {
        done = FALSE;
        display_rf_menu();
        switch (get_char())
        {
            case 'a' : /* turn on RF power and enable interrupts */
                msp_port3.byte = P3OUT;
                msp_port3.bit.rf_enable = 1;
                P3OUT = msp_port3.byte;

                /* enable the RF transmitter and receiver */
                ME2 = UTXE1 | URXE1;

                /* enable RF receive interrupt */
                IE2 = URXIE1;

                rf_ena = TRUE;
                done = TRUE;
                break;

            case 'b' : /* turn off RF power and disable interrupts */
                msp_port3.byte = P3OUT;
                msp_port3.bit.rf_enable = 0;
                P3OUT = msp_port3.byte;

                /* disable the RF transmitter and receiver */
                ME2 = 0; // disable the transmitter & receiver

                /* disable RF receive interrupt */
                IE2 = 0;

                rf_ena = FALSE;
                done = TRUE;
                break;
        }
    }
}
case 'c' : /* put RF in sleep mode */
msp_port5.byte = P5OUT;
msp_port5.bit.rf_shutdown = 1;
P5OUT = msp_port5.byte;
done = TRUE;
break;

220

case 'd' : /* take RF out of sleep mode */
msp_port5.byte = P5OUT;
msp_port5.bit.rf_shutdown = 0;
P5OUT = msp_port5.byte;
done = TRUE;
break;

default : break;
}

230
} while (!done);
}
break;

case 'd' : /* RS232 Menu */
{
do
{
done = FALSE;
display_rs232_menu();
switch (get_char())
{
case 'a' : /* shutdown RS232 transmitter */
msp_port5.byte = P5OUT;
msp_port5.bit.rs232_enable = 0;
P5OUT = msp_port5.byte;
done = TRUE;
break;

case 'b' : /* turn on RS232 transmitter */
msp_port5.byte = P5OUT;
msp_port5.bit.rs232_enable = 1;
P5OUT = msp_port5.byte;
done = TRUE;
break;

default : break;
}
} while (!done);
case 'e' : /* ADC Menu */
{
    do
    {
        done = FALSE;
        display_adc_menu();
        switch (key=get_char())
        {
            case ESC : /* wait for ESC or CR to exit menu */
                case CR :
                    done = TRUE;
                    break;
                default :
                    cls();
                    process_adc(key);
                    break;
        }
    } while (!done);
}
break;

case 'f' : /* HPI Menu */
{
    do
    {
        done = FALSE;
        display_hpi_menu();
        switch (get_char())
        {
            case 'a' : /* enable host port interface */
                enable_hpi();
                done = TRUE;
                break;
            case 'b' : /* disable host port interface */
                disable_hpi();
                done = TRUE;
                break;
        }
case 'c' :  /* write a test word to HPI Write location */
    write_hpi_address_register(0x0A00);
    write_hpi_data_word(0x1234,TRUE);
    done = TRUE;
    break;

310  case 'd' :  /* read first word at HPI Write location */
    write_hpi_address_register(0x0A00);
    read_data = read_hpi_data_word(TRUE);
    sprintf(buffer,"VC5509 Memory Location 0x0A00: %X",read_data);
    add_message_to_display(buffer);
    done = TRUE;
    break;

    case 'e' :  /* send VC5509 host port interrupt */
    send_dsp_interrupt();
    done = TRUE;
    break;

    default : break;
          }
      } while (!done);
}
break;

330  case 'g' :  /* Flash Menu */
{
   do
   {
      done = FALSE;
      display_flash_menu();
      switch (get_char())
      {
      case 'a' :  /* write test word to flash location 0x6000 */
         write_flash(0x6000,0x1234);
         done = TRUE;
         break;

340  case 'b' :  /* erase flash memory location 0x6000 */
         erase_flash(0x6000);
         done = TRUE;
         break;

      case 'c' :  /* read the memory at location 0x6000 */
         read_data = read_flash(0x6000);
sprintf(buffer,"Flash Memory Location 0x6000: %X",read_data);
add_message_to_display(buffer);
done = TRUE;
break;

default : break;
}
} while (!done);
}
break;

360 case 'h' : /* Misc Menu */
{
do
{
    done = FALSE;
display_misc_menu();
    switch (get_char())
    {
        case 'a' : /* print out running time of processor */
            sprintf(buffer,"\r\n%d days",days);
            add_message_to_display(buffer);
            sprintf(buffer,"%d hours : %d minutes : %d seconds",hours, minutes, seconds);
            add_message_to_display(buffer);
            done = TRUE;
            break;
        case 'b' : /* print out MSP power supply voltage */
            process_adc('d');
            done = TRUE;
            break;
        case 'c' : /* print out MSP temperature */
            process_adc('c');
            done = TRUE;
            break;
        case 'd' : /* reset display message area */
            clear_display_area();
            done = TRUE;
            break;
        default : break;
    }
} while (!done);
F.15  prototype.h

