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November 1, 2004

Dr. Andrew Rawicz
School of Engineering Science
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Re: ENSC 340 Design Specifications for a Tactile Vision Glove for The Blind

Dear Dr. Rawicz:

The attached document, *Design Specification for a Tactile Vision Glove for The Blind*, outlines our design project for ENSC 340 (Special Project Course). We are in the process of designing and implementing a glove that would inform a visually impaired person, via tactile feedback, of the existence and shape of the nearby obstacles. With the help of our product, the blind person can find his desired path and identify unknown objects.

This Design Specification provides details of implementing all the features and capabilities of the Tactile Vision Glove declared in our functional specification. Included in this document is the complete design elaboration of hardware, assembling, software and user interface corresponding to the proof of concept prototype to be delivered by mid-December, 2004. Because our group will use this document as a reference for design, the sections are fairly detailed. Also included is a test plan to verify the proper functionality of our product.

S3 Technologies consists of three motivated, enthusiastic, had working and talented fourh-year engineering students: Shaun Marlatt (CEO), Sina Afrooze (COO) and Mahmoud-Sam Zahed (CFO). Should you have any questions or concerns, please do not hesitate to contact us at s3tech-ensc@sfu.ca.

Sincerely,

Shaun Marlatt

Shaun Marlatt
President and CEO
S3 Technologies

Enclosure: *Design Specification for a Tactile Vision Glove for The Blind*

Design Specification for a

Tactile Vision Glove for the Blind

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Design Specification
for a Tactile Vision Glove for The Blind

November 1, 2004
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Executive Summary

Increasing number of visually impaired all around the world has encouraged many engineers to take advantage of advances in integrated circuit technology and engineering materials to develop devices that meet the special needs of this large group of people. Tactile Vision Glove is one of the devices that will use recent microelectronics technology to increase the mobility and independence of those who are visually impaired. This device enables the user to detect nearby objects by providing distance and shape information through tactile feedback.

The development of the Tactile Vision Glove will occur in two phases. Phase 1 is the development of the proof of concept device and phase 2 is the development of the production prototype. After completion of the first phase, to be completed by mid December, 2004, the Tactile Feedback Glove will:

- detect objects and give tactile feedback through vibration
- work consistently for several environmental conditions
- have certain user interfaces and several modes

After completion of the second phase, the device will also:

- work consistent under ambient effects and different weather conditions
- have battery life indication and special low battery reaction
- have extra safety and reliability
- be available in different sizes and materials

The development of the proof of concept prototype of the Tactile Vision Glove is being accomplished based on the design specifications discussed in this document.

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Table of Contents

Copyright © 2004, S3 Technologies

List of Figures

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List of Tables

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1 Introduction

The Tactile Vision Glove is an assistive device for the blind that enables them to 'see' remote objects from a distance through touch. The glove helps the blind person to determine the make-up of their relative surroundings, by measuring the distance to nearby objects, then conveys their approximate shape to the blind person through tactile feedback. Using the Tactile Vision Glove, a blind person will be able not only to locate the objects and obstacles and their distance from him/her, but will also sense the rough shape of the object, as if they were actually touching it.

Our project will be developed in a series of stages, beginning with a proof of concept design to be delivered by mid December, 2004. If the proof of concept design proves successful in user tests, work would begin on a production prototype with greater functionality.

1.1 Scope

This document describes the design specifications proposed by engineers at S3 Technologies for the Tactile Vision Glove. The designs are to deliver the functional requirements mentioned in the *Functional Specification for a Tactile Vision Glove*. The scope of this document covers all aspects of the project including: hardware, assembling, software, and user interface. Furthermore, a comprehensive test plan has been included.

The proof-of-concept stage is entirely described in this document. However, since the market will demand more substantial improvements in terms of price and quality many of the requirements are reserved for the production prototype only. Moreover, we expect to gain extensive experience throughout the development of the first version and improve the proposed design accordingly. As a result, any further changes to our functional specifications will require additional changes to this document.

1.2 Intended Audience

Design engineers will use this document to design and assemble components of the Tactile Vision Glove.

Marketing managers will use this document to promote the product in the market and inform the blind of the convenience they can obtain using the Tactile Vision Glove.

Project managers and quality engineers will use this document to ensure that the progress is towards the development objectives and verify that the final product has met the desired specifications.

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1.3 Referenced Documents

[1] Proposal for a Tactile Vision Glove. S3 Technologies.

[2] Functional Specification for a Tactile Vision Glove. S3 Technologies.

[3] Data sheet of Sharp GP2D12

[4] Microchip Technologies Inc. PIC18F2331 Datasheet

2 System Requirements

2.1 System Overview

The Tactile Vision Glove, as the name indicates, is a glove that has several distance sensors and vibrators mounted on it. The sensors are oriented so that when the glove is worn by a blind person, with the hand held in a palm facing forward configuration, the sense of distance between the glove and the target object is accurately conveyed. **Error! Reference source not found.** illustrates a conceptual Tactile Vision Glove, where the sensors and vibrators are located, and how the device is operated. Feedback through the glove about the distance of objects is conveyed through the intensity and frequency of the vibration. With the amount of vibration of each of the vibrators being proportional to the distance measured by the sensors in the palm of the hand, with more vibration conveying closer distance. Through the use of the vibrating transducers, the blind person is able to feel the rough shape of the object or obstacles without actually touching them.

Figure 2.1. Overall structure of the Tactile Vision Glove

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2.2 Physical Design

The physical design of the prototype tactile vision glove must meet several requirements from the functional specification. These requirements are briefly summarized here:

R[3] Ability to feel the environment with fingertips.
R[7,15] Detachable electronics for servicing/cleaning.
R[8] Light weight.
R[13] Electronics isolated from skin.
R[16] Battery power provided through power cable.
R[66] Easy to put on.
R[56] Easily reachable user interface.

