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March 2, 2004

Lakshman One
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Simon Fraser University
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RE: Ensc 440 Project Design Specifications for the BEAM Pedometer

Dear Mr. One,

Attached is the BEAM Pedometer Design Specifications for Ensc 440: Capstone Engineering Project. The included document summarizes the design requirements of the BEAM Pedometer. The BEAM team currently is designing and implementing the BEAM Pedometer, an accurate and low cost distance-measuring device for fitness and health enthusiasts.

The purpose of the attached document is to outline the full design requirements of the BEAM Pedometer prototype, and some design requirements of the final product. In this document, we explain in depth the design details of each functional requirement listed in our Functional Specifications.

The BEAM team includes four dedicated senior engineering students: Eliot Aharon, Manpreet Johal, Aaron Payment, and Biljana Pecelj. If you have any questions or comments please feel free to contact me via email at eaharon@sfu.ca or the team at ensc440-beam@sfu.ca.

Sincerely,

Eliot Aharon
CEO
BEAM Inc.

Enclosure: *Design Specifications Version 1.0 for the BEAM Pedometer*

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Pedometer
Design Specifications

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Date: March 2, 2004
Revision: 1.0

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Executive Summary

Over the years, various studies have shown the connection between obesity, diabetes, heart disease, and stroke. The devastating diseases associated with obesity can be avoided through regular exercise and a healthy diet. New studies indicate that walking 6,000 steps a day is sufficient for good health and 10,000 steps a day can result in weight-loss [1]. Such studies have encouraged walking and step counting, making pedometers a very popular fitness item. The team is in the process of designing and implementing the BEAM Pedometer, an accurate and low cost device.

The project development will occur as a two-step process. The first phase of the project is the development of the prototype. The prototype will have the following features:

1. Accurate step counting algorithm
2. Distance traveled measured in km
3. Easy to use user interface
4. RF module connecting ankle and display units

The second phase of the development will include:

1. Display unit redesigned into a wrist attachable module
2. Protective casing for the ankle and wrist module
3. Watch feature
4. Size comparable to already existing pedometer units

The first development phase will end by the first week of April 2004.

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Glossary

Acronyms

ASCII	American Standard Code for Information Interchange
CPU	Central processing unit
ISR	Interrupt Service Routine
LCD	Liquid-crystal display
MIPS	Million instructions per second
RF	Radio frequency
SII	Seiko Instruments, Inc.

Definitions

Accelerometer	An instrument used to measure acceleration.
Pedometer	An instrument that gauges the approximate distance traveled on foot by registering the number of steps taken.

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1. Introduction

The BEAM *Pedometer* is a fitness gadget that people can use to measure accurately the distance traveled and the number of steps walked in a day. The unique combination of an *accelerometer* combined with a highly accurate algorithm improves the accuracy of the BEAM Pedometer. The team is currently in the first phase of development. By April 2004, the proof of concept phase will be completed.

1.1. Scope

This document explains the design details of the functional requirements that the fully completed prototype BEAM Pedometer must meet by April 2004. On top of the full set of design details for the proof of concept device, we have provided a partial set of design details for the commercial version of the BEAM Pedometer.

1.2. Intended Audience

The intended audience of this document includes design engineers, managers and the marketing department.

Design engineers will use these design specifications while developing the modules for the BEAM Pedometer.

The project manager will use the design specifications to gage project progress and the development goals of the first phase.

The marketing team will use the design specifications during the initial development of promotional materials.

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2. System Overview

The system consists of two modules: an ankle unit and a display unit. The ankle unit consists of an accelerometer attached to a Velcro strap, which wraps around a user's ankle. The display unit indicates the number of steps taken and the distance traveled by the user. An Atmel microprocessor processes the data collected, and calculates the steps and distance traveled. Figure 1 illustrates the system overview of the BEAM Pedometer.

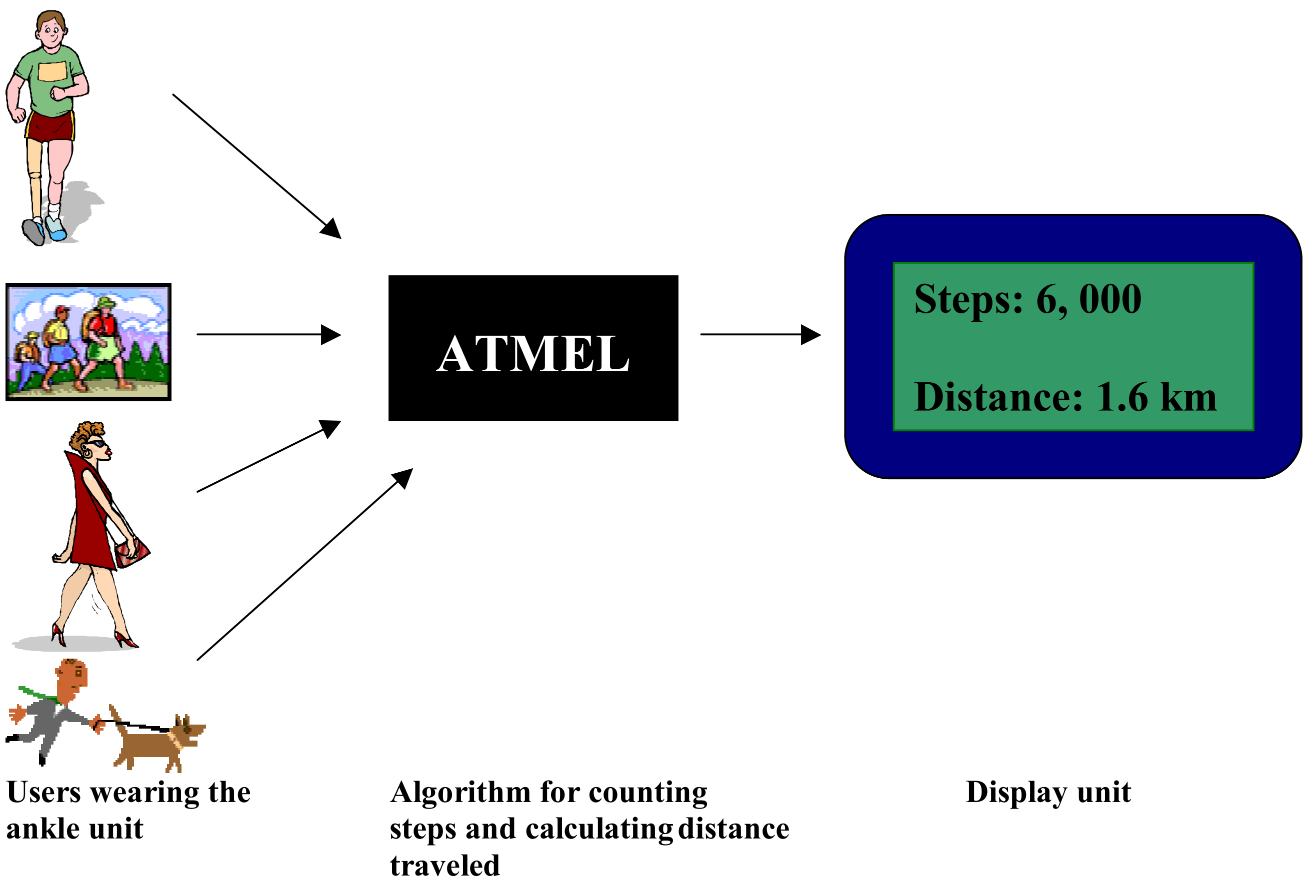

Figure 1: System overview

The BEAM Pedometer is a unit designed to determine the distance traveled by a pedestrian or runner. This being the case, several design requirements must be met. These specifications can be classified into several categories. The following sections contain detailed descriptions of each category.

