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**Development of an Augmented Haptic Control for In-Vehicle**

**Law Enforcement Applications**

by

Edward R. Guest III

A Thesis Submitted to the

Graduate Faculty in Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

Department: Electrical and Computer Engineering

Major: Engineering

Specialization: Electrical Engineering

Approved:

Members of Committee:

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In Charge of Work

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For the Major Department

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For the College

Rowan University  
Glassboro, New Jersey  
2003

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## **Abstract**

Typical police vehicles are filled with as much technology as the department can afford. Everything from the newest digital camera system to a simple entertainment radio is within the reach of an officer. Currently, most of these systems are installed without any consideration toward the other systems or the interaction required between the driver and the car. The lack of a systems approach in the installation has spawned a project to look at the safety and overall system installation in the New Jersey State Police vehicles.

The research presented in this thesis suggests consolidation of the various controls into one intuitive controller that employs haptic technologies. A prototype controller was developed using an Immersion rotary haptic knob and a tactile feedback indicator. The parameters of this interaction design were explored through experimentation with a group of subjects using a testing procedure. From this information a prototype controller was developed and optimized to provide better user/vehicle interaction and a cleaner, safer cockpit.

## **Acknowledgements**

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I would also like to thank my family and friends for all of their support throughout my collegiate experience. Without their unending support and the comedic relief provided by certain individuals this experience would not have been nearly as enjoyable.

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# 1. Introduction

Technologies to assist an officer in the line of duty are proliferating in today's public safety arena. Law enforcement sees some of the greatest concentrations of technology. Unfortunately, most technologies are being installed into the cockpits of troop cars without much attention to impact on the interaction between driver and equipment. Worse yet, little attention has been paid to the impact on safety. In the absence of a systems approach to better integrate one technology with another, the technology in vehicle cockpits will become progressively more cluttered as opposed to an efficient suite assisting officers during their daily tours of duty.

Many of today's troop car cockpits have reached a critical limit of space used for technology, further underscoring the need for a redesigned approach. Figure 1 shows two example vehicle cockpits. Both installations are typical for agencies trying to include technology in their vehicles.



**Figure 1 - Examples of vehicle cockpits.**  
The vehicle on the left is from the New Jersey State Police and the vehicle on the right is from the Oklahoma City Police Department.

It is apparent that much of the interior space is occupied by the collection of systems and their interfaces installed into the vehicle. Examples of commonly deployed systems include mobile radios, emergency lighting and sirens, onboard computers, and speed detectors. This is in addition to the standard OEM equipment such as AM/FM radios and climate controls.

Interfaces are problematic for several reasons. The interfaces are space consuming, they require the officer to know where each interface is located, and an officer must be able to use them without significant distraction from driving and other activities. Consolidation of user interfaces would increase the usability and functionality of the technology suite.

A further benefit realized by consolidating interface technologies is the potential for minimizing clutter in the center console area. This could open up a clear path from the driver side to the passenger side, which offers the officer a secondary escape route from the vehicle in the event that one is required.

The availability of an alternate escape route might someday save a life. In 1998, New Jersey Trooper Scott Gonzalez was fatally wounded while trapped in his troop car [1]. The tragedy unfolded after Trooper Gonzalez identified the vehicle of a reported armed individual who was en route to a residence to inflict bodily harm. Gonzalez knew of the individual's violent nature and followed cautiously. After the suspect arrived at the residence, Trooper Gonzalez blocked the driveway to prevent escape, whereupon the suspect rammed Trooper Gonzalez's vehicle pinning the driver's door closed. Gonzalez was fatally shot in his troop car. While it is uncertain if an alternate path out of the

vehicle would have saved Trooper Gonzalez, the strong likelihood provides further impetus to improving the vehicle cockpit to provide enhanced egress.

Recognition of the need for consolidated control and a clean cockpit has not gone unnoticed. Visteon Corporation, an \$18.4 billion dollar Ford spin-off, has created a division specifically for Law Enforcement Vehicle Technology. In October 2002, Visteon introduced TACNET, its aftermarket control system targeted specifically to agencies using the popular Ford Crown Victoria troop car [2]. The system uses a police agency's existing equipment and integrates all of the controls and displays using a touch-screen display with limited voice activation. Figure 2 depicts an image of the TACNET system installed in a vehicle.



Figure 2 – Visteon's TACNET concept cockpit.

### **1.1 Computer Controlled Devices**

One obvious opportunity for consolidating controls into one interface point uses the onboard computer system as the centralized controller. The computer as the centralized interface control can eliminate other standalone controllers and minimize

cockpit clutter. To a limited extent, this approach has been used by the New Jersey State Police (NJSP) with their technology suite incorporating a touch-screen display. Similarly, Visteon has further integrated the technology subsystems to allow touch screen computer control.

Computer control can help consolidate equipment and free up space, but it may be at the expense of the interaction between user and equipment. In fact, concentrating control functions usually implies far more complex control. Consider users accessing many standard functions with a computer. Most functions are accessed using either a touch screen monitor or a mouse/keyboard combination. Existing interaction methods typically requires the user to look at the display to determine what menu they are in and/or to select what function they want to activate. If the user also happens to be driving, it poses the dual challenge of computer interaction while trying to simultaneously focus on the road. A more intuitive interaction method is needed to provide control functions, but uses alternatives to visual prompts. *Haptic interfaces* offer a modality providing more intuitive interfaces based largely on the sense of touch.

## **1.2 Haptic Interfaces**

### **1.2.1 Introduction to Haptics**

Haptics involves coupling the sense of touch with a computer-generated world [3, 4]. Briefly, haptics deals with providing methods for a user to utilize touch or physical feeling as a component of their interaction with a computer, especially in a virtual environment. There are two sub-fields of interest to this application: force (kinesthetic) feedback and tactile feedback.



Kinesthetic feedback is the interaction between the muscles and tendons that give the sensation of a force being applied, generally used to represent a force that would oppose the motion of the user. For example, if the virtual environment consisted of a rubber band, the force felt by the user pulling on the virtual band would be a kinesthetic force. This feedback is very useful for conveying a virtual object's hardness, weight, and inertia.

Tactile feedback involves interaction with the nerve endings in the skin. The nerve endings indicate heat, pressure, and texture of the object, which portrays smoothness, slippage, temperature, and contact geometry of an object [5, 6]. The combination of both force and tactile feedback make haptic devices a valuable interaction tool.

An interface device that exploits the sense of touch is valuable because touch is the principle contributor to a number of high-level, integrated perceptual functions. Examples include: assessment of objects, verification of engagement, continuous monitoring of activities, building mental models for invisible parts of a system, and forming judgments of other people [7]. All of these functions are components of everyday life that we take for granted and occur without significant thought. The possibility of making the sense of touch a component of feedback holds the promise of contributing to a new generation of more intuitive and useful interfaces.

### **1.3 Statement of the Problem**

This thesis describes a prototype haptic controller for use in a police vehicle. The controller was developed to improve the officer/vehicle interface as well as to consolidate

the various control points present in a police vehicle cockpit. A further benefit is a substantial reduction in cockpit clutter.

The controller consists of a kinesthetic force feedback knob to control the various functions within the police vehicle and a tactile feedback knob to help the user identify the currently active function within the control system. The work began using a commercially available haptic controller development kit [8]. A tactile feedback knob was developed to give the control system a non-visual status indicator. This feature allows the officer to keep his/her eyes on the road instead of on the computer screen.

#### **1.4 Scope of Thesis**

This thesis describes an approach taken to develop a haptic controller for use in a police vehicle. The case for haptic control was developed through an analysis of New Jersey State Police vehicles and a literature search of alternative control methods. During the adaptation of the haptic controller it was determined that an additional feedback feature was needed to take full advantage of the haptic approach. Without additional tactile feedback, the user would still have to view the computer screen to determine the current activated system. Development of the tactile feedback device also included testing of sample subjects for optimizing parameters for the final design.

The objectives of the research work presented in this thesis are to develop:

- A new haptic controller for police vehicles.
- An additional tactile feedback indicator.
- A better user/vehicle interface.

## **1.5 Organization of Thesis**

This thesis is organized as follows. Chapter 1 includes a description of the current status of technology within the police car and its associated problems. This chapter also includes a description of how computer controlled devices and haptic controls may be a solution to those problems. Chapter 2 begins with a literature search on the current uses of haptic technology followed by an explanation of the issues related to using haptic technologies in a police vehicle. The chapter ends with a brief overview of the anatomy of the human hand and its functions relating to force-feedback. In chapter 3, the approach taken to develop the haptic controller and the method of testing for optimization are described. Chapter 4 follows with the results obtained from test volunteer subjects. In chapter 5, the conclusions drawn from testing and development of the haptic controller are explained. Chapter 6 proposes several opportunities available for future work relating to the implementation of a haptic controller for police vehicles.

## **2 Background**

### **2.1 *Haptics***

#### **2.1.1 Current Haptic Implementations**

Today's haptic technologies range from simple controllers to complex systems. For example, at the simple end, haptics are used to add force feedback features to standard video game controllers; a complex application is in surgical simulators for clinical training. The possible uses of haptic technologies seem to be limitless. A better understanding of haptic devices can be gained from descriptions of the operation of representative devices.

One of the most complex systems to incorporate haptics is the Accutouch Endovascular Simulator, shown in Figure 3, produced by Immersion [9]. This simulator allows clinicians to practice medical procedures such as pacemaker lead placement, angiography, and angioplasty. These procedures require careful attention to interpretation of the fluoroscopic images coordinated with the subtle feel transmitted through guide wires, catheters, and other interventional devices. The system simulates both the look and feel of the actual procedure allowing clinicians to practice and develop proficiency before performing on a real patient.



**Figure 3 - Immersion Accutouch Endovascular Simulator.**

What makes this simulator life-like is the merger of look and feel. The look is accomplished by using a combination of the same visual screen set-up as the real device, computer-generated models to reproduce the anatomy of a patient, and a mannequin. The feel is accomplished using haptic simulators to provide life-like force feedback through the various instruments used in the procedure: guide wires, catheters, etc. [9]. The controls required to couple the simulation with visual and haptic feedback elements is very complex.

A slightly less complex haptic device is the Phantom, which was developed at the Massachusetts Institute of Technology and is now produced by SensAble Technologies. The Phantom, shown in Figure 4, is a general-purpose haptic device that is offered in five different models to accommodate different sizes of workspaces, forces, and motion ranges. The Phantom has six degrees of freedom: the three translational degrees (left-right, up-down, forward-backward) and three rotational degrees of freedom (yaw, pitch, and roll) giving it a full range of motion feedback. The device can be interfaced with any standard computer environment to allow applications to add the sense of touch as additional feedback available to a user [10].