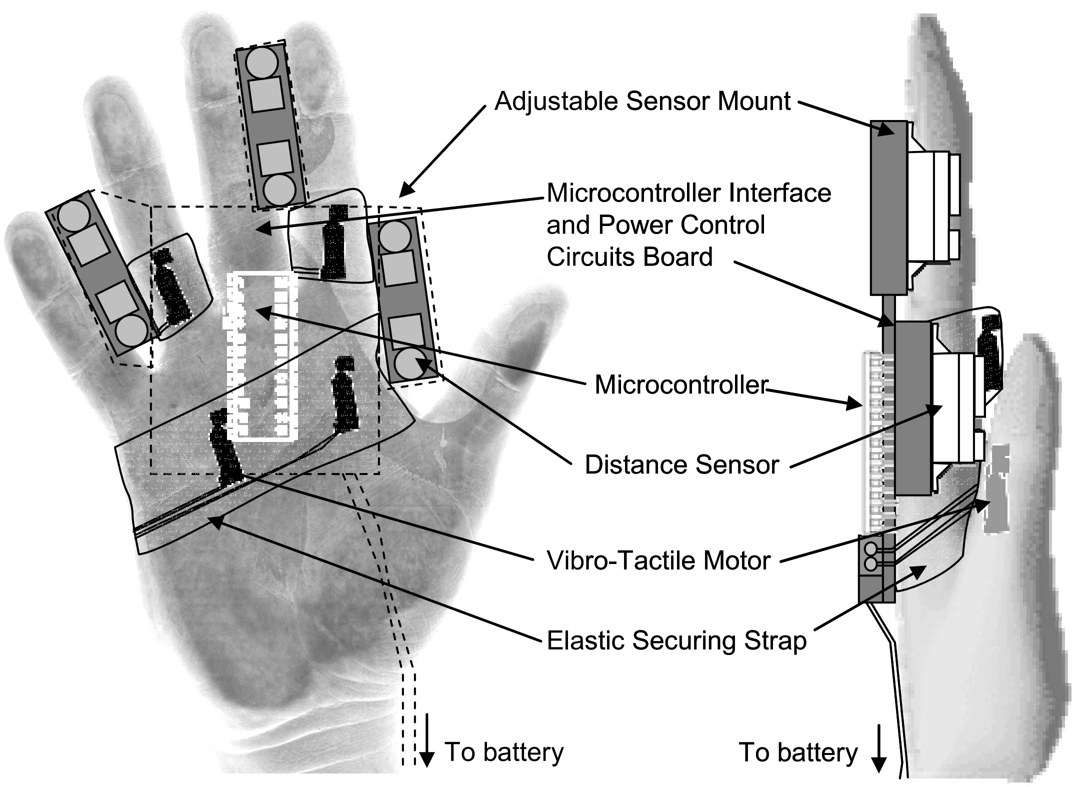

Figure 2.2. Physical placement of components on the hand

The physical layout of the tactile vision glove must conform to the hand of a typical user. In the production version, an actual ergonomic glove-like device will be used that fully encapsulates the electronic components. However, for ease of debugging, the prototype layout, shown in Figure 2.2 is designed so that the components and electronics are easily accessible R[7,15].

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Battery power is provided by a cable that travels from the electronics board on the back of the hand to the battery at the users waist R[16]. The fingertips are also exposed in the prototype design (although this is only a production requirement R[3]). Since the sensors are rigidly mounded to the circuit board on the back of the hand, but not to the fingers, the user will also be able to grasp objects while using the glove although finger positions other than that illustrated in Figure 2.2 may block the sensors. The physical design of the glove also limits the number of electrical components leaving a lightweight package, because the battery sits at the waist R[8]. In the prototype version, the electronics are isolated from direct contact with the skin through insulation on the interconnecting wires as well as a padded insulating layer on the bottom side of the electronics board on the back of the hand R[13]. Finally, two elastic bands across the upper palm and fingers secure the glove to the users hand making it simple to put on R[66].

Not shown in Figure 2.2 is the user interface. The user interface in the prototype version in located on the circuit board on the back of the hand R[56]. The user will be able to easily reach this interface with their other hand. The power switch is located on the battery to prevent accidental deactivation. A speaker, which provides audible error or warning tones, is also located on the circuit board containing the microcontroller.

3 System Hardware

In this section the hardware components of the Tactile Vision Glove are described in details. The main required components are distance measuring sensors, actuators and processor.

3.1 Sensors

The distance measuring sensors must meet certain requirements as outlined in the functional specification document. These requirements are summarized as:

R[11] Harmless Optical emissions
R[20] Good resolution in foggy weather
R[23] Consistent reading for different colors
R[30] Detection Range of 4cm to 150 cm
R[31] Gap detection of 10cm from 100 cm away

The chosen sensors are infrared distance measuring sensors from Sharp Microelectronics. These sensors have low power LED and comply with FCC regulations R[11]. There are two main types of infrared sensors: short range and long range.

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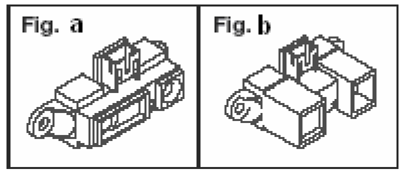

Figure 3.1: Distance Measurement Sensors

These sensors, shown in Figure 3.1, both generate analog output; however they differ in their range of detection. The sensor in Figure 3.1(b) has a long distance measuring range of 15-200 cm while the sensor in Figure 3.1(a) has a short range of 2-30 cm. For the proof of concept device, we only use the wide range sensors due to time and financial limitations. Nevertheless, since the detection ranges of these two kinds of sensors overlap, for the production version of the device, we can attach the two sensors together and use a more complex algorithm in the program to cover the range of 2 cm to 200cm R[30].

The voltage vs. distance characteristic of these sensors was examined for different experimental condition. Three surfaces with different colors, namely white, dark blue and black, were examined for orientation angle of zero degrees (i.e. the surface was perpendicular to the infrared beam). Also the output voltage was measured using the white surface at 30 degrees and 60 degrees orientation angles. The obtained results are as follows:

1. The sensor is not sensitive to colors that are not very dark. For these colors, the output voltage is accurate within 15 cm to 200 cm range with tolerance of 1cm to 5 cm respectively R[23]. In the range of 200 cm to 300 cm, the output voltage is still accurate with tolerance of 5cm to 15 cm respectively. The maximum detectable range is 500 cm and after that, the output voltage is zero.

2. For very dark color surfaces (black), the output is the same until 50cm. Then from 50 cm to 100 cm, the distance appears to be 5 cm to 10 cm closer than the white surface. After 100 cm, the voltage suddenly drops and at about 120 cm the output voltage is zero.

3. For orientation angle of 30 degrees, the output is exactly the same as 0 degrees angle. For 60 degrees, in the range of 15 cm to 50 cm, the distance appears about 5 cm greater comparing with the white sheet at zero degrees. After 50 cm, the output voltage is the same as the white sheet with zero degrees orientation angle R[23].

4. The detection region of the sensor diverges from 3 cm to 5 cm in diameter in the range of 15 cm to 80 cm almost linearly. Then the detection region converges to 3

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cm in diameter at 120 cm distance and then it stays almost the same until 300 cm R[31].