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3. System Hardware

The block diagram in Figure 2 outlines the major components of the BEAM Pedometer system.

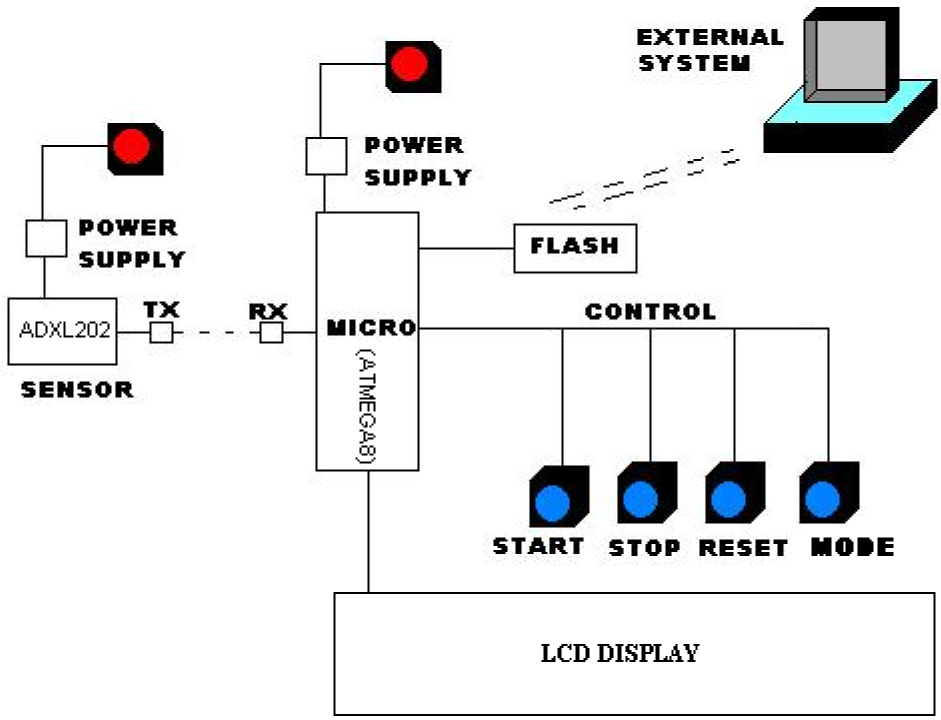

Figure 2: BEAM Pedometer general block diagram

The two critical components of the BEAM Pedometer are the Atmel ATmega 8 microcontroller and Analog Devices ADXL202 accelerometer shown in the above figure. The Beam Pedometer is required to perform in high-speed real time applications very accurately; therefore, the chosen sensor and processor greatly influence the resulting product. The following sections show that the chosen components were necessary in the implementation of the BEAM Pedometer.

It is important to note that an existing *RF* module was used to implement the information transfer between the two units, and little is known of the exact specifications of the existing RF unit. Since the RF module does not interfere with the functionality of the BEAM Pedometer, any RF module of sufficient bandwidth may be used.

3.1. BEAM Hardware Components

3.1.1. ATmega8 Risk Processor

The Atmel ATmega8 is a powerful microprocessor, which is the brain of the BEAM Pedometer. The ATmega8 is ideal for use in real time processing as it performs up to 16 *MIPS* and has a configurable processor clock with a very powerful instruction set for high-speed math operations. The ATmega8 is also equipped with in-system programmable flash allowing for future updating of the BEAM Pedometer algorithm. An added feature is its small size and simple interface allowing for its use in space conscious applications such as the BEAM Pedometer. Figure 3 shows the pin outs of the ATmega8 DIP package used in the BEAM Pedometer.

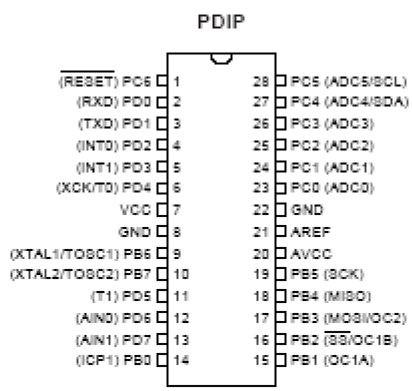

Figure 3: ATmega8 DIP package

3.1.2. ADXL202 Accelerometer

The ADXL202 accelerometer is a dual axis surface mount accelerometer with duty cycle output for easy interfacing to virtually any microcontroller. The ADXL202 is the sole sensor on the BEAM Pedometer, and the main functional component on the ankle unit. Based on tests performed at the onset of BEAM, it was determined that only a single axis of the accelerometer would be used in the proof of concept design, but for the future commercial product it is expected that both axes will be used, utilizing the second axis for error control.

The ADXL202 was configured to have approximately a 10 ms period and 50 kHz bandwidth. The chosen duty cycle period and bandwidth reduce the complexity of the RF module required, and allow for a slower sampling rate to be performed by the microprocessor while still obtaining accurate results. The physical layout of the ADXL202 is shown in Figure 4.

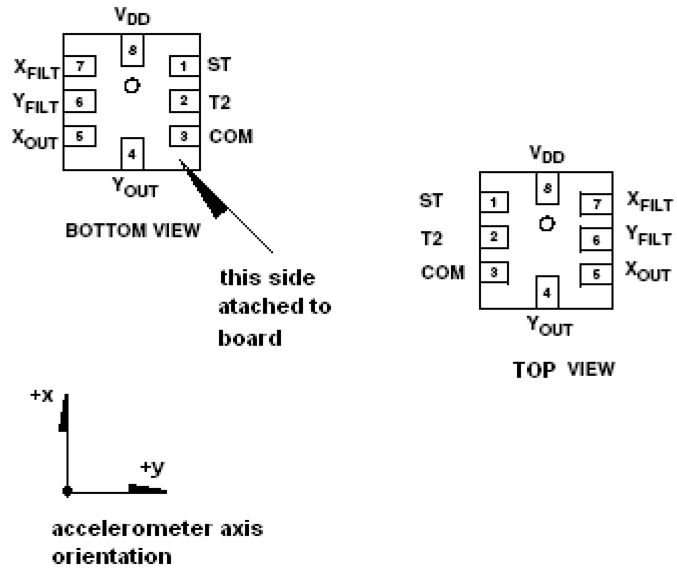

Figure 4: ADXL202

The schematic in Figure 5 indicates the circuit used to implement the accelerometer.