**Figure 4 - SensAble Technologies Phantom.**

The Phantom is being used in many research areas. One of them is haptic collaboration over the internet, meaning that a user at one location can touch a virtual object that is located somewhere across the internet as another on-line user is touching the same virtual object [11]. Early efforts have focused on touching and manipulating simple objects, such as touching a box and through the collaboration of two users,

attempting to pick up the box. This work has led to exciting events such as the first “virtual handshake” across the internet [12]. Modeling virtual textures is another application for the Phantom. In this case, the goal is to allow users to feel the texture of products in a virtual environment before purchasing, allow them to feel the sand at a vacation resort, or sense the smoothness of a piece of glasswork. One research group is studying the necessary computations involved with being able to render texture using a haptic device [13]. The interface is not the only consideration when attempting to use haptics in a virtual environment. The computational complexity must also be kept in mind since it requires substantial computing power to provide near real-time behavior in the virtual environment.

An example of a simple haptic device is the iFeel Mouse produced by Logitech [14]. Based on the same core technology from Immersion as the Accutouch surgical simulator, the familiar mouse input device has been given haptic functionality needed for users to add the sense of touch to their computing experience. A DC motor with an eccentric weight makes the mouse vibrate. The driver software adds vibration to such actions as scrolling across icons or between menus. The vibrations allow a user to feel the desktop of a Windows® machine, feel a hyperlink while surfing the web, or feel the action in a haptic-enabled game. The iFeel mouse, shown in Figure 5, adds another dimension to computer interaction.



**Figure 5 - Logitech iFeel mouse.**

There are a wide variety of haptic-enabled gaming controllers that represent the same level of haptic simplicity as the iFeel mouse. All the popular gaming system controllers are “rumble-pack” enabled; for example, the Sony Playstation and the Nintendo Xbox [15, 16]. Gamers can now experience the added sensations of the impact from running into a wall while racing to the gentle rumble of an engine failing in a flight simulator.



**Figure 6 - Haptic enabled gaming controllers.**

The most relevant application of haptics to this research is the BMW iDrive control system, shown in Figure 7 [17]. This system, first introduced in the BMW Z 9 Concept car, uses a haptic enabled rotational knob in conjunction with a dash mounted control display.



**Figure 7 - BMW iDrive controller.**



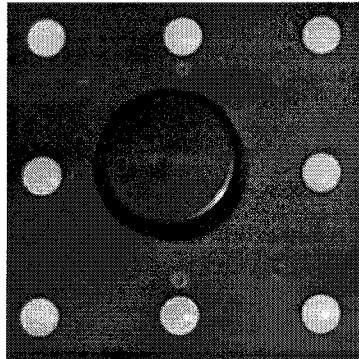
The combined system allows a driver control of seven hundred different systems in the car, all with force-feedback. The display acts as an indicator for the active menu showing the different options available. The knob is located in the center console, in the area where the driver's right palm will naturally come to rest. Although there is capability of controlling seven hundred options BMW designers say that nearly 90% of the deep-level options will never be used after initial set-up. Although the control is labeled an intuitive controller, many of the complex activities, like destination selection for the navigation feature, are locked out while the vehicle is in gear. This feature ensures that the driver will not be distracted from the road by looking at the control screen during the operation of a relatively complex task. Features available during movement include climate controls, entertainment radio, etc.

The haptic technologies discussed above represent only the beginning of what the technology can be used for. There are many exploratory applications underway that will further define the potential of this technology. For example, haptics could be used to enable the blind to better use a computer by being able to visualize the environment through touch. Haptic visualization could be used to bring museum displays to life and allow people to touch sculptures and other art works without degrading the original [3]. Haptic technology appears to have a very promising future.

### **2.1.2 Automotive Control Implementation in a Police Vehicle**

A haptic interface as the central control will add an intuitive interface based on the sense of touch to complement the use of sight. The interface is based on an Immersion rotary haptic knob [8], which can be programmed to have a wide variety of

sensory feedback modes. Figure 8 shows the interface controls available with the rotary knob. There is a cylindrical knob controlled by a DC motor, which provides force feedback. The knob also includes an integral momentary switch. There are eight additional momentary switches arranged in a square that can be used for an application.



**Figure 8 - Immersion development suite haptic interface knob.**

### **2.1.3 Frequency versus Immediacy**

A compelling issue about the relationship between an interface and the functions controlled can be raised [18]. Due to the nature of police work, it is very likely that an officer will need to change what they are doing at a moments notice. The concept of frequency versus immediacy (F-I) expresses the relationship between the frequency with which an item is selected and the immediacy of that item, which describes the urgency of the action. Figure 9 plots frequency versus immediacy to give an idea of what items should have a higher priority in the menu system.

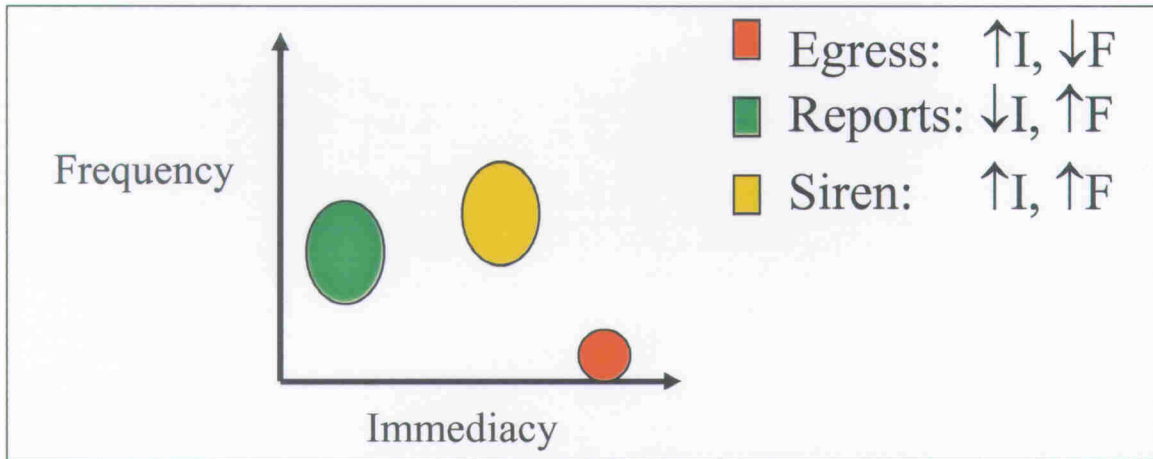


Figure 9 - Frequency vs. immediacy plot.

For example, writing reports is a common daily occurrence. Report writing would therefore have a high frequency, but low immediacy because the officer is highly likely to be parked and can manage selection navigation before reaching the report generating function. On the other hand, lights and siren equipment are used frequently and when required should be instantly accessible without traversing a menu system. Thus, the siren function has both high frequency and high immediacy. Table 1 summarizes some F-I relationships for troop car functions.

Table 1 - Sample frequency vs. immediacy tasks.

Task	Frequency	Immediacy
Report Writing	Medium	Low
Siren and Light Activation	High	High
License Plate Lookup	High	Medium
Map Lookup	Medium	Medium
Entertainment System	Medium	Low
Climate Control	Low	Low

The F-I considerations must be carefully considered when consolidating many interfaces into one control point for a menu-based system. Using the Immersion haptic development device as a model, it would be possible to use the accessory momentary switches to shorten access speed for certain high-immediacy functions. The trade-off is that adding multiple switches increases the complexity of the user interface and detracts from the simplicity of the haptic control.

There are other problems with using just the haptic rotary knob and its momentary switches as the interface. When actively navigating within the menu system, its intuitive nature should allow the user to know which menu they are in through the feel of the knob. However, it is necessary to rotate/activate the knob in order to get tactile feedback. This is not always desirable because activating the system can either put the system into a different submenu or transition it to a different task. Therefore, an ideal interface would be a passive interface point that portrays what subsystem is active without the need to change the position of any controls.

#### **2.1.4 Passive Indicator**

There are several possible solutions to adding a non-active interface point into a control system including, a head-up display, a planar display, audible cues, an indicator knob, etc. Each of these options can communicate information back to the user; however, they each have pros and cons in this application.

A head-up display (HUD) projects a visual menu onto a treated windshield or an attached display visor. As the user traverses the menu system, the HUD would be

continuously updated to show the current menu position. This approach is available as an option with Visteon's TACNET product [19].



**Figure 10 - Head-up display from Visteon's TACNET.**

Disadvantages for the HUD are the high set-up and system cost. As a minimum, HUD system costs include a projector and either a treated windshield or a reflective add-on.

Planar displays could take on a multitude of forms. One version would use LEDs of different colors and positions to indicate which menu is active. Each LED or combination of LED's would indicate the active level within a certain menu system. A second form would use a more complex LCD display of words and numbers to represent a menu. These options have the same drawbacks. First, they involve the standard issues of placement and visualization, but they further complicate the user interaction. Conventional LEDs cannot be mounted onto the windshield, leaving the dashboard, center console, or other area of the cockpit as possible options. Unfortunately, these are the same areas where it is important to avoid installing equipment in order to preserve

rapid egress. Furthermore, any installation presents a new interaction problem: users will be distracted from the road, which is an undesirable effect.

Audio cues could be useful feedback to the user but come with their own problems. For example, a method would need to be established for triggering the audio cues based on the interval, user selection, or other technique. However, this would require the interface to be active as well as passive to provide cues when requested and/or at certain intervals. Other problems with audible cues are competition in the ambient cockpit environment from radio sources such as broadcast AM/FM and two-way mobile radios, which could mask the cues.