Figure 3.2 shows the graph of output voltage vs. distance for the case of white surface at zero degrees orientation angle. Because the response of the sensor to change in distance is not linear, we need to separate the response curve into several pieces that each one is approximately linear and use this linear approximation to find the distance

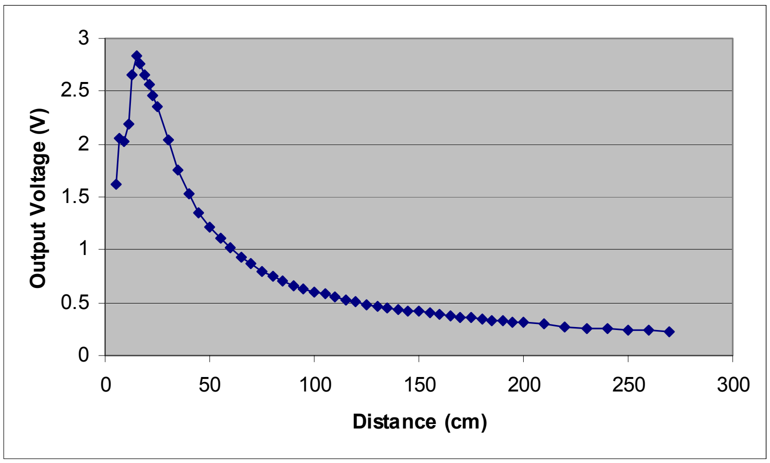

Figure 3.2. Output Voltage vs. Distance for the Infrared Distance Sensor

The exact results of the experiments on the distance sensors can be found in Appendix A.

3.2 Tactile Transducers

One of the more challenging aspects of the tactile vision glove is the generation of meaningful tactile feedback for the user. The usual challenges involved with the generation of tactile information are the high power density required to generate tactile sensation, as well as the bandwidth of the human tactile response.

3.2.1 Requirements

Because the tactile vision glove is battery powered, the method of tactile force generation should use a minimal amount of power, while meeting the requirements outlined in the functional specification document. These relevant functional requirements that are to be satisfied by the tactile transducers summarized here:

R[7] Lightweight.

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R[33] Low Frequency Vibration/Not Audible.
R[34] Vibration Intensity Control.

3.2.2 Design

In order to satisfy the requirements of the functional specification, the Panasonic KHN4NB pager motor was chosen. The specification for this motor is shown in Table 1.

Table 1 KHN4NB Specifications

Working Voltage (V)	1.1-1.7
Starting Voltage (V)	0.5
Starting Current (mA):	125
Rated Voltage (V):	1.25
Rated Load Speed (r/min):	9,700
Rated Current (mA):	95
Weight (g):	.59
Vibration (N):	.68

The motors are also characterized by quick response, quite operation R[33] and long life making them ideal for our application. In addition the KHN4NB is a very compact package with a diameter of 4mm and total length of 16.5mm. Several of these motors easily fit on the hand. The light weight of the motors also lowers the total weight of the tactile vision glove R[7].

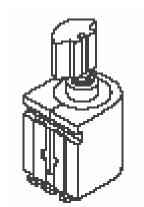

Figure 3.3: Panasonic KHN4NB Pager Motor

3.2.3 PWM Power Control

By using pulse width modulation (PWM) the control circuitry for the power intensity control R[34] of the pager motors is greatly simplified. Many microcontrollers have PWM capabilities so the programming task of motor control is also simplified by this choice. In essence, the use of pulse width modulation controls the power to the motor by varying the width of digital pulses on a square wave carrier with a fixed period. The

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power supplied to the pager motors is then proportional to the currently selected duty-cycle, which is given by the following equation:

$$duty\_cycle = \frac{Pulse\_width}{PWM\_Period} \times 100\%$$

The use of PWM greatly simplifies the design because:

a. PWM functionality is provided in the microcontroller.
b. PWM allows the use of a fixed reference voltage.

Figure 3.4 illustrates a typical proportional voltage control circuit for PWM. The power amplifier stage provides a low impedance output for the motor, while the feedback loop facilitates proportional voltage control.

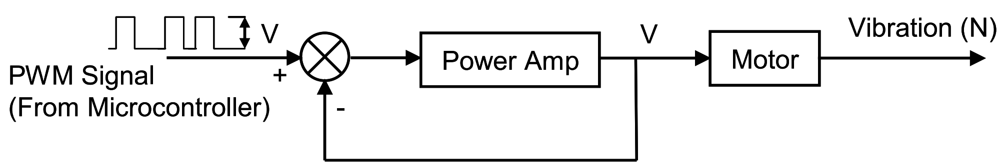

Figure 3.4. Amplification of PWM signal for direct motor drive from the microcontroller. The feedback loop provides proportional voltage control.

In Figure 3.5, the power amplifier stage could be implemented with a single chip such as the TLV4112 general purpose high power op-amp (Figure 3.5).

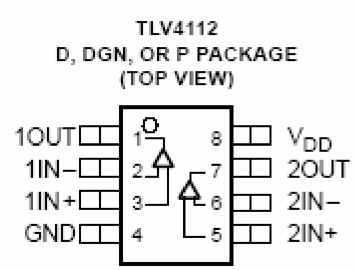

Figure 3.5 TLV4112 General purpose high power op-amp 8 pin PDIP package.

The TLV4112 is capable of supplying in excess of 300 mA per channel, which more than satisfies the power requirements of the motors. It also operates at low supply voltages of 3-6 V on single side rail (VDD) so it is also compatible with the voltage supplied by the battery powering the glove. Also, because there are 2 amplifiers per chip, only 2 of these chips are required to power all the pager motors, saving precious space. The TLV4112 is also relatively cheap at approximately $3 per chip.

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3.2.4 Noise Control

Because the motor is an inductive load, the sudden changes in signal voltage inherent in PWM control will result large voltage spikes on the order of 100V. To prevent damage to the microcontroller PWM output pins it is necessary to provide either isolation through an optocoupler at the microcontroller output or low pass filtering on the power amplifier output before the signal is sent to the motor. Either solution will be sufficient to protect the PWM output pins.

3.2.5 PWM Software Implementation

The basic stages of initializing and generating a PWM signal using a microcontroller with PWM hardware are as follows:

1. Set PWM carrier frequency.
2. Set PWM on time (Sets the Duty Cycle).
3. Choose Pin to send PWM output to – on microcontrollers with multi-channel PWM capability.
4. Enable PWM timer.
5. Enable on chip PWM.

Once the PWM is initialized, the duty cycle is controlled by modifying the PWM on time (stage 2).

3.3 Microcontroller

With three sensors, four actuators and five interface buttons on the glove, we need a processor with 5 input pins, 7 output pins and 4 A/D channels. A good choice for our application would be PIC18F2331. There is a speed requirement for the processor in the functional specification of the device in R[35] that needs the response time of the system to be less than 100ms. To fulfill this requirement, this processor has high process speed guaranteed by a 40 MHz crystal, high speed 5 channels A/D and 14 bit power control PWM module that all meet our requirements.

3.4 Circuit Connections

The circuit diagram of the interconnections between sensors, actuators and processor is shown in Figure 3.6. The heart of the system is PIC18F2331 microprocessor that controls the operation of individual components in the circuit.