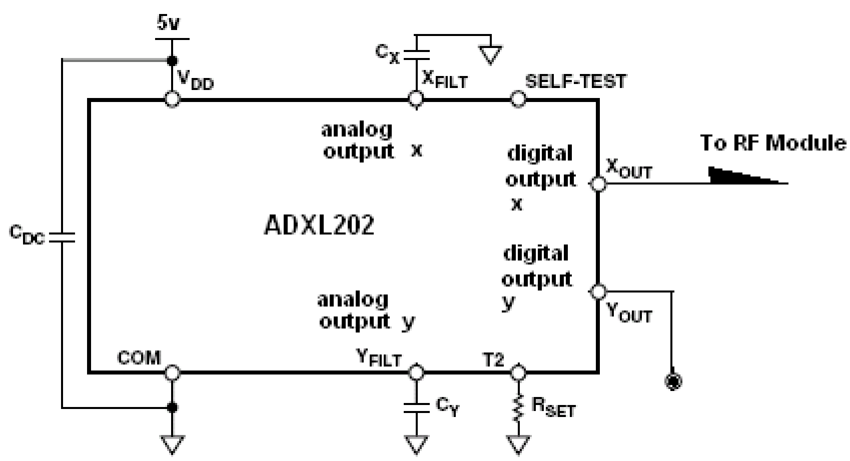

Figure 5: ADXL202 schematic

The respective component values of the ADXL202 schematic are shown in Table 1.

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Table 1: Component values for ADXL202 schematic

Component	Value
R_{SET}(sets duty cycle period)	1MΩ
C_Y(sets y-output bandwidth)	0.1µF
C_X(sets x-output bandwidth)	0.1µF
C_{DC}(decoupling)	0.1µF

3.1.3. Seiko Instruments LCD

The *SII* LCD is a generic 4 x 20 display with onboard character generator and RAM. The 8 bit data interface and 3-bit control interface allows for quick and easy output from a controller such as the ATmega8. The SII LCD is equipped with two identical headers of 16 pins for easy hardware interfacing from all angles. Figure 6 shows the LCD pin out.

PIN FUNCTIONS

No.	No.	Name	Function
1	17	V_{SS}	GND
2	18	V_{CC}	Power supply voltage + 5 V
3	19	V_{LC}	Liquid crystal driving voltage
4	20	RS	L: Instruction code input. H: Data input
5	21	R/W	L: Data write from MPU to LCM. H: Data read from LCM to MPU
6	22	E	Enable
7	23	DB0	Data bus line
8	24	DB1	Data bus line
9	25	DB2	Data bus line
10	26	DB3	Data bus line
11	27	DB4	Data bus line
12	28	DB5	Data bus line
13	29	DB6	Data bus line
14	30	DB7	Data bus line
15	31	V_A*	Anode
16	32	V_C*	Cathode

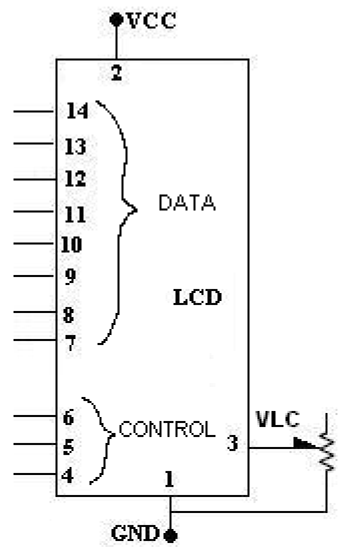

Figure 6: SII LCD pin out

It is important to note than in our implementation we are not using the backlight LED on pin 15 and 16 to reduce the power consumption of the overall unit

3.1.4. Unknown RF Module

The RF module connecting the ankle and display units was taken from the RF module of a remote control car of unknown make. The RF module fulfills the bandwidth and timing requirements of the ADXL202 accelerometer. On the receiver end, it was important to add circuit logic to ensure that the RF output was between 0 and 5V at the input to the ATmega8 microcontroller. The basic RF module is shown in Figure 7.

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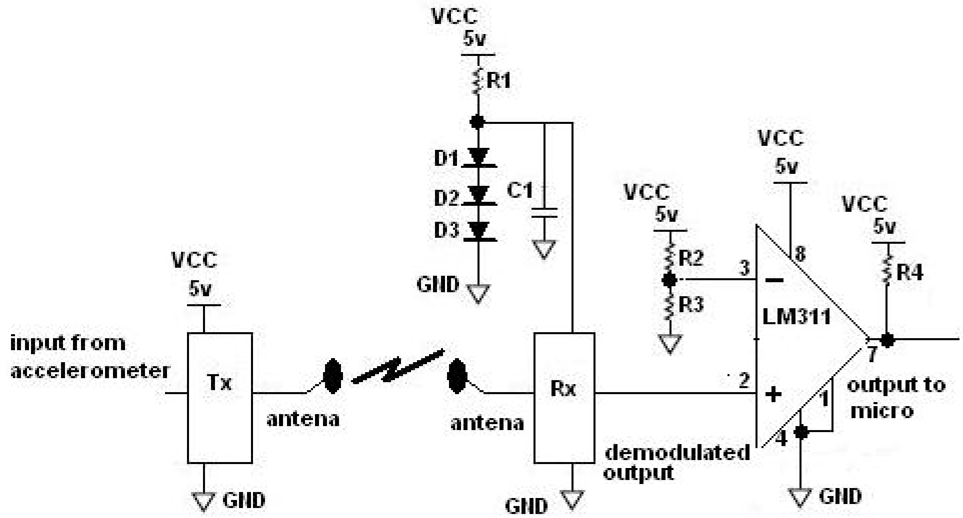

Figure 7: RF module schematic

The respective component values are listed in Table 2.

Table 2: RF module component values

Component	Value
R1	470 Ω
R2	100 kΩ
R3	100 kΩ
R4	10 kΩ
C1 (decoupling)	33 µF

3.1.5. Power Supply

Each section of the BEAM Pedometer system is supplied with 5V regulated from a 9V battery. Figure 8 shows the schematic of the generic power supply used for both the ankle and display units.

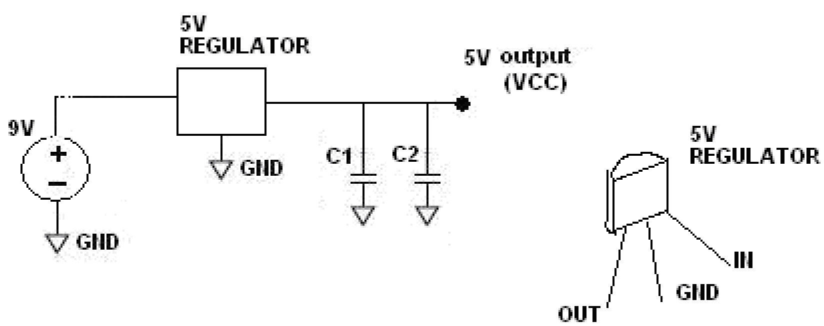

Figure 8: Power supply schematic

The specific component values are shown in Table 3.

Table 3: Power supply component values

Component	Value
C1 (low freq decoupling)	0.1 µF
C2 (high freq decoupling)	33 µF

3.1.6. In-System Programmer

Atmel supplies an in-system programmer, which allows development on a separate development board. The availability of this apparatus allows for the specific feature of upgradeable programs for the user. The in-system programmer is accomplished with a specific 6-pin program header, attaching to specific pre-configured programming pins on the ATmega8. Figure 9 shows this header and its interconnections with the ATmega8.