Haptics could contribute yet another feedback method to communicate menu position. Sense of touch eliminates some of the problems associated with visual and audio cues, particularly temporal, while introducing new challenges. A new haptic indicator could be coincident with the existing haptic interface, or in a separate location. Collocating the indicator with the existing interface knob greatly increases the complexity of the mechanical design. Consideration of what the interface should feel like is also important. A major design challenge is to develop methods for imparting static feel to a rotary knob. The nature of the rotary haptic interface requires rotating the knob to traverse various menus and make selections. Meanwhile, the position indicator would need to convey the current menu, while at the same time the knob still needs to be used to navigate within the submenus. Therefore, the knob would be required to have a complex control to change the shape of the knob to preserve static indicator location as the knob is rotated, or the haptic control knob would need to have two concentric parts that would be

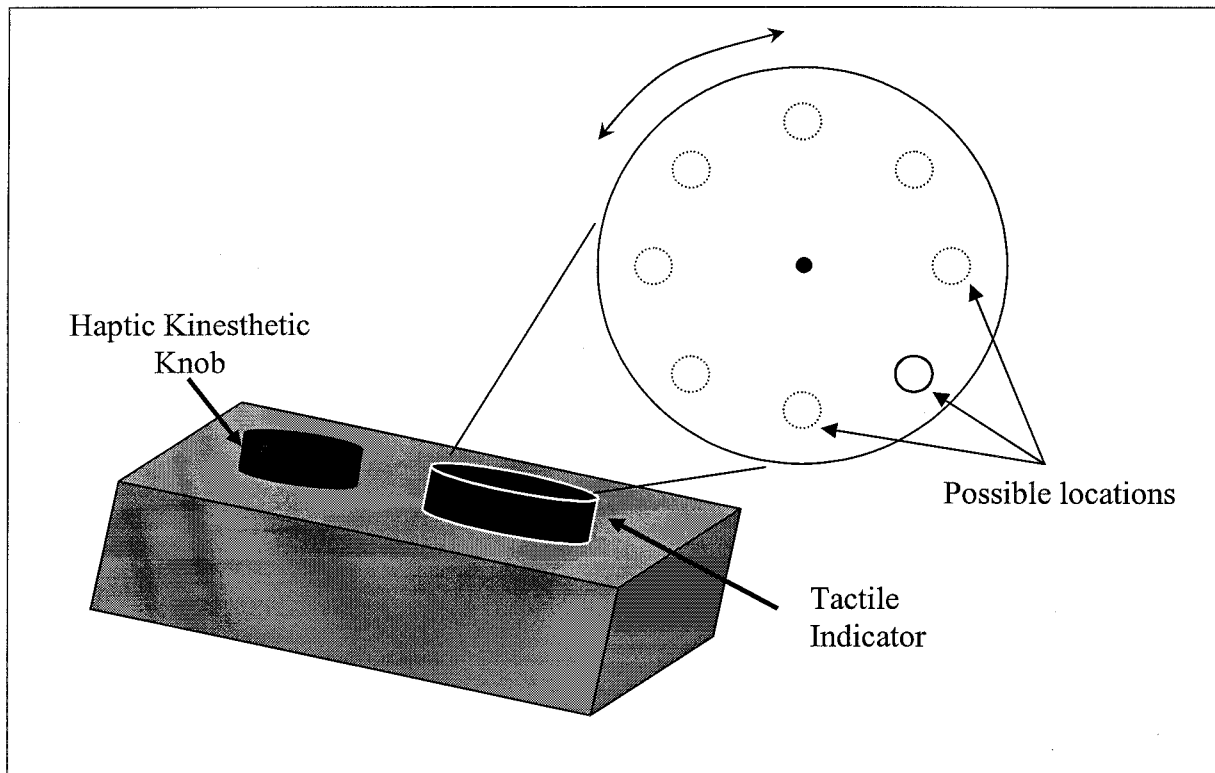
controlled and/or rotated independently of each other. These considerations were viewed as prohibitive, so another alternative was sought.

Another option would create a separate indicator that is not a part of the haptic interface knob. If the indicator is too far from the haptic knob, it introduces the problem of excessive motion as the user moves their hand between the indicator and then back to the haptic knob. This could prove cumbersome and inefficient. Potential problems would be minimized if the indicator is located relatively close to the haptic interface knob.

Finally, the shape and design of the indicator are critical considerations. The indicator could be designed with inherently strong positional cues such as making the indicator in the shape of an arrow. While this could provide the user with an easily identifiable indicator, it would result in ease of operation that is very position dependent. Preferably, an indicator should provide a more uniform shape, but still communicate adequate positional feedback.

### 2.1.5 Design of a Tactile Feedback Interface

The method selected for this investigation uses a disc with a raised feature placed in the location of the palm as illustrated in Figure 11. The disc can be rotated to a number of fixed positions that correspond to one of a corresponding number of potentially active menu states.



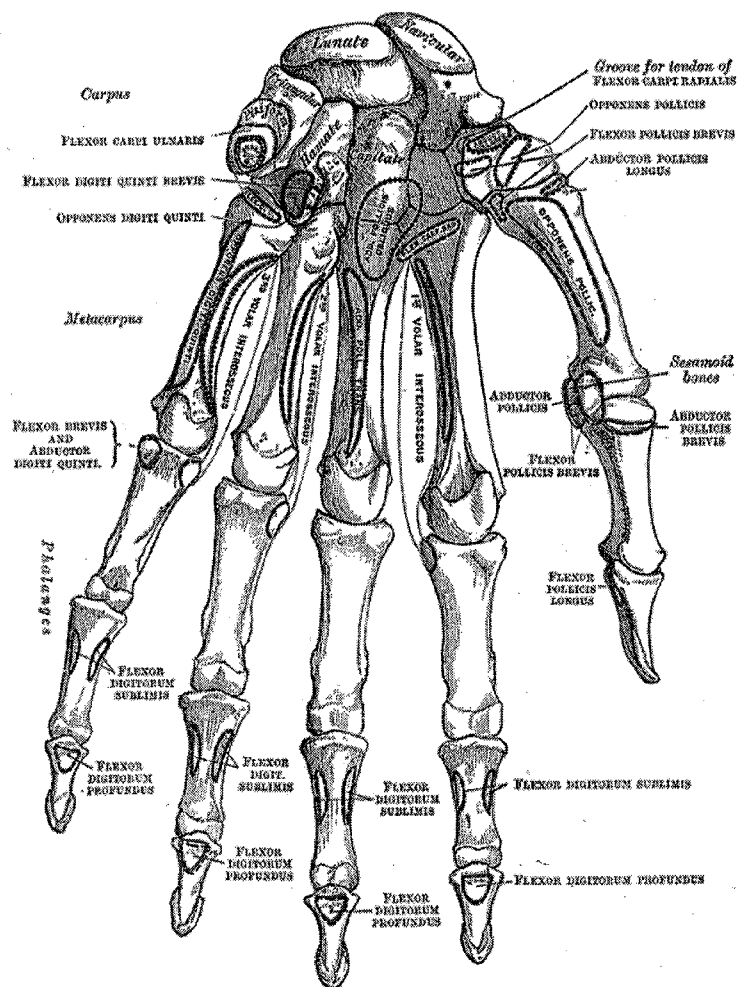
**Figure 11 - Prototype haptic interface.**  
A more detailed schematic can be found in Appendix B.

Implementation of a secondary haptic feedback knob provides users with a method of readily determining the current active menu. Additional design considerations include the average size of a person's hand, the spatial sensitivity of the palm, and the intuitive feel of the interface.



## 2.2 Anatomy of the Hand

Metacarpal bones form the palm of the hand and the bones of the fingers are the phalanges [20, 21]. The metacarpal bones radiate from the wrist and are then extended by the phalanges to form the four fingers and the thumb. The fingers consist of three phalanges (proximal, middle, distal), while the thumb consists of only two (proximal and distal) [22].



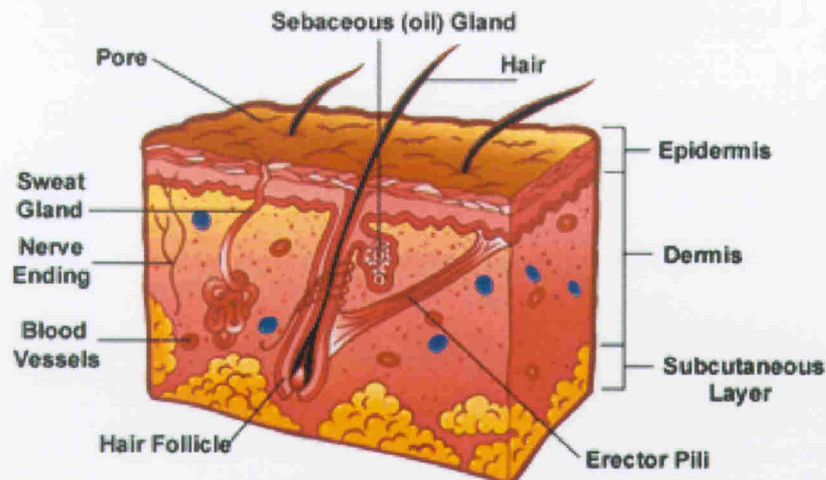
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Figure 12 - Human hand bone structure.

The combination of joints, ligaments, and muscles in this structure are what give the hand its versatility. The hand has 23 degrees of freedom just in the metacarpals and phalanges, plus an additional 6 degrees of freedom including the wrist [23]. This allows for a great range of motion and corresponding ability to grip, hold, and manipulate objects. This range of motion coupled to the sense of touch gives humans the ability to perform precision tasks. The hand is a very precise sensor of both kinesthetic and tactile forces, making it the optimum interface point between human and machine control. The muscles of the hand consist of four compartments [24]: thenar, adductor, hypothenar, and the central. There are many muscles within each of these compartments that work in conjunction with other muscles to provide the movement and functionality of the hand. For instance, the muscles in the thenar compartment work together to provide the opposition of the thumb, which is very important for the precise activities of the hand. All of the muscles in the hand are responsible for sensing kinesthetic forces. The tension or relaxation of the muscles and tendons are interpreted as forces by the brain.

Nerve endings for sensing tactile forces are primarily in the structure of the skin. The skin found on the hands is thicker than that found in most of the body [25]. Thicker skin is also found on the palmar side of the fingers and the soles of the feet.

Skin consists of three different layers: the epidermis, the dermis, and the subcutaneous layer, as shown in Figure 13 [26]. Each layer has its primary function; in the discussion that follows, only the sense of touch will be explained.



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Figure 13 - Model of the human skin [27].

The sense of touch is directly related to the area of skin and the corresponding types of sensory receptors found in that area. The cutaneous receptors can be subdivided according to the type of stimulus to which they respond. The major types are mechanoreceptors, thermoreceptors, and nociceptors [28]. Mechanoreceptors respond to mechanical stimuli such as stroking and deformation of the skin. The mechanoreceptors can be further divided into rapid and slowly adapting. The size of the receptor field also depends on the type of receptor. Slowly adapting receptors are the Merkel cell endings. Ruffini's corpuscles are responsible for touch, pressure, and position stimuli. The Merkel endings are found in small fields whereas Ruffini's corpuscles are found in larger fields. Thermoreceptors are responsible for detecting changes in temperature; nociceptors respond to stimuli that threaten to produce damage.

The combination of receptors in the different layers of the skin gives the sense of touch. Many studies have investigated the sensitivity of various parts of the body to different stimuli. One area of particular interest to this project is the peripheral neural representation of indentation of skin [29]. The sensation of a small object causing an indentation in the skin is a frequently-experienced tactile sensation. The skin has a minimum deformation threshold that is required for the subject to detect and localize the indentation. Figure 14 shows the pressure thresholds obtained for the various parts of the body as reported by [29].