To use the sensors and motors selectively, we use transistor-based switches connected to the microcontroller, labeled in red in Figure 3.6. Each sensor's input is connected to one of the output pins of the microcontroller by means a switch that supplies 6 Volts to the

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sensor when the corresponding output pin of the microcontroller is high. The outputs of the sensors are connected to the A/D channels directly.

The actuators are also connected to the output pins of the microcontroller through a switch that provides them with a pulse-width-modulated (PWM) voltage supply with amplitude of 2 volts.

Three Buttons located on the glove give the user the ability to switch between operating modes of the device (differential or absolute mode), intensity mode of vibration (Normal and Low Intensity) and power mode (Normal and Low Power mode). Two other buttons allow user to set the maximum amount of vibration intensity. These buttons are digital switches that are connected to the input pins of the microcontroller.

The battery is connected to voltage regulators to divide the power between various components. The battery is also connected directly to an A/D channel of the microcontroller and the controller monitors its output voltage periodically to assure there is enough power supplied to circuit components.

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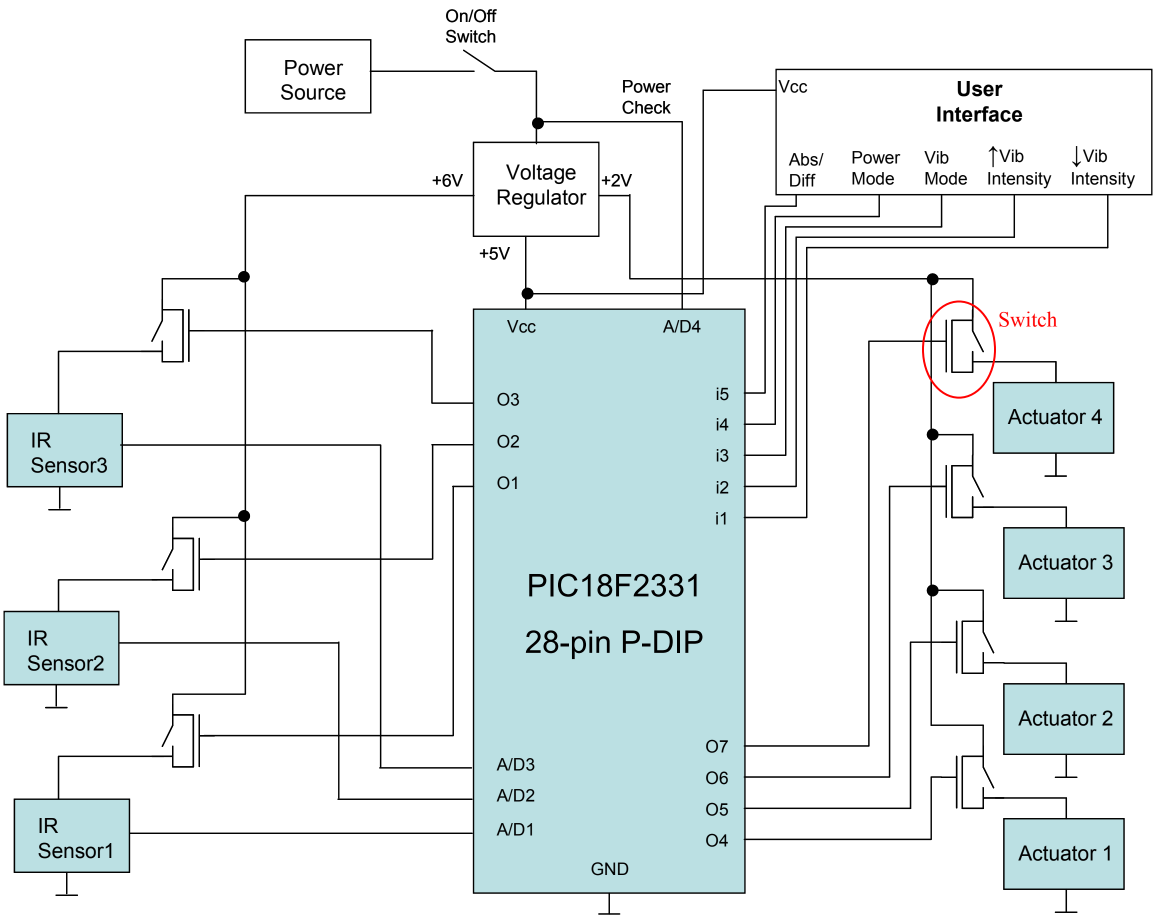

Figure 3.6. Block diagram of the circuit configuration

3.5 Power Supply

We need three different supply conditions to run the sensors, motors and the microcontroller. Each of the devices requires a different combination of voltage and current supply. Consequently, we decided to use a single battery and divide up its power by voltage regulators to satisfy this diverse power requirement. The regulator for each device should fulfill the corresponding current and voltage requirements. Table 1 summarizes power requirements.

Table 1- Power Consumption Summary

Module	Voltage	Nominal Current Draw
PIC18F2331	5 V	40 = 25 mA + 15mA (I/O ports)
Sensors	6 V	50 mA
Motors	2 V	95 mA × 4 = 380 mA

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A simple line regulating circuit can be used to provide 5 and 6 Volts rails. The standard 7805 and 7806 regulators are selected for the microcontroller and sensors respectively. With the use of a 9 Volts Lithium Ion battery, we can easily step down the voltage to the required 5 or 6 Volts. Moreover, these regulators can provide an output current in the order of 500mA which is well above our requirements. A sample test circuit configuration is shown in Figure 3.7. The capacitors are to filter and bypass so that an improved regulation can be achieved.

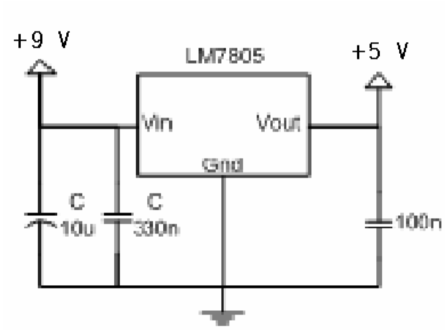

Figure 3.7: Power Regulator Circuit

As observed in Table 1, the motors would consume a high amount of current. However, it should be noted that we use pulse width modulation to run the motors. If we assume that on average the duty cycle of each vibrator when vibrating is about 50%, then its power consumption will be one halved. Also it must be noted that when device is in differential operation mode, on average 80% of the time the vibrators are off. Therefore the time average power consumption will be about *20% * 50% * IV* which is equal to approximately 20mw for each vibrator.

We decided to use a simple voltage divider fed into a high current Op-amp used as a voltage buffer to provide the requirements for the motors.

4 Software Algorithm Implementation

One of the major design issues in the development of Tactile Vision Glove is to come up with a fast and efficient algorithm that has fast response time. There are certain requirements in the functional specification document that must be fulfilled in the algorithm implementation. These requirements are summarized below:

R[34] Ability to set maximum Vibration Intensity
R[35] Short Response time (less than 100ms)
R[36] Audible Feedback

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R[37] to R[50] requirements for different modes of the device
R[58] Ability to set maximum vibration intensity

In this section we describe the algorithm that will be implemented in the microcontroller using C language programming.