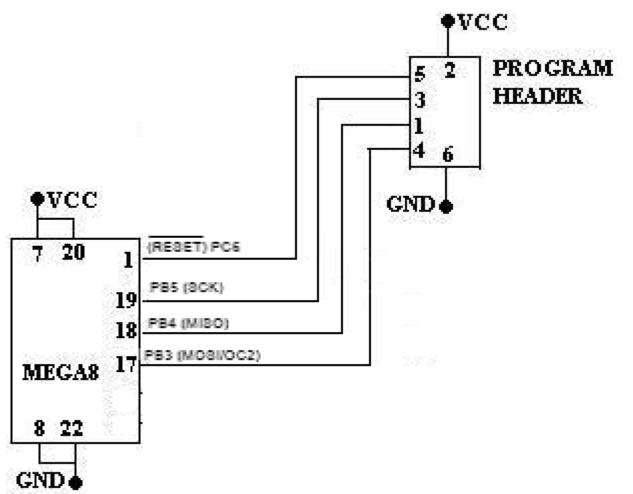

Figure 9: Programmer header schematic

3.2. BEAM Hardware interconnections

The following section shows the entire system in its respective functional blocks and as schematics in Figures 10 and 11.

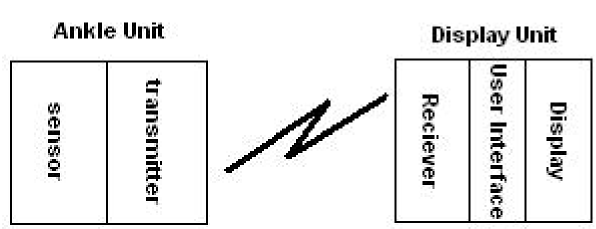

Figure 10: General system block diagram

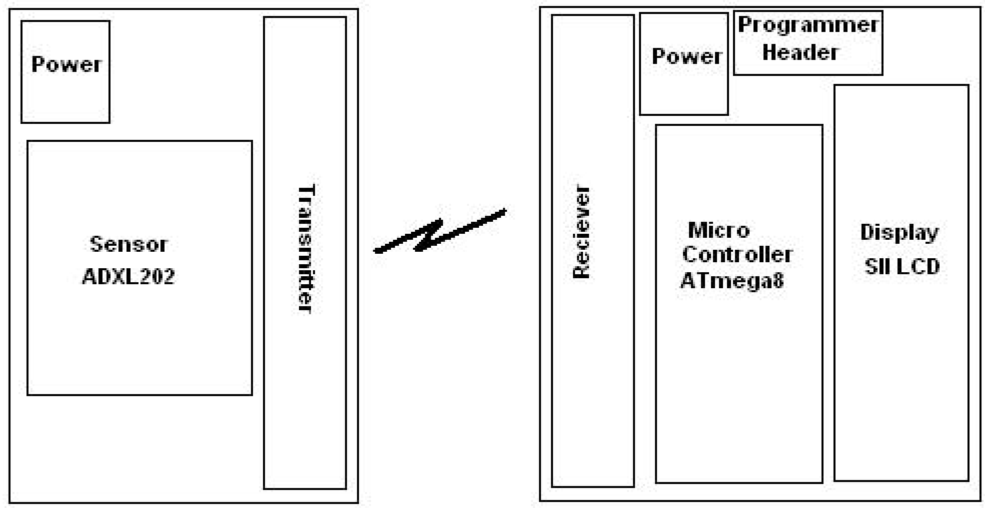

Figure 11: System block diagram

The schematic of the ankle unit is shown in Figure 12.

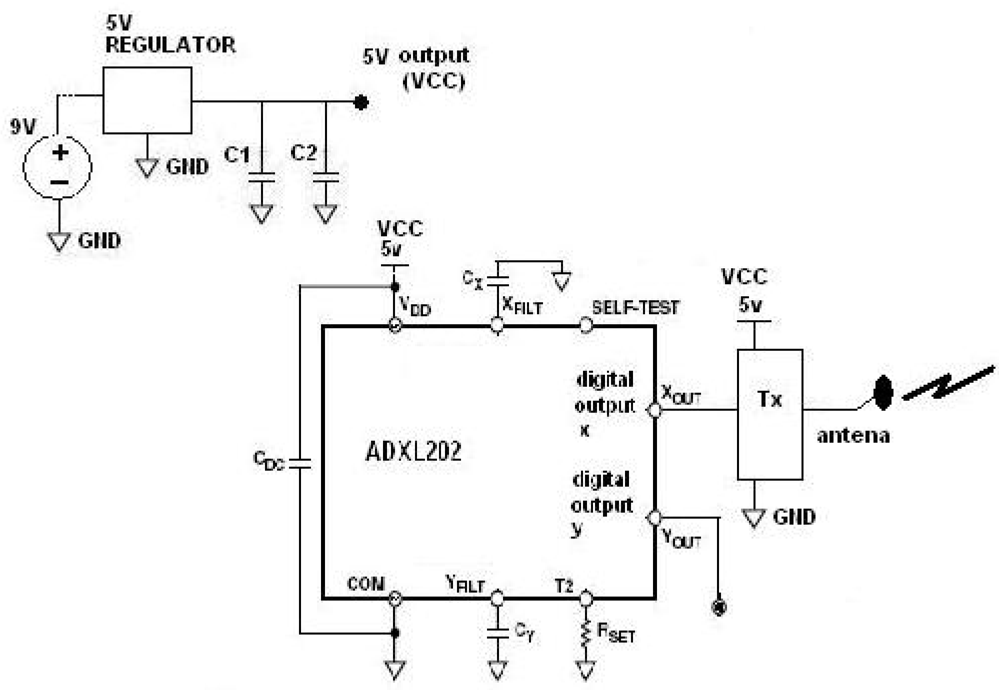

Figure 12: Ankle unit schematic

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The schematic of the display unit is shown in Figure 13.