/*  Personnel Detector
  Elliot Ranger
  Master of Science Thesis
  Massachusetts Institute of Technology
  in conjunction with Charles Stark Draper Laboratory
  */

void clear_low_power_mode(Uint16 mode);
void clear_hpi_low_power(Uint16 mode);
void initialize_system(void);
void initialize_serial_interface(void);
void initialize_adc(void);
void initialize_porte(void);
void initialize_timers(void);
void disable_watch_dog_timer(void);
void print_message(Uchar *message);
Uchar get_char(void);
void process_commands(void);
void process_adc(Uchar channel);
void cls(void);
void display_header(void);
void display_footer(void);
void display_main_menu(void);
void display_vc55_menu(void);
void display_geophone_menu(void);
void display_rf_menu(void);
void display_rf232_menu(void);
void display_adc_menu(void);
void display_hpi_menu(void);
void display_flash_menu(void);
void display_misc_menu(void);

void enable_hpi(void);
void disable_hpi(void);
void write_hpi_control_register(Uint16 data);
void write_hpi_address_register(Uint16 data);
void write_hpi_data_word(Uint16, Uint16 auto_incr);
Uint16 read_hpi_data_word(Uint16 auto_incr);
void send_dsp_interrupt(void);
void send_dsp_command(Uint16 command);
void print_hpi_message(void);

void add_message_to_display(Uchar *message);
void clear_display_area(void);
void print_display_area(void);

void boot_dsp(void);
void copy_dsp_code_to_flash(void);
void verify_dsp_code(void);

void erase_flash(Uint16 address);
void write_flash(Uint16 address, Uint16 data);
Uint16 read_flash(Uint16 address);

void start_signal_processing(void);
void stop_signal_processing(void);

F.16 signal_proc.c

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 * */
```c
#include "include.h"

void start_signal_processing(void)
{
    // make sure control register is cleared out
    ADC12CTL1 = 0x0000;

    // clear any interrupt flags and enable interrupts on channel 15
    ADC12IFG = 0x0000;
    ADC12IE = BITF;

    // repeated sequence starting at address 8 using timer B
    // to control the sampling rate
    ADC12CTL1 = (CONSEQ_3 | SHS_2 | ADC12SSEL_3 | SHP | CSTARTADD_8);

    // turn on ADC core
    ADC12CTL0 |= (ADC12ON);

    // single NOP to make sure ADC core is on
    ;

    // enable conversions
    ADC12CTL0 |= ENC;

    // start Timer B using ACLK as the source in up mode
    TBCTL = TBSSEL_1 | MC_1 | ID_0;
}
```

```c
#include "include.h"

void stop_signal_processing(void)
{
    // stop_signal_processing: resets timer B, disables all ADC interrupts and
    // turns off the ADC core.
}
```
{ /* reset timer B */
    TBCTL = TBCLR;

    /* disable ADC12 interrupts and clear any pending interrupts */
    ADC12IE = 0x0000;
    ADC12IFG = 0x0000;

    /* turn off enable conversion */
    ADC12CTL0 &= (~ENC);

    /* turn off ADC */
    ADC12CTL0 &= (~ADC12ON);
}

//******************************************************************************************
* adc_handler: receives an interrupt when the ADC has done 8 conversions
* transfers the data to the VC5509 using dsp_data_address to
* keep track of where the next set of conversions should go.
//******************************************************************************************
interrupt [ADC Vector] void adc_handler(void)
{
    Uint16 i;
    Uint16 scaled;

    /* transfer the data to the VC5509 */
    if ((ADC12IFG & BITF) == BITF)
    {
        /* set the correct address location to start writing data */
        write_hpi_address_register(dsp_data_address);
        for (i=8;i<=15;i++)
        {
            scaled = ADC12MEM[i] << 3;
            write_hpi_data_word(scaled,TRUE);
            dsp_data_address++;
        }

        if ((dsp_data_address >= 0x14AF) && (dsp_memory_block == DATA_BLOCK_1))
        {
            send_dsp_command(PROCESS_DATA_BLOCK_1);
            dsp_data_address = DSP_HPI_WRITE_2;
            dsp_memory_block = DATA_BLOCK_2;
        }

        if ((dsp_data_address >= 0x19AF) && (dsp_memory_block == DATA_BLOCK_2))
{  
    send_dsp_command(PROCESS_DATA_BLOCK_2);  
    dsp_data_address = DSP_HPI_WRITE_1;  
    dsp_memory_block = DATA_BLOCK_1;  
}