The complete flow chart of the system algorithm can be found in 0Appendix B. The flowchart has a simple and efficient basic that can be summarized in following sequences:

1. Turn one of the sensors on.
2. Turn the timer on for 50 ms (This is the start up time for the sensor) R[35].
3. Check for user inputs and perform proper action for each input R[37 to 50].
4. If the timer over flow flag is not set, go to step 3, else go to next step.
5. Read the output of the sensor through A/D.
6. Turn the sensor off and turn next sensor on.
7. Turn the timer on for 50 ms.
8. Adjust the vibration of vibrators according to the new value read from the sensor.
9. Go to step 3.

Since the power supply of the product is a battery, we should try to minimize power consumption as much as possible and avoid frequent charging or replacing of the battery. As a result, we use the microcontroller and additional circuit to switch the power between the three sensors in a round-robin fashion and keep only one of them on at a time, which can be noticed in the above listed algorithm sequence. Therefore, after the first sensor is read, it is turned off and the second sensor is turned on to collect data and so on.

After turning on a sensor, a timer is turned on to count for 50 ms time space. This amount of time allows the sensor to stabilize and output a reliable value R[35].

There are two major blocks in the above list of sequences that need to be further explained, namely Checking for user inputs and Adjusting vibrations.

4.1.1 Checking for User Inputs

This block is composed of four sub blocks that check for five buttons that can be pressed by the user.

4.1.1.1 Operation Mode Button

In this block, the operating mode of the device is switched between absolute mode and relative mode with each button press. The action taken in this block is setting a variable and giving an audio signal. The variable is then checked by the vibration adjustment

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block to know what operation mode the device is in R[39 to 42]. An audio signal feedback is given to the user to indicate the operation mode change R[36].

4.1.1.2 Power Mode Button

This block is very similar to the one mentioned in 4.1.1.1 above. In this block a variable indicating the power mode of the system is switched between Normal and Low Power. When the power mode is switched from Normal to Low Power mode, as stated in the *Functional Specification for a Tactile Vision Glove*, the device has to switch to differential mode and low intensity mode. These two actions are done through setting corresponding variables that are then used in vibration adjustment block R[45 to R50]. Again, as an audio feedback to the user generated to indicate the power mode change R[36].

4.1.1.3 Intensity Mode Button R

This block is again very similar to the one mentioned in 4.1.1.1. The value of the variable corresponding to the intensity mode switched between Normal and Low Intensity with each button press R[43 to R44]. An audio feedback is given to the user indicating the mode change R[36].

4.1.1.4 Maximum Intensity Control Buttons

This block increments or decrements the variable indicating the maximum intensity value by one each time that the button is pressed or every 200 ms if the button is pressed and hold down. After each increment, it sets the vibration of all of the vibrators to maximum value so that the user can feel the maximum intensity. When the button is released, the vibrators go back to previous operation mode R[58].

4.1.2 Adjusting Vibrations

This block uses the values of the three sensors, the operation mode variable, and intensity mode variable to calculate the vibration intensity of each of the four vibrators. It first uses the voltage reading of the sensor and piecewise linearization approximation of the voltage vs. distance characteristic of the sensor to calculate the distance measured by the sensor. Then it linearly interpolates between the three distances measured by sensors to calculate the approximate distance of outside objects from each of the four vibrators.

If the system in operating in absolute mode, it calculates the vibration intensity of each vibrating by linearly interpolating between maximum intensity for 15 cm distance and no intensity for 500 cm distance.

If the system is in differential operation mode, it first updates the average value of distances for three sensors. It then calculates the difference between the distance

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calculated for each vibrator with the average value (vibrator – average), and uses this difference to calculate the intensity of that vibrator accordingly.

If the intensity mode is set to Reduced Intensity, it scales the intensity of all of the vibrators. Then it sets the duty cycle in PMW for each vibrator to achieve the calculated vibration intensity for that vibrator.

5 Test Plan

Each of the major components will be tested and after verification of the proper operation we test the whole product.

5.1 Hardware Test Plan

The testing of the hardware components started with ordering a few samples of the proposed components in the first month of the semester. We tested the distance measuring sensor for its output at different distances in different conditions explained above. The response of the vibrators was also tested using different input voltages and various PWM signals.

The rest of the hardware test plan is left for the final assembled prototype.

5.1.1 Power Supply Test Plan

Because three different voltage levels will be used to power the different components in the device, it is important to maintain consistent and uniform power. The power that will feed the microprocessor, the Sensors and the actuators will be fully tested to make sure that the power being supplied remains within the specified tolerances under full load conditions (operating in absolute mode with all motors being on) and under idle conditions (the microcontroller is in sleep mode).

5.1.2 Overall System Test Plan

The overall performance of the device should not be changed due to sudden movements or shaking of the hand. The glove should be tested and it should be verified that all the connections are functioning properly under normal movements of the hand.

5.2 Software Test Plan

The proper operation of our algorithm is tested in different situation to ensure every specification of the algorithm is implemented correctly.

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5.2.1 Feeling of Edge Test Plan

We try to detect the edge of several objects and assure that the interpolation of the three sensors to the four vibrators is correct and the realistic sense of touching an edge is transferred to the user.

5.2.2 Mapping Test Plan

We test the mapping between the distance and vibration intensity to ensure that the system uses correct mapping algorithm. More specifically, we set the distance to 50 cm and 100 cm and verify that the vibration feeling is in one-to-two ratio.

5.2.3 User Interface Test Plan

The buttons located on the glove will be tested to avoid any faulty operation and assure proper response with unnoticeable delay (maximum 200ms).

6 Conclusion

This document has outlined the design specification for the proof-of-concept Tactile Vision Glove, exclusively. We are scheduled to deliver the outlined specifications by mid December, 2004. The design specifications are well defined and their implementations are planned. As a result, S3 Technologies has a clear path that along with available skills and funding assists us to meet our commitments.