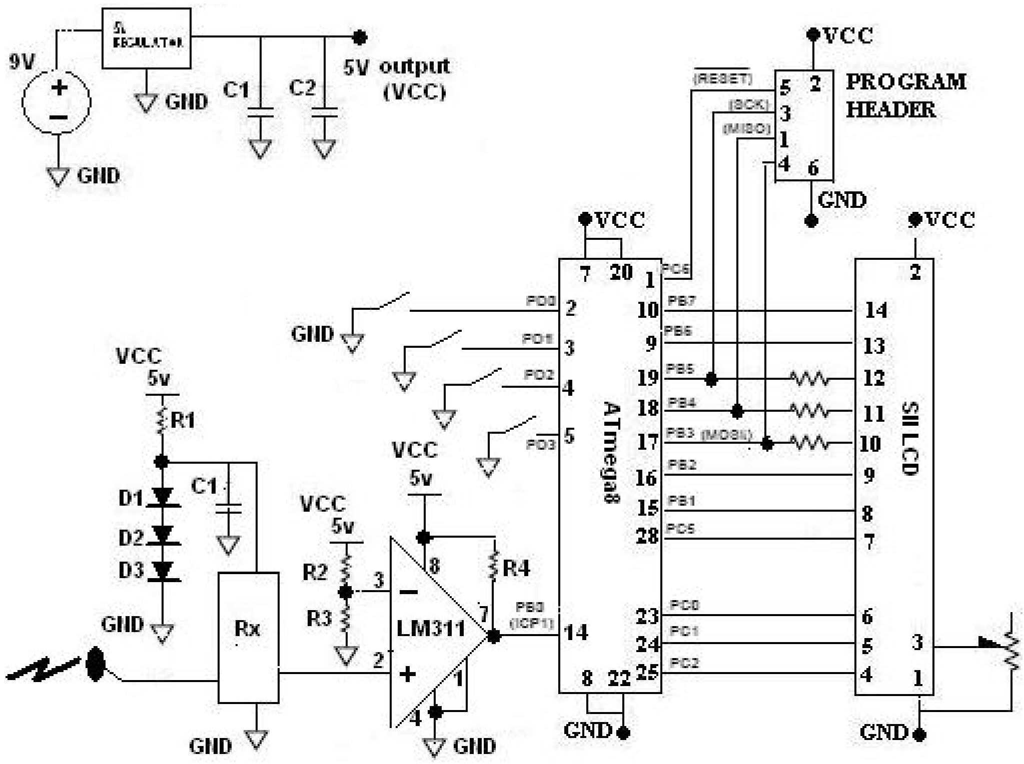


Figure 13: Display unit schematic

Please note that the component values corresponding to the above figures are listed in the previous section and will not be repeated here.

4. System Software

The software involved with the BEAM Pedometer can be divided into four specific sections: the LCD interface, user input control, input capture, and algorithm calculation as seen in Figure 14.

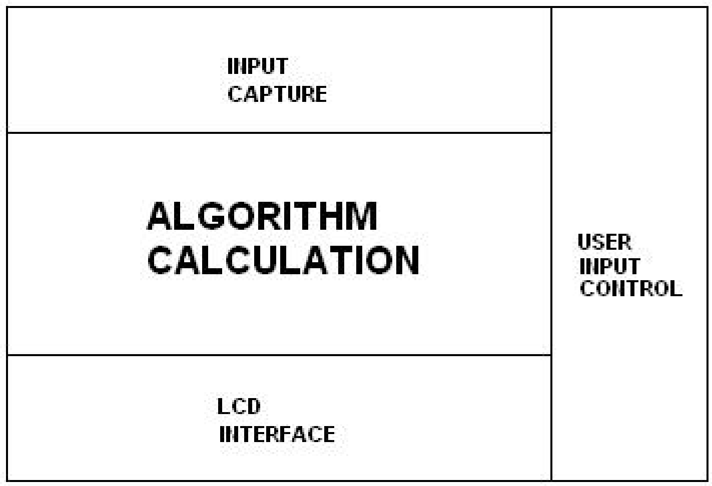


Figure 14: General system software overview

Each subsection is equally important for the functionality of the BEAM Pedometer and will be discussed in the following sections.

4.1. ADXL202 and Atmega8 Interfacing

The ATmega8 and ADXL202 are equipped with many features allowing for easy interfacing. The following section looks at some of the reasons behind various implementation strategies.

4.1.1. Output from Accelerometer

The ADXL202 accelerometer is designed to produce a pulse width modulated signal for easy connection to any microcontroller. Since the output is not being directly fed into the ATmega8 microcontroller, but first through an RF module, there is an induced delay. Since the delay is matched at both the rising and falling edges of the transmitted pulse. Hence, we can assume that the effects are negligible when analyzing the duty cycle and period of the input signal. An example of an ADXL202 output pulse is shown in Figure 15.

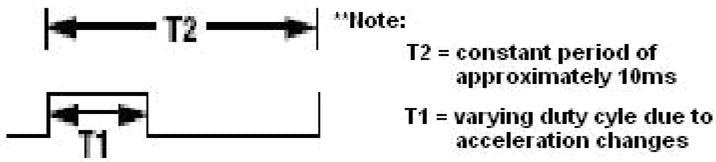


Figure 15: ADXL202 output pulse

4.1.2. Input Capture

Input capture of the pulse width modulated signal is implemented as an interrupt driven event. This method allows the *CPU* to continue processing other instructions while it waits for interrupt events to occur, thus operating in a real-time fashion. Figure 16 shows the interaction of the interrupt driven program and with the other software sections.

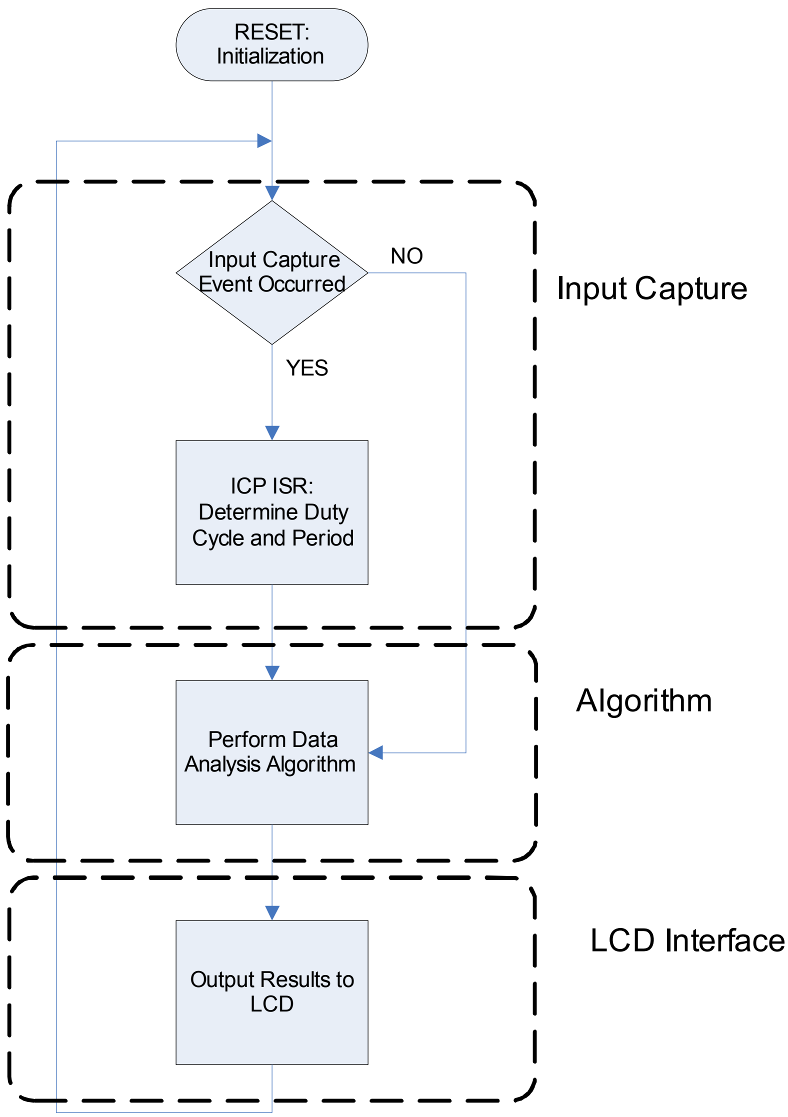


Figure 16: Input capture flow diagram

The *ISR* associated with the input capture event is setup to calculate the times T1 and T2 as outlined in Figure 2, and store the results into the SRAM for later manipulation in the algorithm calculation. The ISR utilizes the 16-bit internal timer of the Atmega8 in order to provide an accurate measure of the times. The time required by ISR must be minimized to ensure that the data can be obtained and analyzed in real-time.