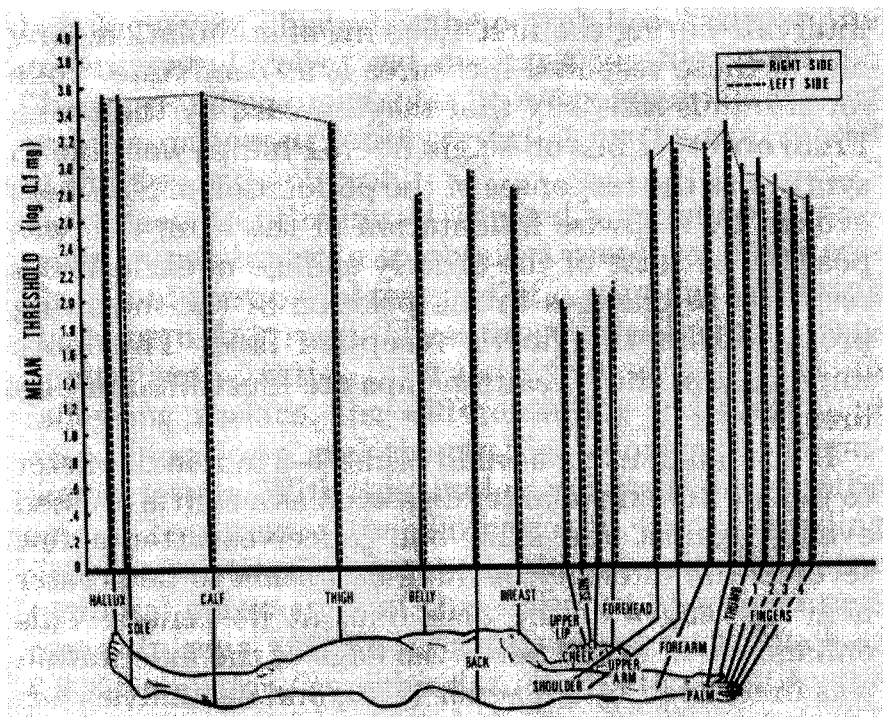


Figure 14 - Pressure sensitivity thresholds.

The sense of touch can return relatively complex information about a stimulus. For example, given an indentation greater than the threshold, subjects can estimate the amplitude relative to other stimuli, the temporal profile, and whether the indentation is stepwise, ramp-wise, or a more complex pattern. A subject is also able to assess the

shape of the contact area, except for the smallest of indentations. Another sensory metric is the capacity of a subject to localize a stimulus. Figure 15 shows these thresholds throughout the body. Data for the palm shows that it is able to localize a stimulus to within 6mm.

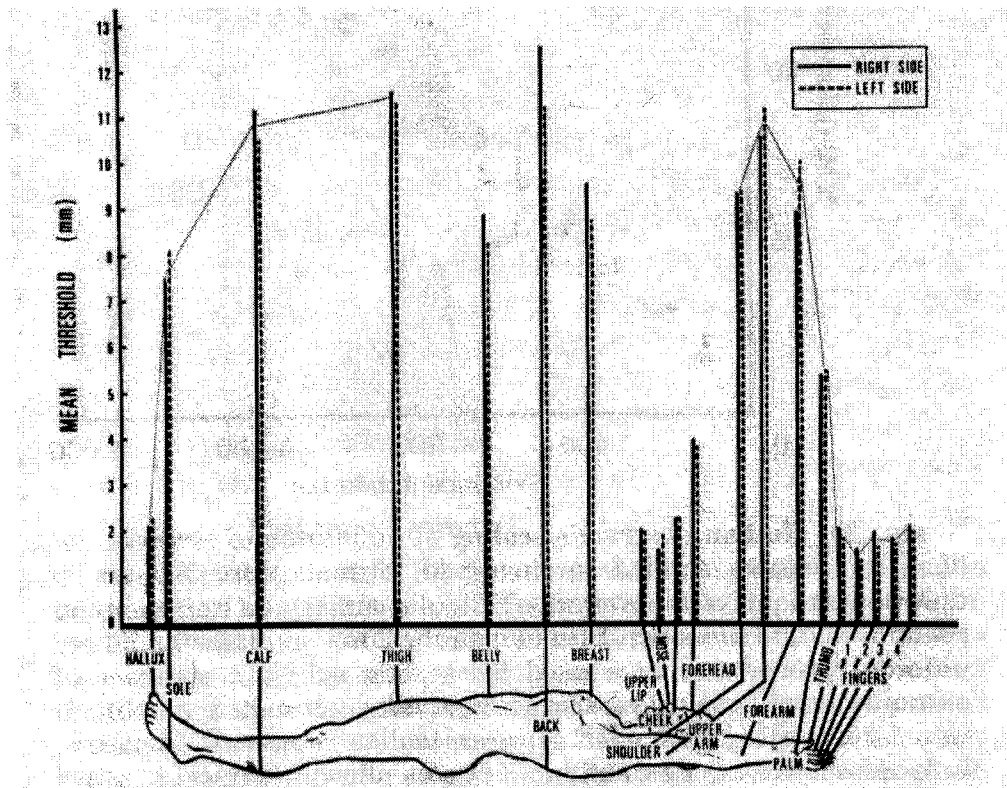


Figure 15 - Localization thresholds

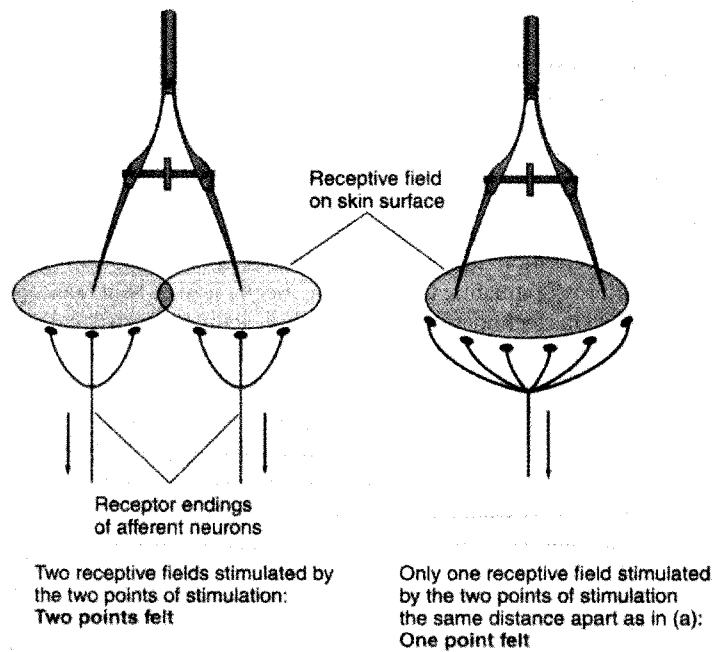
The various sensory thresholds contribute to the sensory acuity in a particular area. For instance, the skin on the calf is thinner with fewer receptors than in the skin of the palm and therefore does not have the same sensory resolution as the palm. Although the palm of the hand is less sensitive than the fingers are, it still has a very impressive ability to localize a stimulus and determine the intensity of an applied force. These attributes make the palm surface a viable option for an additional feedback point.

Understanding the relationship between the structure of the hand and the sense of touch allowed for a better conception of how a user's hand would interact with a haptic controller. The added knowledge of the sensitivity of the palm provided initial design criteria to uphold.

### **2.2.1 Two-Point Discrimination Test**

There have been many studies of the sensitivity of various parts of the body using the two-point discrimination test [26, 30], which determines the minimum separation between two points on the skin that a subject perceives as two separate points. A pair of points set to a known distance is pressed on the subject's skin. The subject then answers "one" or "two" depending on how many points are felt. The ability to discriminate the number of points depends on the number of receptor fields stimulated.

Figure 16 illustrates the test showing why one point would be felt as opposed to two points. Results for the palm show a two-point discretion threshold (TPDT) of 7~10mm [29, 30]. By comparison, the fingertips have a TPDT of 2~3mm, which means that the palm is not as sensitive to spatial stimuli.



**Figure 16 - Two Point Discrimination Test.**

## 3 Approach

The design of a consolidated haptic control considers both the input controller and the non-active indicator, since the intuitive feel of one directly relates to the other. If the cognitive loading associated with one element is too great, the other element will be overshadowed because too much effort is needed to make the interface useful. Therefore, careful tradeoffs were made between the active interface point and the indicator.

### 3.1 *Devices to be Used*

The novel haptic feedback device reported here was developed using a combination of commercially available and custom components. The development of the haptic interface point was tasked first, followed by the development of an indicator to complement the use of the force-feedback device.

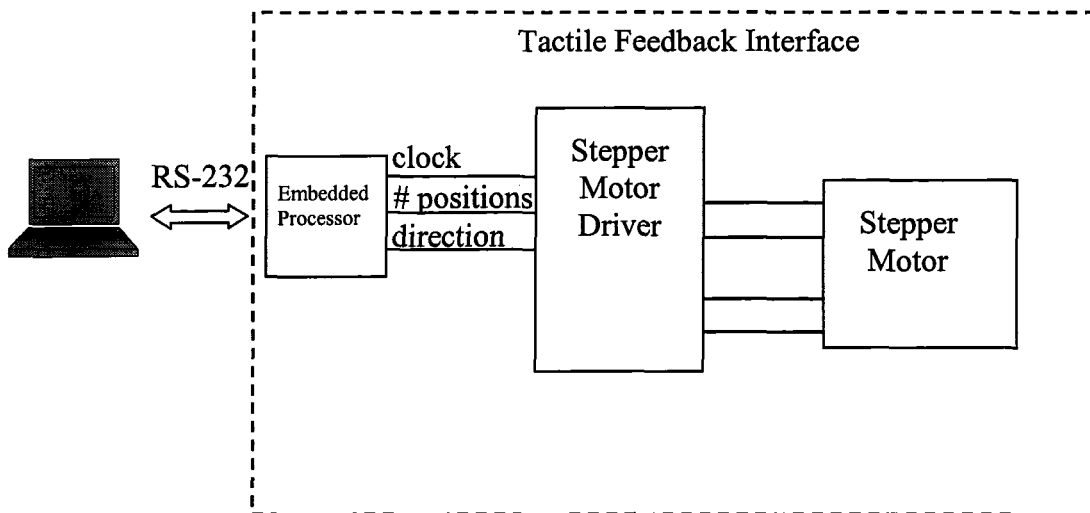
#### 3.1.1 Immersion Rotary Haptic Knob

Immersion Corporation produces a development kit that contains a rotary knob that is haptic enabled, and includes a software development kit with sample control software. The knob supports four force-feedback effect prototypes that can be customized to specific applications [31]. The effects include: *periodic effects* such as vibrations and constant forces, *condition effects* such as springs and dampers, *detent effects* to display preferential positions for the knob, and *barrier effects* which prevent the knob from being turned past a certain point. With the knob capable of up to eight fundamental effects being loaded at once, the developer can design an interface that will give the user a customized haptic experience.