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7 Appendices

Appendix A Distance Sensor Calibration Results

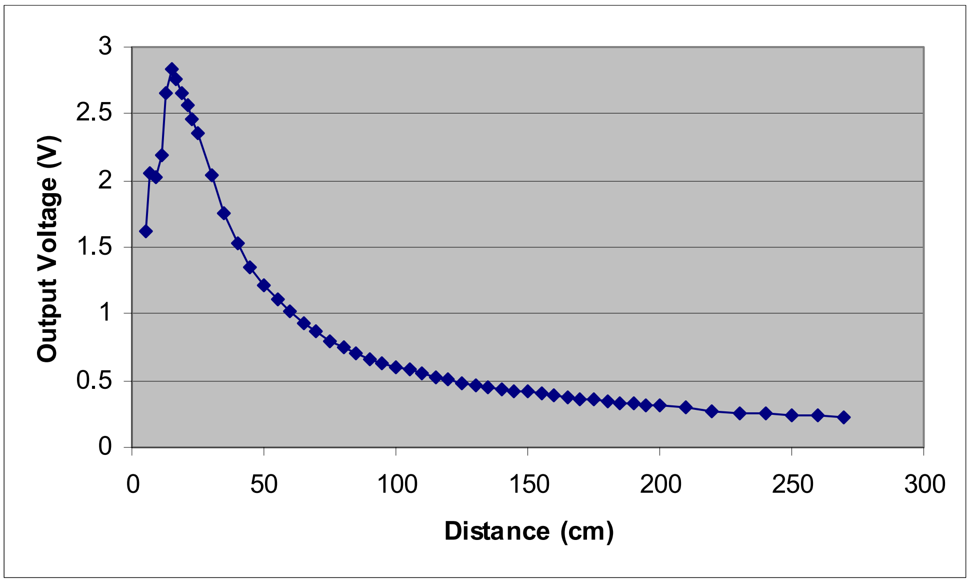

Figure 7.1. Voltage vs. Distance for White sheet at 0 degrees orientation angle

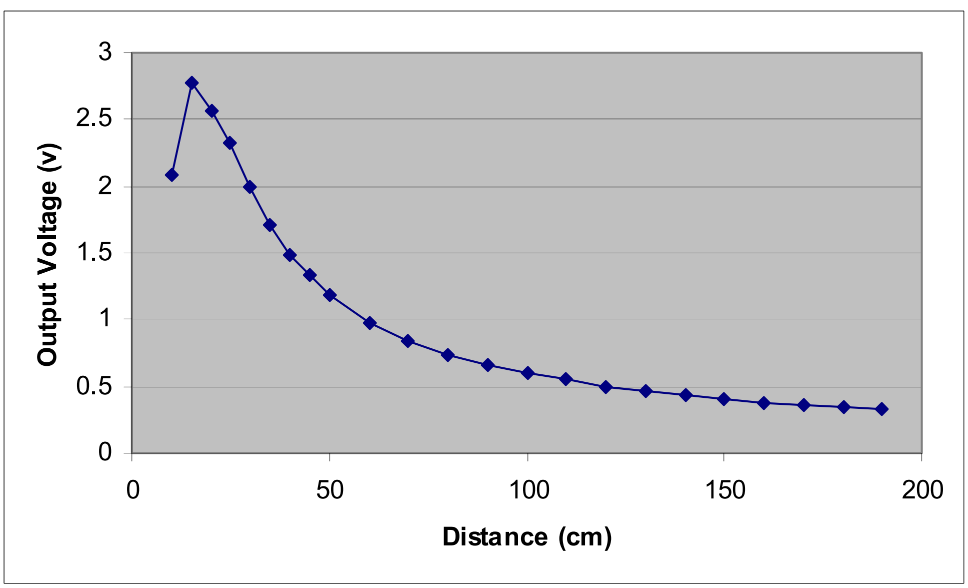

Figure 7.2. Voltage vs. Distance for White sheet at 30 degrees orientation angle

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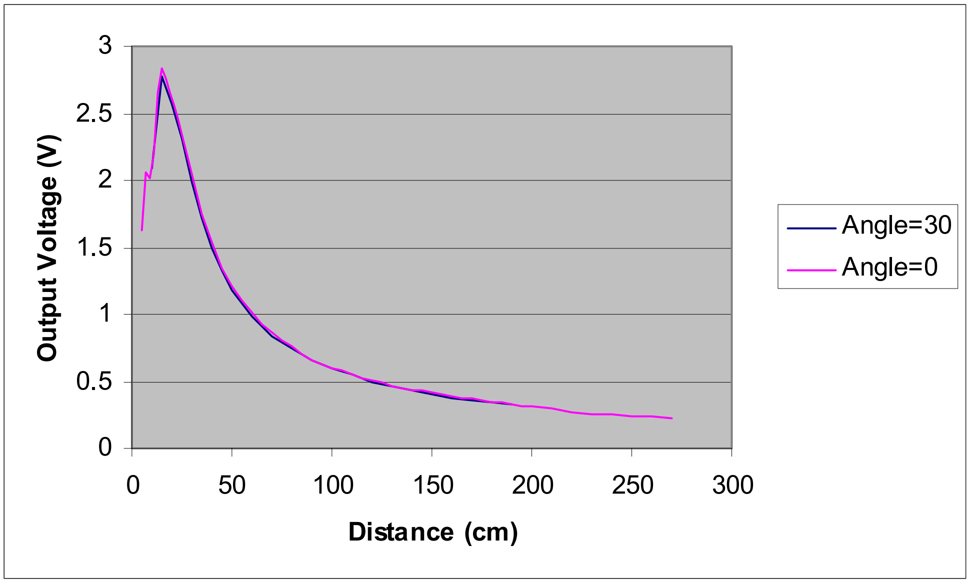

Figure 7.3. Voltage vs. Distance for White sheet at 0 and 30 degrees orientation angle for comparison