4.2. Distance Measurement Algorithm

The distance accumulation algorithm associated with the BEAM Pedometer is the core of the BEAM Pedometer System. Without this algorithm the BEAM Pedometer is no different from any other already commercially available pedometer. The procedure used to first determine, then implement the algorithm is discussed in the following sections.

4.2.1. Determining an Algorithm

Before it is possible to choose an algorithm it is necessary to first collect data and effectively characterize the output while walking from the ADXL202. This was accomplished using a device (MA40) borrowed from, and modified by MARON Engineering Ltd. for the purpose of data logging. Figure 17 shows the basic block diagram of the system used to log data. The data was then transfered to a spreadsheet for further manipulation.

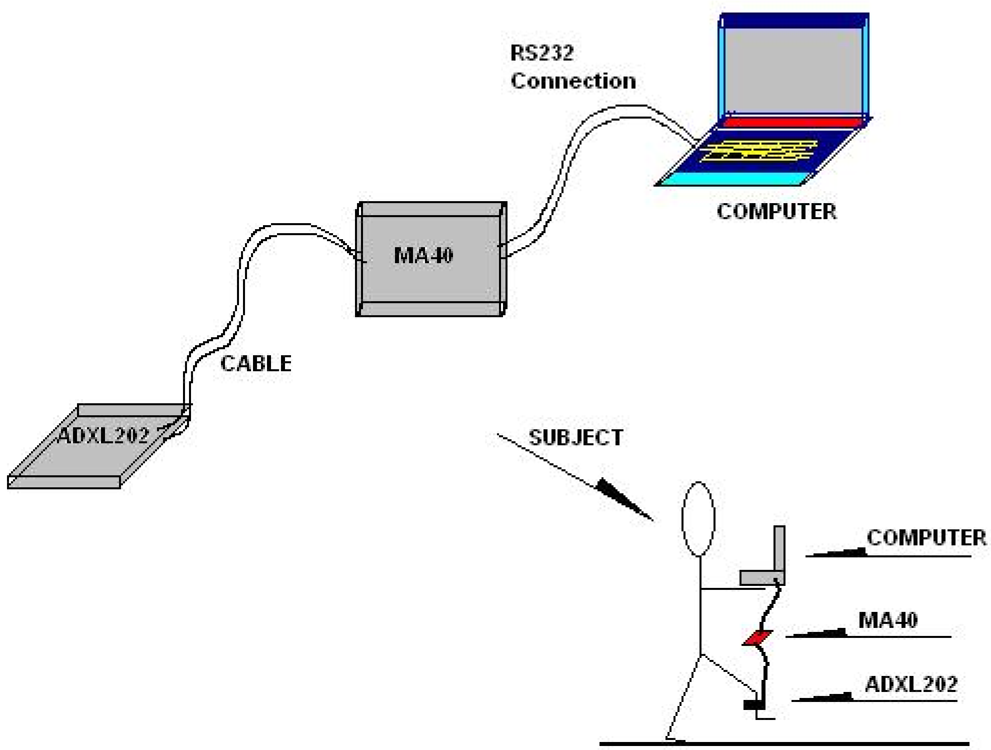
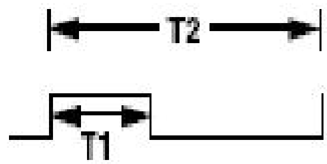


Figure 17: Data logging setup

The duty cycle output from the ADXL202 shown in Figure 15, and again here in Figure 18, results in the collected data format shown in Figure 18.



TIME	$T2_X$	$T1_X$
t_{i-1}	• • •	• • •
t_i	• • •	• • •
t_{i+1}	• • •	• • •
⋮	⋮	⋮

Figure 18: Data from MA40

The resulting acceleration derived over a ten meter distance is shown in Figure 19.

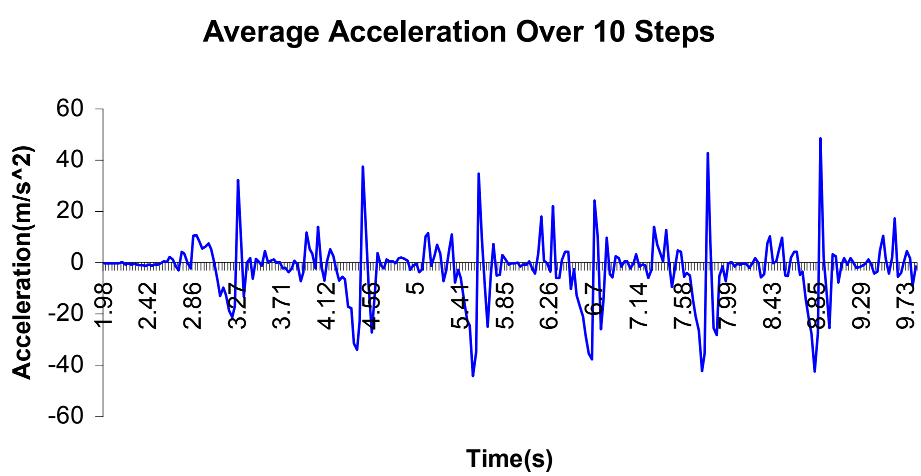


Figure 19: Collected accelerometer data

This data can then be interpolated to formulate a distance-accumulating algorithm. It is important to note that the algorithm is a work in progress and will be updateable through the in-system programmer as the accuracy improves.

4.2.2. Algorithm Implementation

The algorithm calculation section of the main program interprets the instantaneous acceleration sampled by the ADXL202, to provide the total distance a person has walked and the number of steps taken by the individual. The algorithm is designed such that it can calculate these parameters independent of the user's physical characteristics, removing the requirement for user input. The benefit of a dynamic algorithm rather than one based on user stride length is improved accuracy in the results when the user has a non-uniform gait pattern.

The algorithm utilizes the results of distance and velocity under constant acceleration. Since the sampling interval of the acceleration is very small relative to the time to take one step, the assumption of constant acceleration over the sampling interval is valid. Equation 1 and 2 are used to calculate the final velocity and total distance traveled over the sampling time. The initial velocity, v_o, is the final velocity of the previous interval, which implies the need to form an array of acceleration samples.

$$v = a \cdot t + v_0 \tag{2}$$

$$d = 0.5 \cdot a \cdot t^2 + v_0 \cdot t \tag{3}$$

In the case of the pedometer only the axis of acceleration parallel to the plane of motion is of interest in the initial prototype design. With the data for the distance of each sample interval in the axis of motion, basic calculus states that the sum over entire interval distances results in the total distance traveled.

The differentiation of a step is obtained by examining the velocity of a foot over one stride length. The velocity versus time plot in this case would have a shape similar to an inverse parabola. To determine whether a maximum has occurred, a sufficient number of data points need to be compared to determine the trend of the data. This implies that the acceleration array must contain a sufficient number of samples, for the trend to be determined; then every maximum point can then be interpreted as one step. Figure 20 outlines the high-level implementation of the algorithm.