### 3.1.2 Tactile Feedback Device

The tactile feedback indicator is a device developed in-house to complement the haptic controller. It consists of a knob, knob support, stepper motor, stepper motor driver, and an embedded processor. The stepper motor is used to rotate a knob to a location coordinated to a specified menu function. Figure 17 is a block diagram of the tactile feedback interface.



**Figure 17 - Block diagram of tactile feedback indicator.**

The computer transmits the position number desired via RS-232. The processor then computes the change required to move the indicator to the correct position following the Pseudo Code below.

1. Initialize input and output ports.
2. Wait for position to be sent on serial port.
3. Compare received position to current position.
4. Calculate number of positions needed to move.

5. Send number of positions to motor driver.
6. Send a character back to compute via serial port.

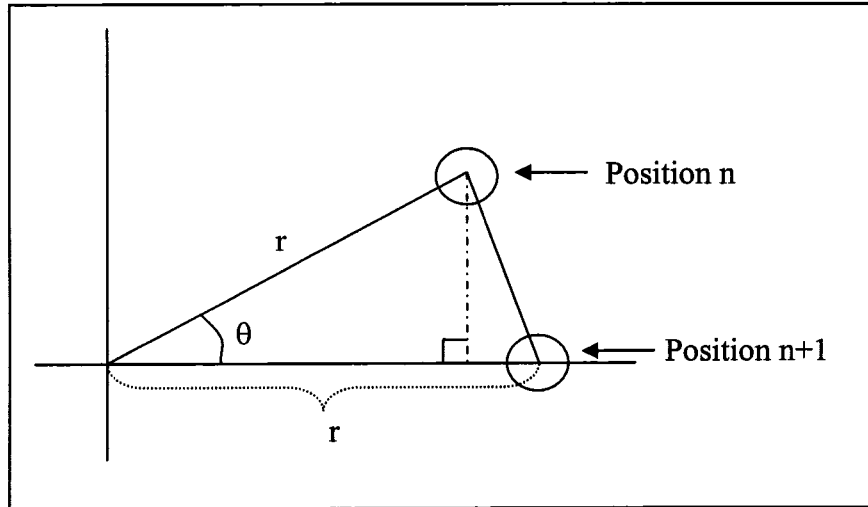
The stepper motor driver uses the number of positions and generates the required pulses to move the motor to the correct location. The internal workings of the device are only as effective as the user interaction with it.

Therefore, optimum values for several device variables such as feature spacing were investigated using both small selective group analysis and large random group analysis. The small group consisted of project team subjects. The preliminary results were used to beta test the device and help bracket features of the device. The large group analysis used volunteer subjects to study the relationship between radial feature location and accuracy of position sensing. The Institutional Review Board application and approval are included in Appendix A.

### **3.2 *Human Capability Testing***

The results from the TPDT given in the background gives a starting point to determine what the palm will be capable of discriminating using one indicator point. That is, we expect that a position change of less than 10mm is unlikely to be reliably detected as two separate loci. It is necessary to exceed the palm's TPDT to make the position change detectable.

Assuming a circular geometry, the radial spacing required to achieve a given TPDT can be determined. Figure 18 illustrates the problem.



**Figure 18 - Example diagram for minimum TPDT.**

Equation (1) is the solution for  $r$ ,  $mm$ , required to meet a given  $TPDT$ ,  $mm$ , with an angular spacing of  $\theta$ , degrees.

$$r = \sqrt{\frac{TPDT^2}{2 - 2\cos(\theta)}} \quad (1)$$

Using this relationship we can determine the absolute minimum radius in terms of TPDT and the angle between positions, shown in Table 2.

**Table 2 - Calculations of minimum radius given the number of position indicators and TPDT value.**

# Positions	$\theta$	TPDT (mm)	$r$ (mm)
8	45	8	10.453
8	45	10	13.066
8	45	12	15.679
4	90	8	5.657
4	90	10	7.071
4	90	12	8.485
6	60	8	8.000
6	60	10	10.000
6	60	12	12.000

To further quantify the minimum spatial separation required, an experimental procedure has been designed. The experiment is explained in a subsequent section.

### 3.2.1 Shape of Indicator

Another factor to consider in the design of the position feedback indicator is the shape of the protuberance. It has been shown that the skin can identify very fine features of objects less than the TPDT [32]. For example, the palm of the hand can easily distinguish between the sharp tip of a pen and the rounded top of the pen cap if placed in the same spot on the palm. An indicator that enhances the stimulation on the palm will improve the feedback of the rotating indicator.

If the indicator is too sharp, the user is likely to avoid using the device over extended periods. Similarly, if the indicator is too dull it may require excessive pressure to obtain reliable feedback. Several possible shapes for the indicator are shown in Figure 19.

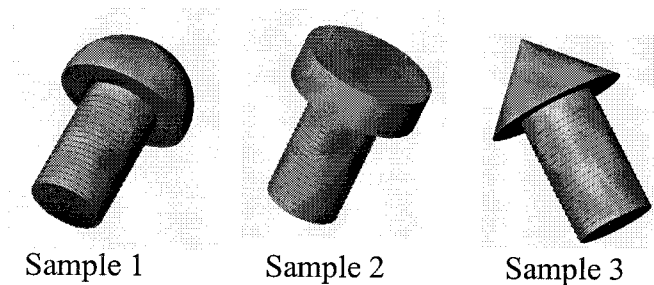


Figure 19 - Sample indicator shapes.

The indicator shapes range from thin and pointed to fat and rounded. Each has its own characteristic feel. Models were built and tested on the mock-up interface to determine which shape best fits this application. Test subjects interacted with the

prototype to evaluate which shape they preferred. Results are important to understand the dynamic interaction between the user's palm and the knob. The trade-off is between a "sharp" enough feeling for rapid sensing of the protuberance while being smooth and broad enough to avoid discomfort for extended periods of use.

### **3.2.2 Position Discrimination**

The total number of different positions, which a user can confidently distinguish between, is a key factor in the development of this feedback device. Too many positions will make it hard for the user to reliably determine what information is being fed back, with the likely result that they will have to look at the computer screen to determine what menu the system is in. This would defeat the purpose of having the tactile force-feedback indicator. In contrast, too few positions provides only limited feedback, which limits the usefulness of the method.

The radius where the protuberance is mounted is another key factor affecting the user's ability to accurately determine differences in position. In general, the larger the radius the better the ability to distinguish between positions because of the increased distance between adjacent positions that results in dimensions greater than the TPDT for the palm. However, a knob that is too large is equally problematic since it should fit comfortable within the bounds of the user's palm. An experiment was designed to determine the optimum radius for the desired feedback to a user.

#### **3.2.2.1 Feedback Knob Optimization Experiment**

The experiment was constructed using a computer interface for control and to record all subject responses. First, the palm indicator was shown to each subject to ensure they understood the operation of the equipment. The subject then familiarized

him/herself with the LabVIEW visual interface designed for the experiment that is shown in Figure 20, more detail of the interface is included in Appendix B. The circles correspond to the possible positions of the indicator. The indicator was then blocked from the field of vision to prevent the subject from gaining any visual cues during the experiment.

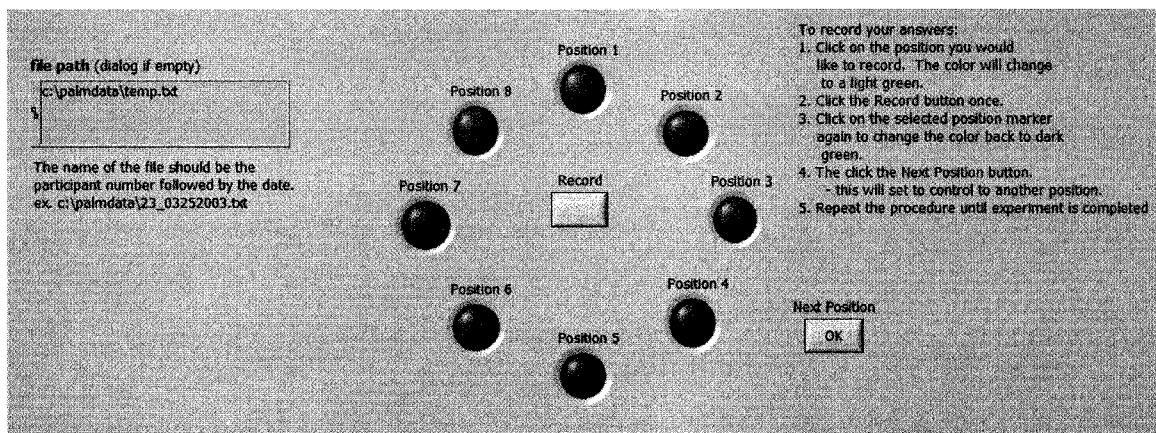


Figure 20 - LabVIEW VI for Palm Experiment

During the measurement phase, subjects were asked to feel the position on the indicator with their palm and record the perceived position. The knob was then rotated to a new random position. Subjects continued this procedure until they recorded a minimum of 40 samples. After the first round of testing had been completed, the radius of the indicator was changed, and the test was repeated for three different radius values: 1.5, 2.0, and 2.5 cm. .

This experiment provided two pieces of information. The first is extracted from the radius data taken by each user. User error performance as a function of radial position was used to find an average optimum radius, which was later used to configure

the interface knob. The most critical information was the statistics for incorrect vs. correct responses as a functions of knob position. This data was broken down further to show position error. For instance, if the actual indicator position was “3” and the user input “4,” then there would be a +1 position error. Similarly, if the user input “1” for the same position, there would be a -2 position error. This information led to a determination of whether or not the palm could reliably and accurately distinguish between the eight possible points presented to the user. If eight was too many to achieve high accuracy, fewer positions would yield better results.

Combined into one graph the data represents percent error vs. radius for an n-position error. The graph has three different curves, one for each n-position error. Given this plot, similar to Figure 21, and a target error threshold, the optimum radius and the maximum number of positions to be used can be determined.