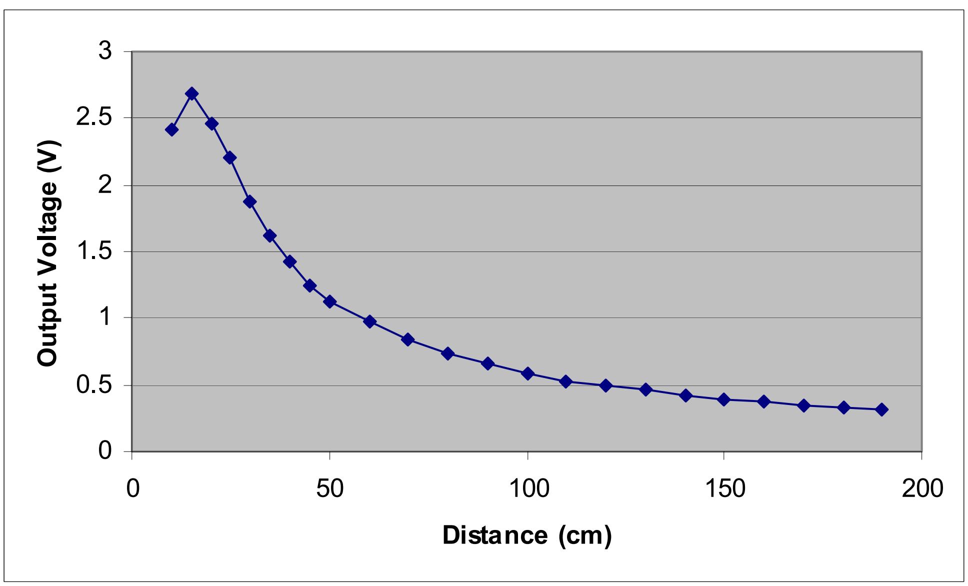

Figure 7.4. Voltage vs. Distance for White sheet at 60 degrees orientation angle

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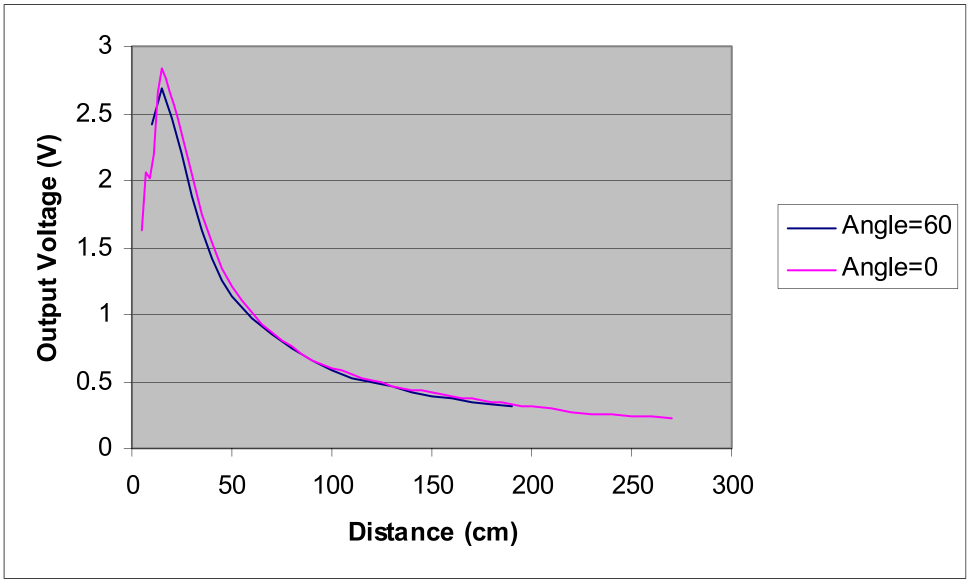

Figure 7.5. Voltage vs. Distance for White sheet at 0 and 60 degrees orientation angle for comparison

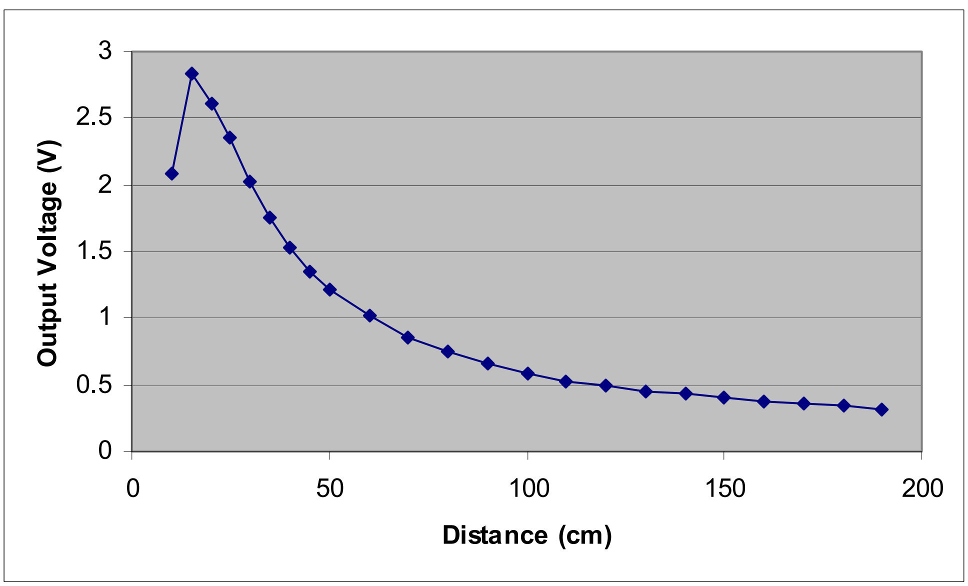

Figure 7.6. Voltage vs. Distance for Blue sheet at 0 degrees orientation angle

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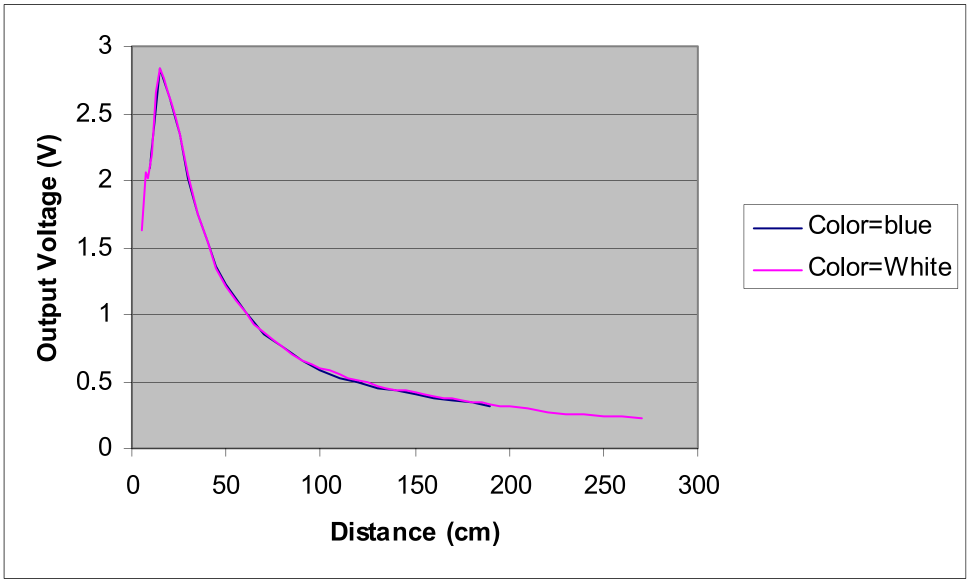

Figure 7.7. Voltage vs. Distance for White and Blue sheets at 0 degrees orientation angle for comparison