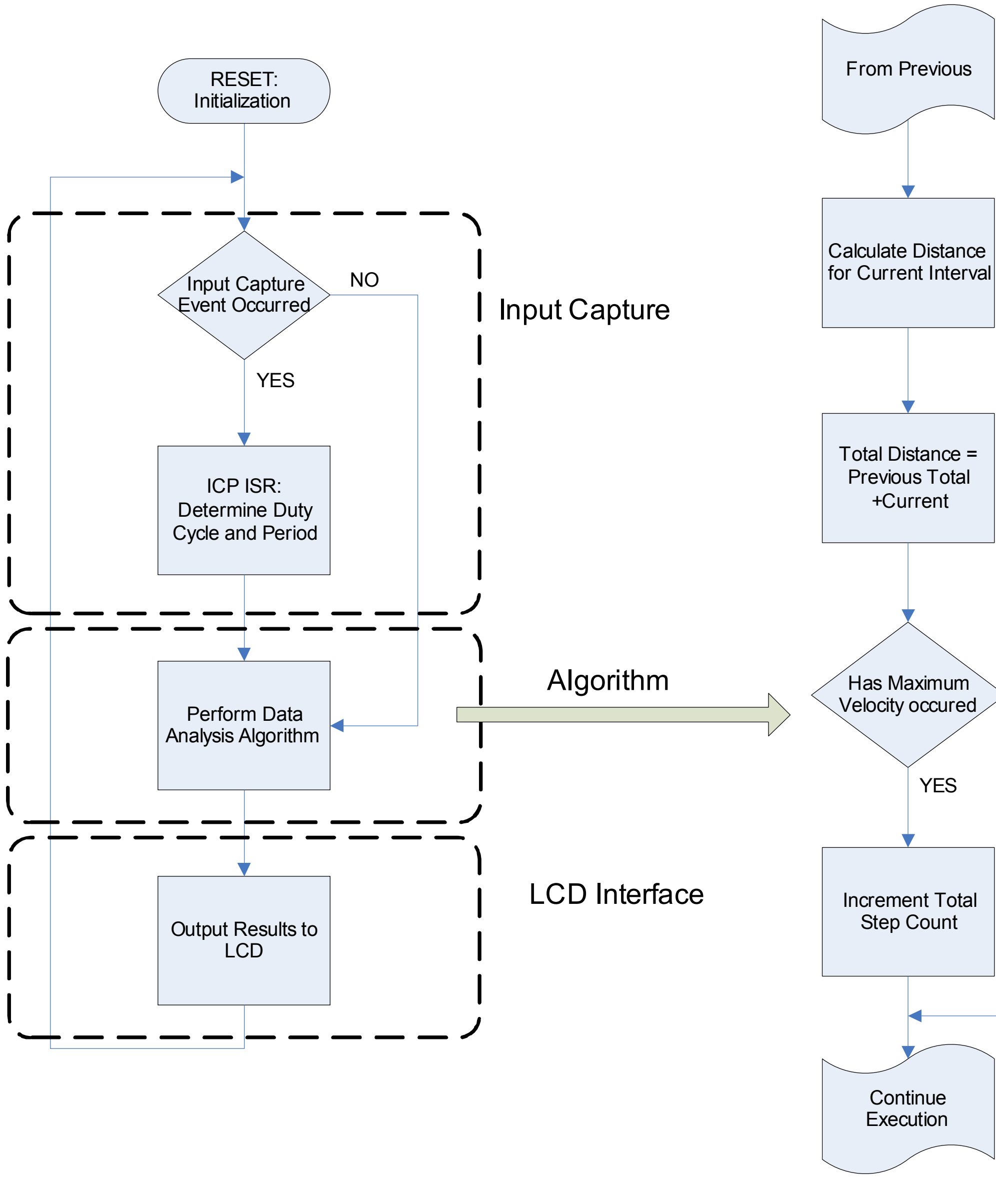


Figure 20: Algorithm flow

4.3. Display Control

The display control provides the user with the information in a viewable and easily understood manner. The LCD contains a lookup table with various ASCII numbers, letters, and symbols corresponding to their binary representation. Since, binary is not a form easily interpreted, conversion of the data from binary to ASCII must be accomplished before outputting to the LCD.

4.3.1. Timing and Sequence of Controls

Data communication between microcontroller and LCD module requires adherence to the communication protocol, outlined in the LCD datasheet [4], to ensure correct transmission and receiving of the data. The implementation of the protocol is outlined in Figure 21.