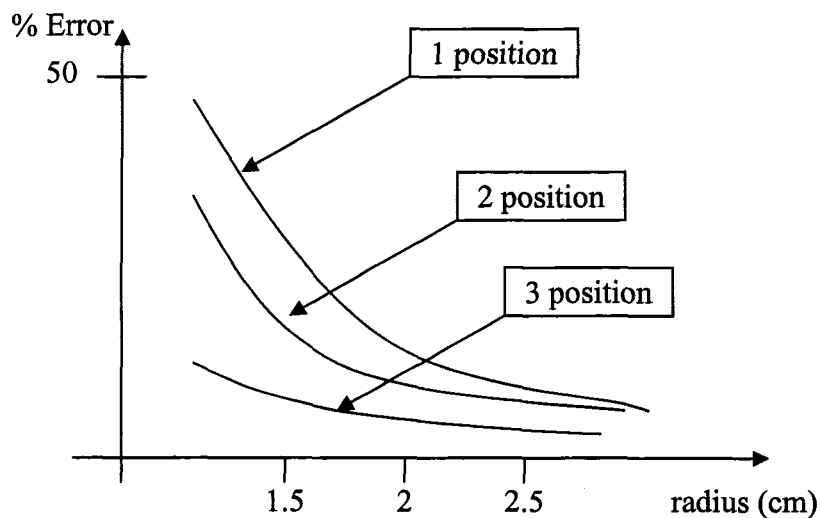


Figure 21 - Sample Analysis Plot

## 4 Results

### 4.1 Immersion Rotary Haptic Knob

The haptic knob to be used for control was developed using the Immersion development suite, which supplied the feedback forces used for in-vehicle control. Figure 22 shows the menu structured as a circle to reinforce the correlation between the visual and touch interfaces.

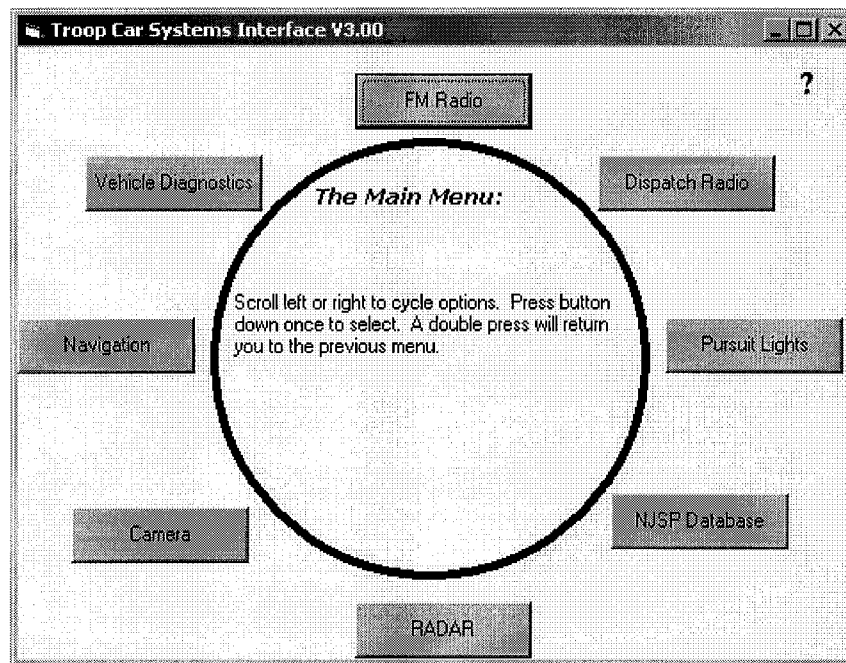


Figure 22 - Sample TCSI Interface.

The current implementation uses the haptic controller to select menu options through the rotation of the knob. When the menu changes between options, a detent force is simultaneously felt on the controller knob. The tactile detents provide the user feedback needed to signify a change in option selection. The selection is then made by



pressing down on the haptic knob. Once in another menu or program the knob can be reprogrammed to provide a different tactile style for other available functions. For instance, in the implementation of the entertainment radio control one type of force is felt when changing stations and a different sensation is used when changing volume. Flexibility in the types of force feedback allows for adapting the control to the best advantage for each application.

Many of the programs the interface needs to control for the troop car application are proprietary to the New Jersey State Police. Therefore, an interface template for implementing haptic controls into a software platform has been developed. This was done through the development of a set of ActiveX controls [33]. The controls allow the programmer to use function calls specifying the parameters desired for control feedback. The modularity of the controls gives the interface both ease of use and transportability between several programming platforms.

## **4.2 Feedback Knob Optimization Testing**

### **4.2.1 Shape of Indicator**

Testing the shape of the indicator found that using an indicator in the shape of a cylinder (sample 2 in Figure 19) was the best combination between smoothness and point distinction. The sharp edge of the indicator renders a distinct recognition point without the discomfort of a sharp point. The long term use discomfort factor was explored during the optimization testing. Since the test was conducted for a continuous thirty minutes, it simulated the use of the interface over a period of time in excess of what an officer would during one session. The tasks performed by the officer will not require the tactile indicator to continually rotate once in the desired menu, eliminating the discomfort that

continual rotation may cause. Test subjects reported minimal—if any—discomfort after the completion of the testing sequence.

#### 4.2.2 Position Discrimination

The results from testing the novel haptic feedback knob are presented and discussed in this section.

An experiment was conducted using nine subjects. Table 3 lists the information collected using the participant questionnaire administered before the experiment. The first column is the subject number assigned, the second is the age of the participant, the third is whether the subject is male or female, the fourth is whether the subject is right or left-handed, the fifth is whether the subject believes they may have a compromised sense of touch in their palm, the sixth is the horizontal width of the palm as shown in Figure 23, and the seventh is the vertical height of the palm as shown in Figure 23.

**Table 3 - Test Subject Information.**

Subject #	Age	M/F	Left/Right	Compromised?	P1	P2
25	23	Male	Right	No	9	10.5
26	22	Male	Right	No	9.4	11.4
27	22	Male	Right	No	9	10.2
28	21	Female	Right	No	8	9.5
29	23	Male	Right	No	10	11
30	21	Male	Right	No	8.5	10.9
31	20	Male	Right	No	9	11
32	19	Female	Right	No	8	9.5
33	47	Female	Right	No	7.5	8.5

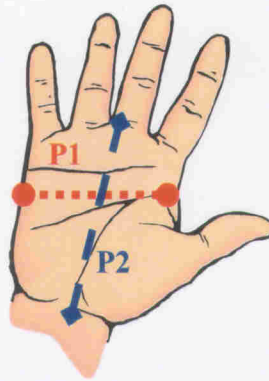


Figure 23 - Dimensions of the palm.

The test was conducted on both male and female subjects with ages ranging from 19-47 years old. The average palm width and height of the subjects was 8.7 cm and 10.3 cm respectively with standard deviations of 0.78 cm and 0.94 cm, respectively. None of the subjects reported being aware of a reason sensation in their hands would be compromised.

Test records included the position presented to the subject paired with the subject's position guess. Using this data, the percent error for a +1, -1, +2, -2, and +/- 1 position error were calculated. A sample is shown in Figure 24. The number of times a position is identified incorrectly was also calculated; a sample is shown in Figure 25. The data collected for all participants can be viewed in Appendix C.

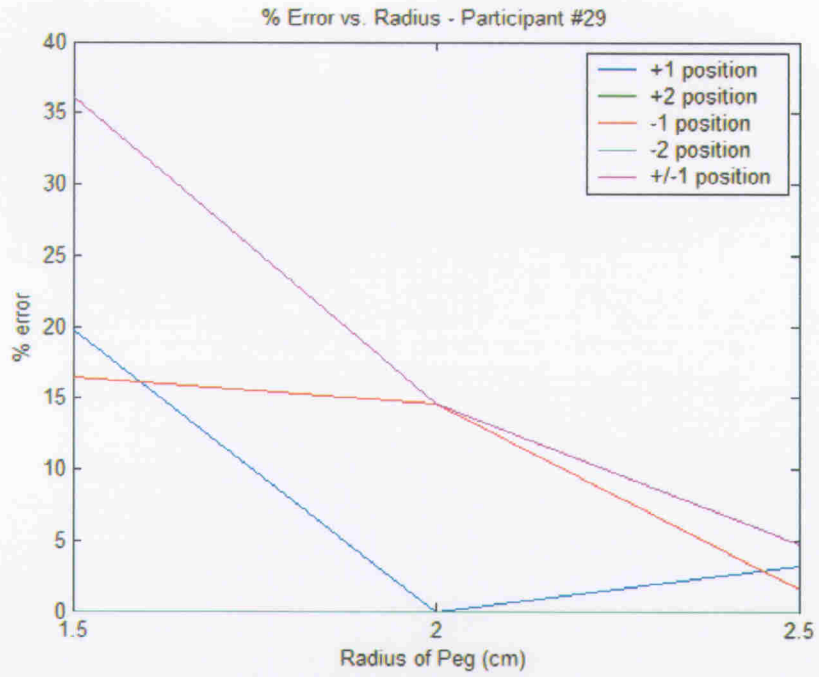


Figure 24 - Sample error analysis of a participant.

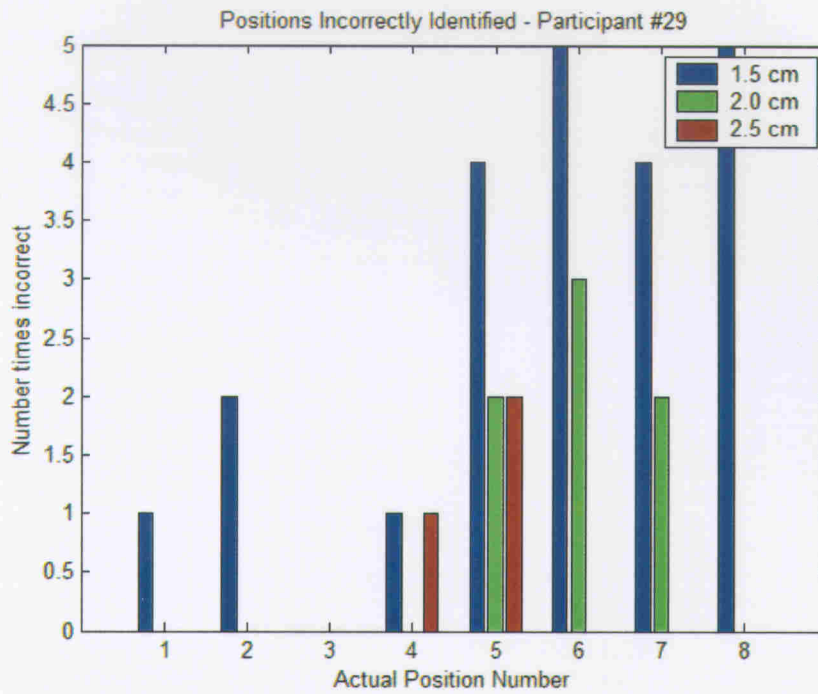


Figure 25 - Sample individual position analysis.