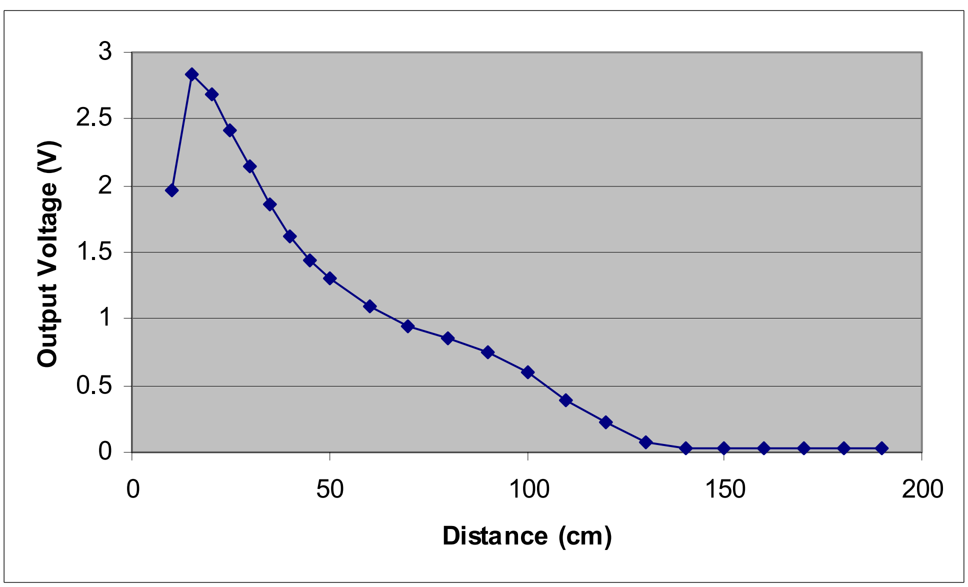

Figure 7.8. Voltage vs. Distance for Black sheet at 0 degrees orientation angle

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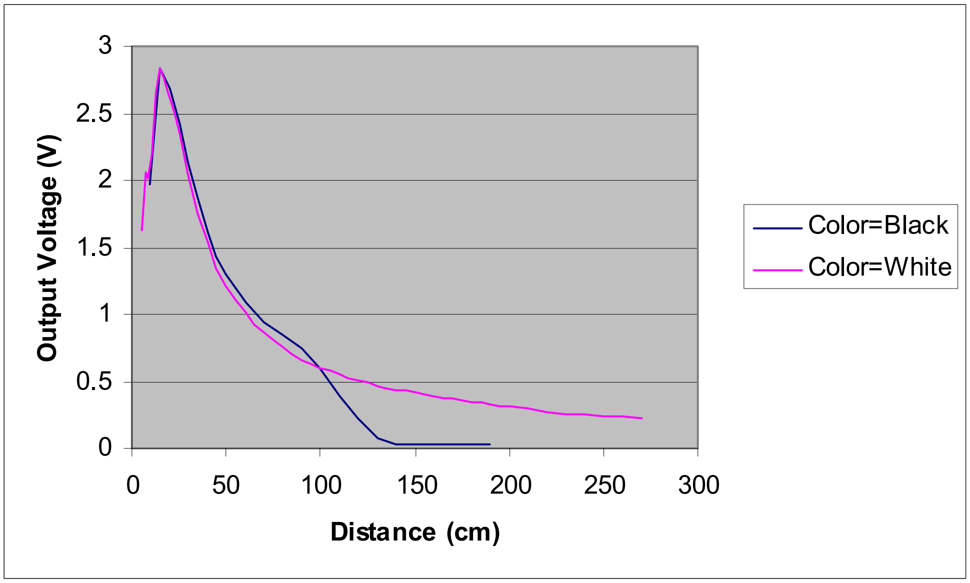

Figure 7.9. Voltage vs. Distance for White and Black sheets at 0 degrees orientation angle for comparison

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Appendix B Flow Chart of the System Algorithm

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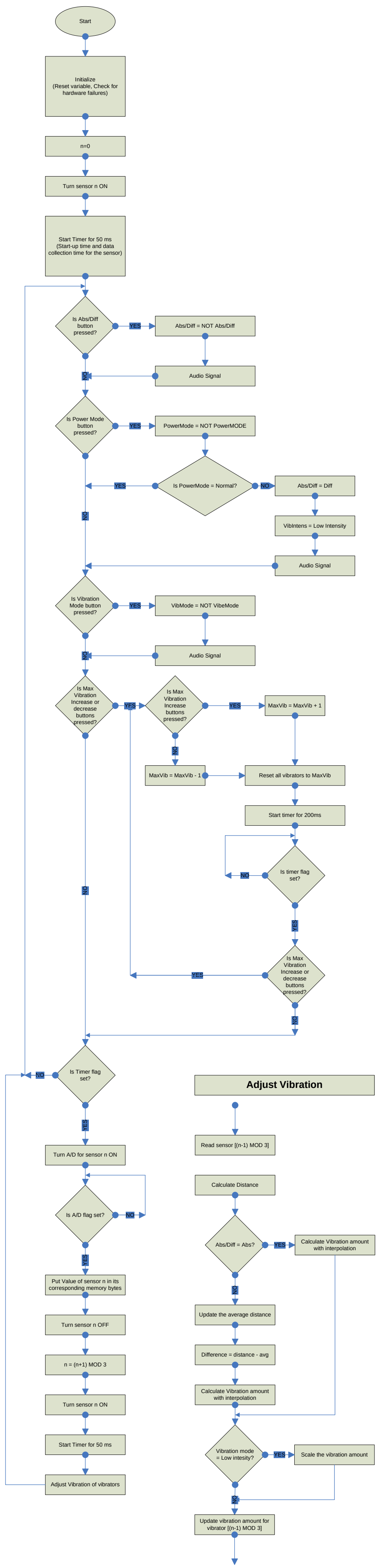

Start
Initialize
(Reset variable, Check for hardware failures)
n=0
Turn sensor n ON
Start Timer for 50 ms
(Start-up time and data collection time for the sensor)
Is Abs/Diff button pressed?
YES
Abs/Diff = NOT Abs/Diff
Audio Signal
NO
Is Power Mode button pressed?
YES
PowerMode = NOT PowerMODE
Is PowerMode = Normal?
YES
NO
Abs/Diff = Diff
VibIntens = Low Intensity
Audio Signal
Is Vibration Mode button pressed?
YES
VibMode = NOT VibeMode
Audio Signal
NO
Is Max Vibration Increase or decrease buttons pressed?
YES
Is Max Vibration Increase buttons pressed?
YES
MaxVib = MaxVib + 1
NO
MaxVib = MaxVib - 1
Reset all vibrators to MaxVib
Start timer for 200ms
Is timer flag set?
NO
YES
Is Max Vibration Increase or decrease buttons pressed?
YES
NO
Is Timer flag set?
NO
YES
Turn A/D for sensor n ON
Is A/D flag set?
NO
YES
Put Value of sensor n in its corresponding memory bytes
Turn sensor n OFF
n = (n+1) MOD 3
Turn sensor n ON
Start Timer for 50 ms
Adjust Vibration of vibrators
Adjust Vibration
Read sensor [(n-1) MOD 3]
Calculate Distance
Abs/Diff = Abs?
YES
Calculate Vibration amount with interpolation
NO
Update the average distance
Difference = distance - avg
Calculate Vibration amount with interpolation
Vibration mode = Low intesity?
YES
Scale the vibration amount
NO
Update vibration amount for vibrator [(n-1) MOD 3]