F.17  timer.c

#include "include.h"

interrupt [TIMER0_VECTOR] void timer_A_handler(void)
{
    time++;
    
    /* increment the number of seconds */
    seconds++;
    seconds% = 60;
    if (seconds == 0)
    {
        /* increment the number of minutes */
        minutes++;
        minutes% = 60;
        if (minutes == 0)
    
    }
/ * increment the number of hours */
   hours++;
   hours%=24;
   if (hours == 0)
   {
      /* increment the number of days */
      days++;  
   }
   }
   }

F.18 typedef.h

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 */

FILENAME. . . . typedef.h
DATE CREATED. . 04/18/2002
LAST MODIFIED. 08/06/2002

typedef unsigned char Uchar;
typedef char Char;
typedef unsigned short Uint16;
typedef unsigned long Uint32;

typedef union
{
   struct
   {
      short vc55_enable : 1;
      short geo_enable : 1;
      short rf_enable : 1;
      short spare : 5;
   } bit;
   Uchar byte;
typedef union
{
    struct
    {
        short geo_A_sel : 1;
        short geo_B_sel : 1;
        short geo_C_sel : 1;
        short spare1 : 2;
        short rs232_enable : 1;
        short spare2 : 1;
        short rf_shutdown : 1;
    } bit;
    Uchar byte;
}
MSP_PORT3_TYPE;

typedef union
{
    struct
    {
        short geo_A_sel : 1;
        short geo_B_sel : 1;
        short geo_C_sel : 1;
        short spare1 : 2;
        short rs232_enable : 1;
        short spare2 : 1;
        short rf_shutdown : 1;
    } bit;
    Uchar byte;
}
MSP_PORT5_TYPE;

typedef union
{
    struct
    {
        short spare1 : 3;
        short rf_cts : 1;
        short spare2 : 4;
    } bit;
    Uchar byte;
}
RF_CONTROL_TYPE;

typedef union
{
    struct
    {
        short hpi_int : 1;
        short byte_en : 2;
        short control : 2;
        short rd_wr : 1;
        short hds : 1;
        short ready : 1;
    } bit;
    Uchar byte;
}
HPI_CONTROL_TYPE;

typedef union
{struct
    {
        short reset : 1;
        short dsp_int : 1;
        short spare : 3;
        short xadd : 1;
        short spare1 : 10;
    } bit;
    Uint16 byte;
} HPIC_CONTROL_TYPE;

F.19 variables.h

/*
 * Personnel Detector
 * Elliot Ranger
 * Master of Science Thesis
 * Massachusetts Institute of Technology
 * in conjunction with Charles Stark Draper Laboratory
 *
*/
/*****************************************************************************/

/* global variables */
MSP_PORT3_TYPE msp_port3;
MSP_PORTS_TYPE msp_port5;
HPIC_CONTROL_TYPE hpic;
Uint32 time = 0;
Uint16 seconds = 0;
Uint16 minutes = 0;
Uint16 hours = 0;
Uint16 days = 0;
Uchar in_buffer[64];
Uint16 buffer_write_pos = 0;
Uint16 buffer_read_pos = 0;
Uint16 rf_ena = FALSE;
Uchar display_lines[3][64];
Uint16 display_current_line = 0;
30 Uint16 dsp_data_address = 0;
    Uint16 dsp_memory_block = 1;
Appendix G

Errata

Problem: Part U12 (MAX1672) pins 2, 15, 7, and 10 were tied together but were not tied to PGND.
Solution: Jumper pins 7 and 8 together. Pins 8, 6, and 5 were correctly tied to PGND on the part.

Problem: Connector J5 pin 9 should be the only connection to DGND, but 4,8,10,12,13,and 14 were tied to DGND as well.
Solution: Cut pins 4,8,and 10 to remove the connection to DGND those pins actually connect to circuitry in the FET pod. Pins 12, 13, and 14 can be left uncut because those pins are unused by the programmer.

Problem: Part U1 the RX_IN and RX_OUT are reversed.
Solution: Lift pins 15 and 16 from the circuit board, and run wires to swap the connections.

Problem: J4 and J7 are specified as pins in the parts listing, but should be sockets.
Solution: Change the part to a socket. The hole spacing on the board is the same for both parts.
Problem: GEO_VREF- was never connected to AGND.
Solution: Connect a jumper wire between the GEO_VREF- side of R13 and pin 2 of part U8.
Bibliography