These graphs summarize how each individual performed during the test. An overall performance was calculated by combining the information from the individual tests as shown in Figure 26 and Figure 27.

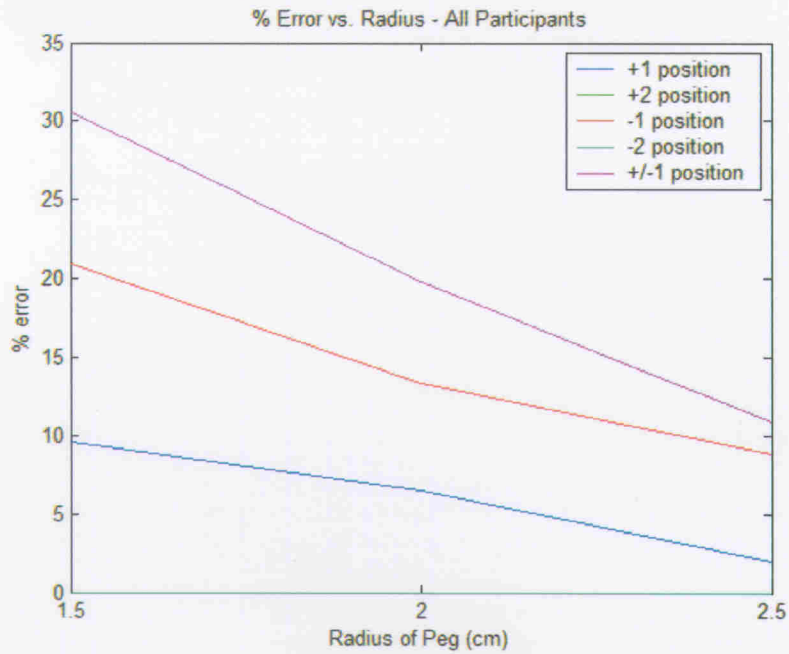


Figure 26 - Average percent error vs. radius for all subjects.

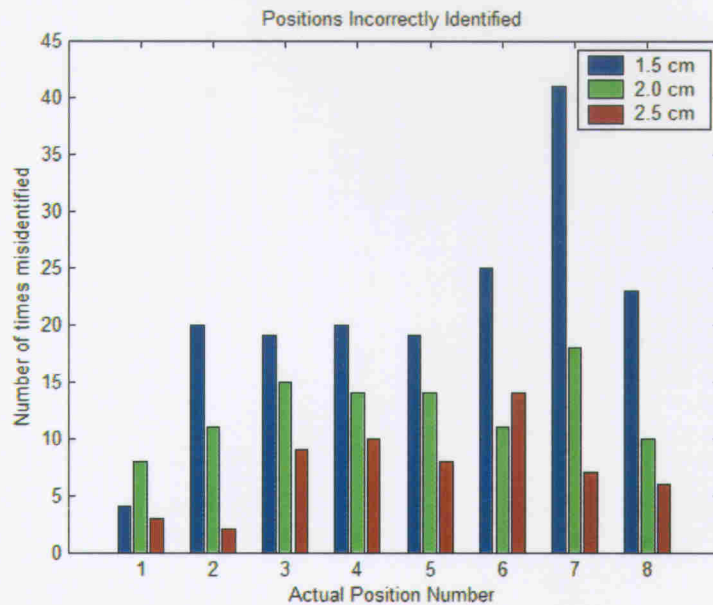


Figure 27 - Total misidentifications for each position.

A trend of a decreasing error percentage as the radius increases is shown in Figure 26. This supports the intuition that subjects were better able to distinguish between positions when the indicator peg positions are further and further apart from each other. If the decreasing trend were followed, a larger radius would decrease the percent error bettering the performance.

However, due to limited radius values available during this testing series the longest radius tested was 2.5 cm with an overall percent error equal to 10.9%, an undesirable value. A second indicator knob was constructed with radius values available up to 3.5 cm. Due to the limited size of the palm, as shown in Figure 28, this value was the maximum size to be tested.

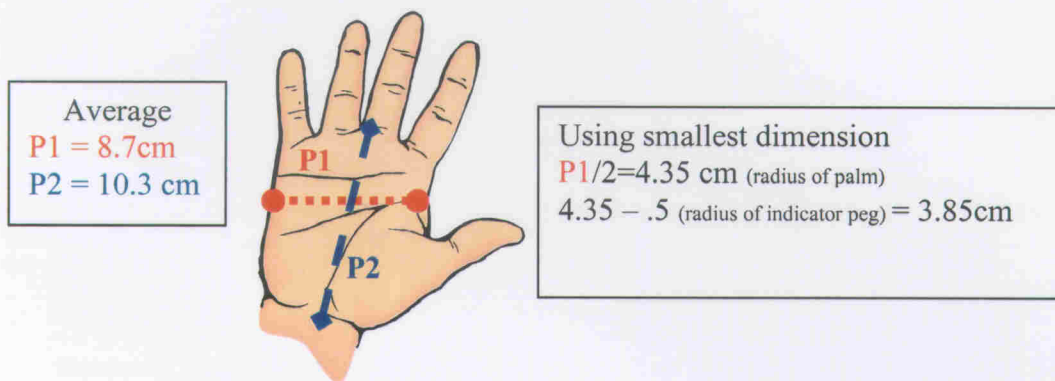


Figure 28 - Maximum radius for indicator location.

Another experiment was conducted using the longer radii on five subjects taken from the original set of nine. The data collected from this experiment is shown in Figure 29 and Figure 30.

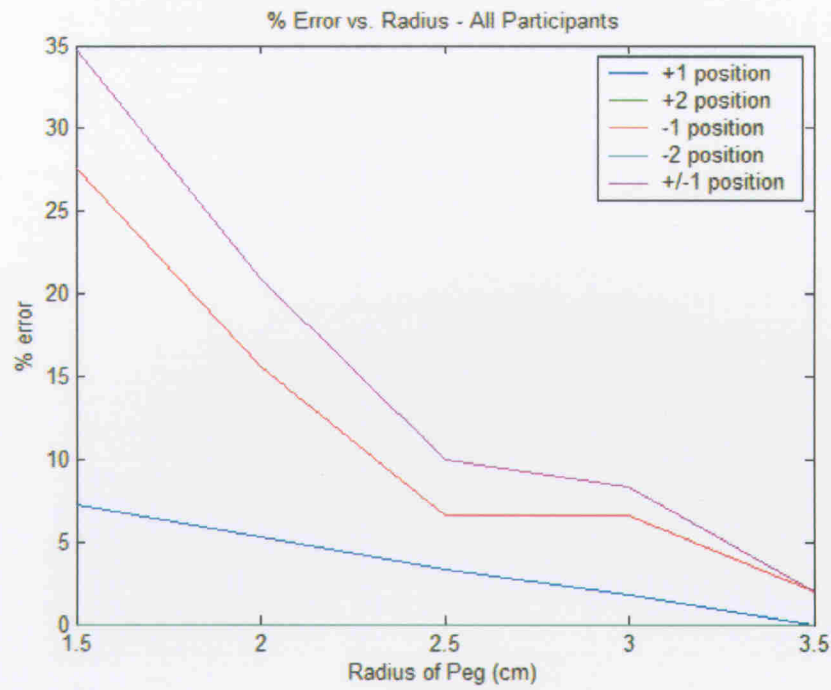


Figure 29 - Average percent error vs. radius for all participants from second trial.

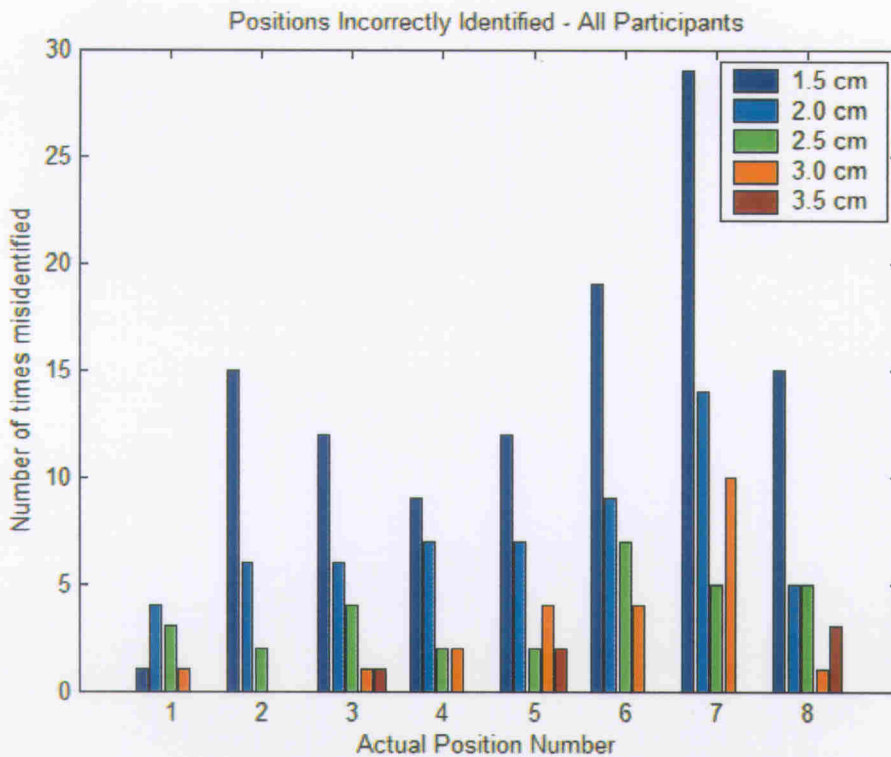


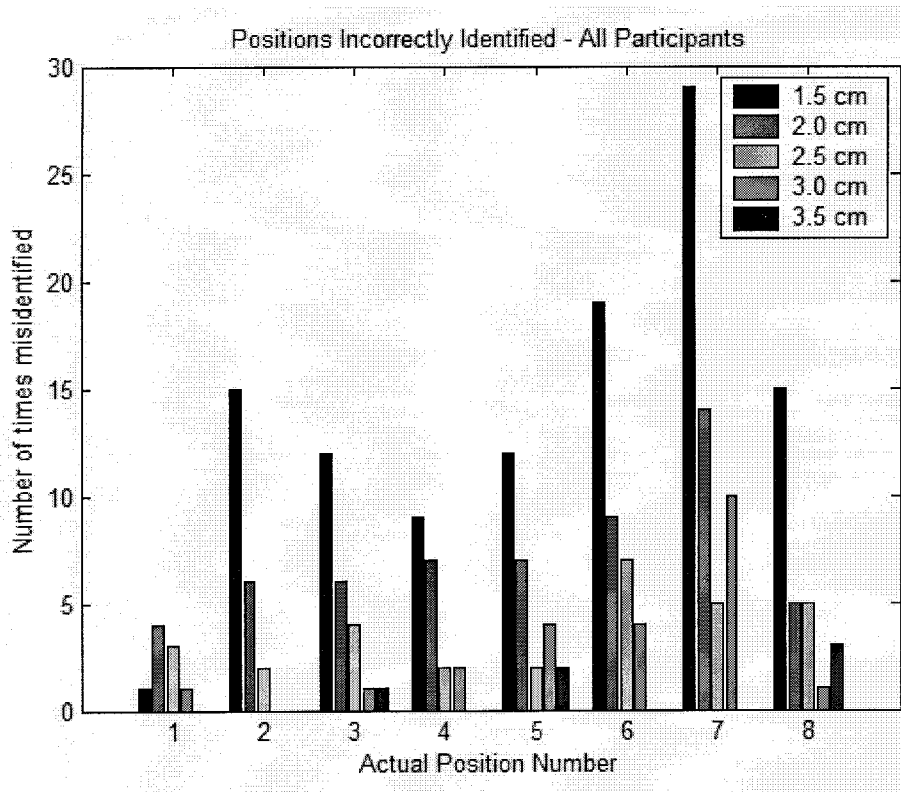
Figure 30 - Total misidentifications for each position after second trial.