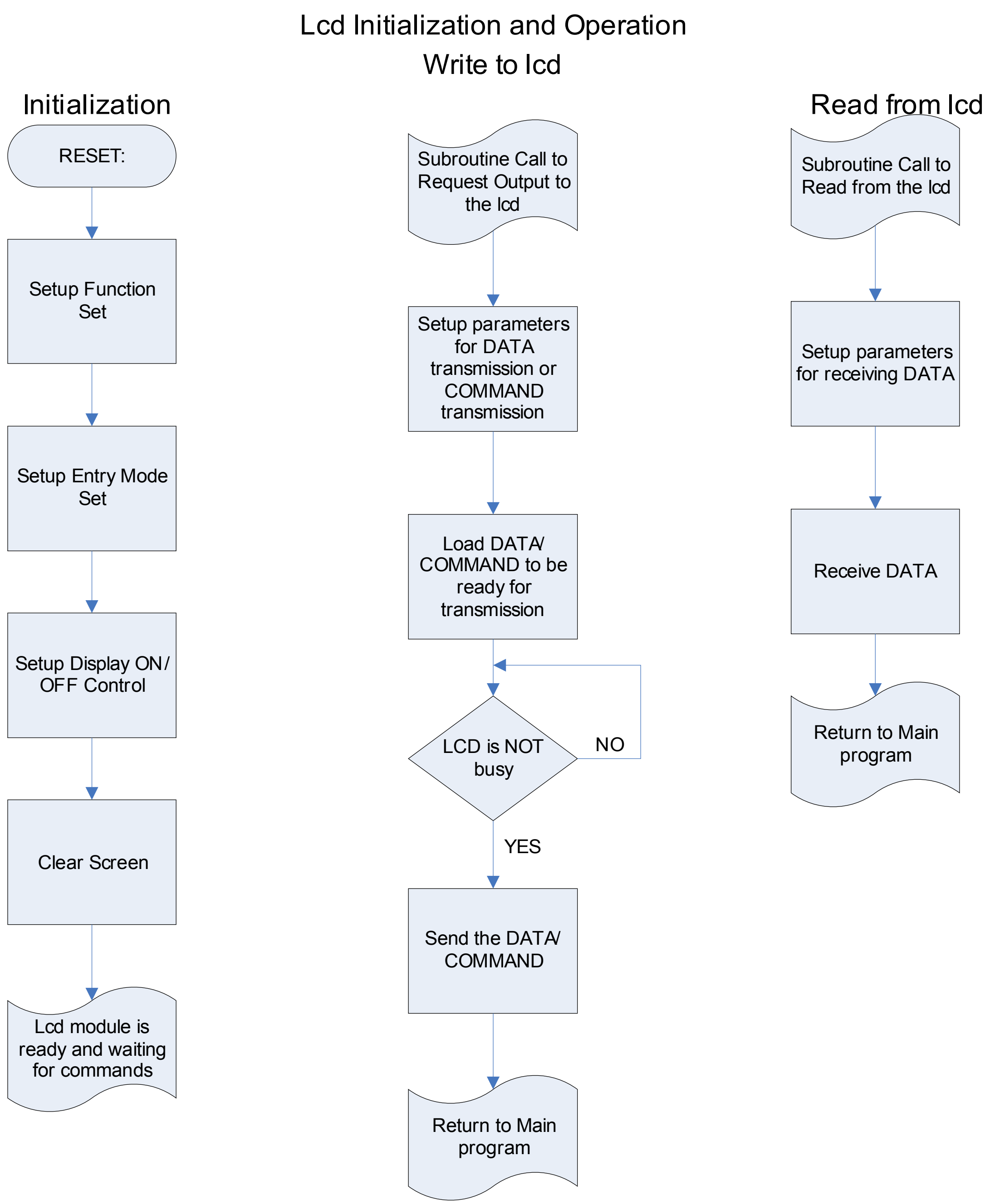


Figure 21: LCD communication procedures

4.4. User Input Control

The user is capable of interacting with the pedometer via four external buttons. The buttons allow the user to start/stop the pedometer from logging, reset the data to zero, and change the display units of the information, between km and miles. The buttons are polled at the start so that the corresponding actions can be carried out in the current execution loop. Figure 22 shows the general operation of the buttons.

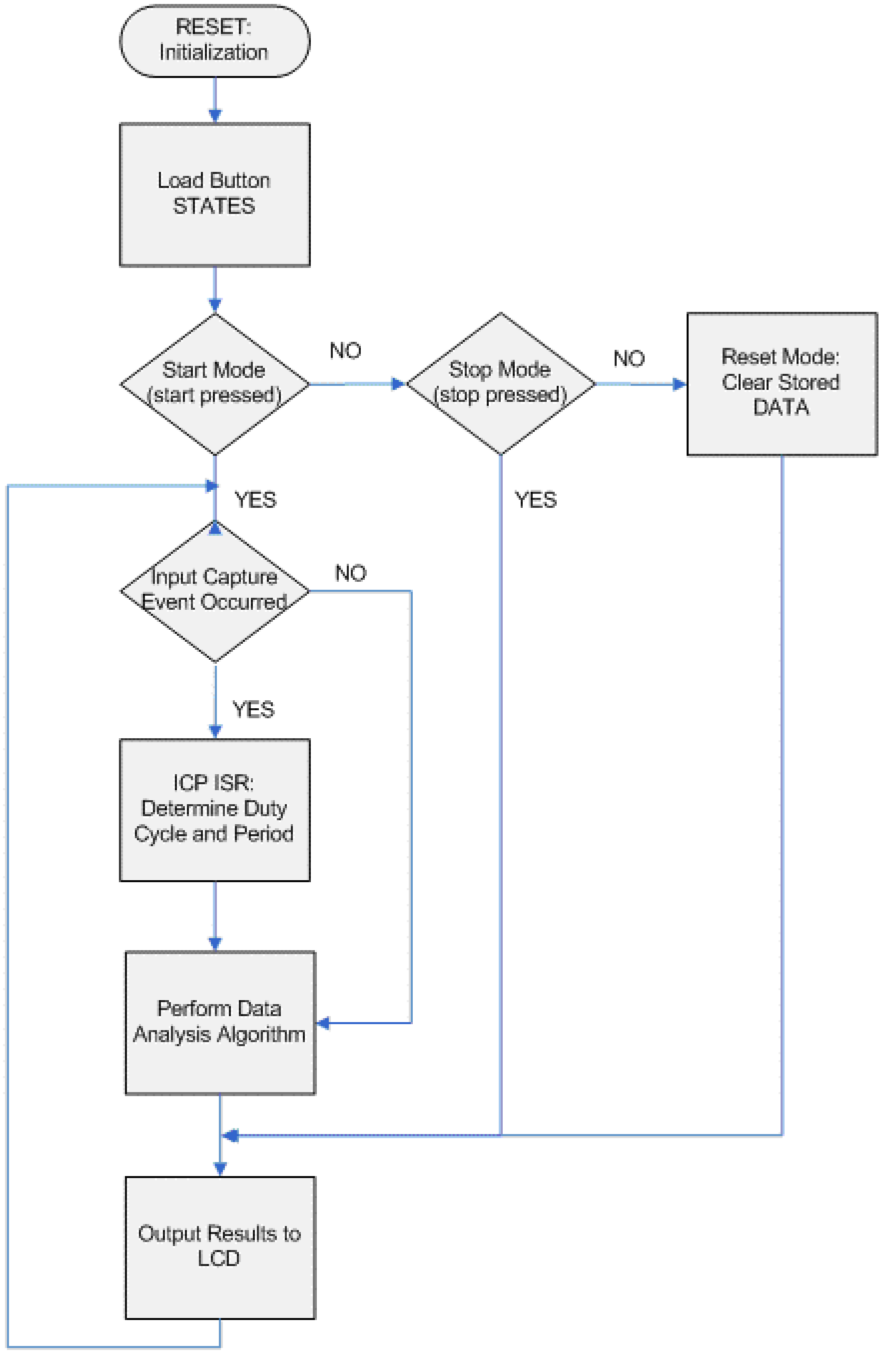


Figure 22: Overall interaction

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5. Test Plan

The following section outlines the method by which we intend to test and characterize the BEAM Pedometer. Testing will focus on power battery life and deterministic accuracy. It is important to note that the tests are designed to prove the functionality of the BEAM Pedometer based on the factors previously described in this document.

5.1. Test Overview

The main functionality of the BEAM Pedometer can be placed into two key categories. The categories are deterministic accuracy of distance traveled in different environments, and battery life over prolonged use. The BEAM Pedometer should behave accurately in all terrain types within an acceptable error of 5 %, while it should have a respective battery life of at least 50 hours of use.

5.2. Testing Strategy

Testing of the BEAM Pedometer will be separated into two distinct sections: Battery Life and Distance Accuracy.

5.2.1. Battery Life

The battery life will be tested by observing several operating factors of the system consisting of LCD intensity, voltage consumption at power supply, and measurement consistency of the distance sensor at varying power levels.

5.2.2. Distance Accuracy

Testing of accuracy will be accomplished by observing the output for several users and comparing it to known distance traveled.

Based on the results of successive tests it will be possible to determine and apply appropriate changes to circuitry and analysis algorithm resulting in an iterative design process to improve the functionality of the BEAM Pedometer.

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6. Conclusion

This document outlined the major design requirements related to the BEAM Pedometer. So far all the hardware components were chosen and integrated. Software flowcharts shown above will allow us to further improve the current software in an organized manner. We are confident that with the outlined design requirements the team BEAM will complete the prototype phase of the project by the April 5th demonstration day.

7. References

[1] ATmega8 - Atmel 2003

[2] Beam Pedometer Functional Specifications Version 1.1 - Beam team

[3] Dual-Axis Accelerometer with Duty Cycle Output - Analog Devices 2000

[4] L2034 – Seiko Instruments Inc. 2002

[5] Liquid Crystal Display Product Catalogue -Seiko Instruments Inc. 2002-2003