The results from the secondary experiment showed the same decreasing trend as the previous results. However, this set of data contained an acceptable error percentage: at the largest radius of 3.5 cm there was a percent error of 1.9%.

In both experimental runs there were other trends that were noticed. There was a trend showing more misclassifications of a point counterclockwise (-1) to the actual point than there were points clockwise (+1). Additionally, there were no position errors greater than one.

The number of times a position was incorrectly identified was expected to correlate with relative sensitivity of the palm. Figure 27 and Figure 30 show a relatively





**Figure 30 - Total misidentifications for each position after second trial.**

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The number of times a position was incorrectly identified was expected to correlate with relative sensitivity of the palm. Figure 27 and Figure 30 show a relatively

consistent distribution of errors; however, positions 6, 7 and 8 show a slightly higher error rate. These positions correspond to the area of the palm closest to the thumb.

## 5 Conclusions

Haptic controls have been added to a police vehicle as a core component of a technology up fit and to help achieve improved interaction design. An Immersion rotary haptic knob suite was adapted to this application. Early assessment revealed problems with users still needing to look at the computer screen because the haptic knob could not communicate absolute position. To solve this problem, a novel tactile feedback indicator was developed and various parameters were tested for optimization.

An experimental prototype was designed and fabricated to support testing of parameters such as number of indicator positions and the radial placement of the feature placed on the tactile feedback knob. Testing suggests that eight positions are possible with percent error less than five. The performance level at a radius of 3.5 cm—the longest available during testing—was optimum. The prototype combination of the Immersion rotary haptic knob with the tactile feedback indicator has not gone through extensive testing; however, the preliminary findings show that this technology has promise. The consolidation of controllers allows improved user/vehicle interaction, and contributes to a clean, efficient cockpit layout. One added bonus of this improvement is a smooth egress path from the vehicle.

The main goals accomplished by this thesis included

- Developed a prototype haptic controller knob for use in a police vehicle, specifically New Jersey State Police vehicles.
- Developed an experimental procedure to test the rotary haptic indicator.
- Achieved better user/vehicle interaction.

## 6 Future Work

Many research and experimental venues are available to be explored in furthering this technology. The most imperative near-term research is the testing of the prototype design in an operational police vehicle. This testing will pinpoint features that need to be changed and further determine if the interface provides better interaction during critical operation.

Another near-term research goal is to further refine the tactile feedback method. For example, provide a variable peg radius dependant on the user. Given an officer profile and an initial calibration sequence, the indicator could be automatically relocated to an optimal position for the officer. This ability will better suit those with larger and smaller hands, instead of trying to compromise with an interface designed for the average hand size. Position error related counterclockwise and clockwise errors to -1 and +1 position errors, respectively. A -1 position error was recorded more often than a +1 position error. Further exploration into this trend could lead to correlating the position error to direction of knob rotation or some other phenomenon. In turn, this may lead to a better indicator if the cause of the lower clockwise position error can be determined and exploited.

Another opportunity for further development is improving the interface between computer and controller. The current implementation uses serial (RS-232) communication to both the Immersion haptic rotary knob and the tactile feedback indicator. This complicates vehicle implementation because of the usually limited serial ports installed in a computer. Alternate communication protocol or interface technique would simplify the interface. Protocols developed for the auto market such as CAN,

ABUS, or CCD are promising alternatives [34, 35]. These protocols address the issues related to trying to decrease complexity of vehicle wiring harnesses in the limited space available in a vehicle to run wires. These issues of limited wiring space and complexity are exacerbated in police vehicles due to the installation of extensive technology add-ons, making space-saving protocols desired.

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- [32] N. Asamura, T. Shinohara, Y. Tojo, N. Koshida, and H. Shinoda, "Necessary Spatial Resolution for Realistic Tactile Feeling Display," *Proceedings of the 2001 IEEE International Conference on Robotics & Automation*, May21-26, 2001.
- [33] I. Horton, *Beginning Visual C++ 6: Chapter 23 Active X Controls*, Canada: Wrox Press Ltd, 1998.
- [34] W. Lawrenez, *CAN System Engineering: From Theory to Practical Applications*, New York: Springer, 1997.
- [35] A. Marino, "HDL Implementation of a Controller Area Network Node," Department of Electrical and Computer Engineering, Rowan University, 2003.

## Appendix A

### A.1 *Institutional Review Board Application*

## Rowan University's IRB REVIEW CHECKLIST SHEET

The reviewers for IRB need to know what you are doing in terms of research activities. Please attach this form when submitting your application to the Grants Office.

**REMEMBER:** The more information you give as to specifics the easier it is for the reviewers to make a decision.

1. { Faculty and students should read the complete IRB application if they are doing a research study.
2. { Complete the application as requested; answer all questions pertaining to your project.
3. { Please provide attachments, as follows:
  - a. Survey or questionnaire
  - b. Consent Form
4. { Disposition Sheet

Should you have any questions, please contact the Grants Office for assistance at extension 4057. Thank you for your cooperation.



## Informed Consent Form

I agree to participate in a study entitled "What can your palm distinguish?" which is being conducted by Edward Guest of the Electrical and Computer Engineering Department, Rowan University. The purpose of this study is to determine how well the average person can distinguish the location of an activation point on the palm of the hand. The data collected in this study will be analyzed and used in a Master's Thesis.

I understand that I will be required to attempt to locate the position of an activation point on the palm of my hand using sense of touch only. My hand will be blocked from my field of vision in order to ensure that no visual cues are used. My participation in the study should not exceed one half hour.

I understand that my responses will be anonymous and that all the data gathered will be confidential. I agree that any information obtained from this study may be used in any way thought best for publication or education provided that I am in no way identified and my name is not used.

I understand that there are no physical or psychological risks involved in this study, and that I am free to withdraw my participation at any time without penalty.

I understand that my participation does not imply employment with the state of New Jersey, Rowan University, the principal investigator, or any other project facilitator.

If I have any questions or problems concerning my participation in this study I may contact Edward Guest at (856) 256-5351 or x5351.

\_\_\_\_\_  
(Name of Participant)

\_\_\_\_\_  
(Signature of Participant)

\_\_\_\_\_  
(Date)

\_\_\_\_\_  
(Signature of Investigator)

\_\_\_\_\_  
(Date)

Participant Number

**INSTITUTIONAL REVIEW BOARD  
DISPOSITION FORM**

Edward Guest  
Principal Investigator

\_\_\_\_\_  
Co-Principal Investigator (if applicable)

320 A Florence Ave.  
Address of Principal Investigator

\_\_\_\_\_  
Address of Co-Principal Investigator

Pitman, NJ 08028  
City, State, and Zip Code

\_\_\_\_\_  
City, State, and Zip Code

(856) 598-0807    guest@ieee.org  
Telephone # Fax # e-mail address

\_\_\_\_\_  
Telephone # Fax # e-mail address

**TITLE OF RESEARCH** What can your palm distinguish?  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**ADMINISTRATIVE DISPOSITION - DO NOT WRITE BELOW THIS LINE**

Your claim for exemption for the research study identified above has been reviewed. The action taken is indicated below:

\_\_\_\_\_ **APPROVED FOR EXEMPTION AS CLAIMED: CATEGORY #** \_\_\_\_\_

Note: Anything that materially changes the exempt status of this study must be presented to the IRB for approval before the changes are implemented. Such modifications should be sent to the IRB Office at the address above.

\_\_\_\_\_ **APPROVED FOR EXEMPTION - BUT NOT AS CLAIMED.** Your claim for exemption does not fit the criteria for exemption designated in your proposal. However, the study does meet the criteria for exemption under CATEGORY # \_\_\_\_\_

\_\_\_\_\_ A determination regarding the exempt status of this study cannot be made at this time. Additional information is required.

\_\_\_\_\_ Your proposal does not meet the criteria for exemption, and a full review will be provided by the IRB.

**EXPEDITED REVIEW:** \_\_\_\_\_ Approved \_\_\_\_\_ Denied

**FULL REVIEW :** \_\_\_\_\_ Approved \_\_\_\_\_ Approved with modifications \_\_\_\_\_ Denied

**DENIED:** \_\_\_\_\_  
See attached Committee Action Letter for additional comments.

\_\_\_\_\_  
Chair, IRB

\_\_\_\_\_  
Co-Chair, IRB

Date \_\_\_\_\_

Date \_\_\_\_\_

**INSTITUTIONAL REVIEW BOARD**

**APPLICATION FOR REVIEW OF RESEARCH**

1. Type of approval review requested (check one): Full Review \_\_\_\_\_ Expedited Review  Review Exemption \_\_\_\_\_

2. PRINCIPAL INVESTIGATOR: Edward Guest

3. DEPARTMENT: Electrical and Computer Engineering

TITLE OF RESEARCH: What can your palm distinguish?

CO-INVESTIGATORS: \_\_\_\_\_

PURPOSE OF RESEARCH (INDEPENDENT PROJECT, MASTER'S THESIS, ETC.): \_\_\_\_\_

Master's Thesis

4. IF YOU ARE A STUDENT RESEARCHER PLEASE PROVIDE THE FOLLOWING:

MAILING ADDRESS: 320 A Florence Ave, Pitman, NJ 08071

EMAIL: Guest@ieee.org TELEPHONE NO. (856) 589-0807

FACULTY

SPONSOR NAME: Dr. John L Schmalzel, Ph.D., P.E.

DEPARTMENT OF SPONSORING FACULTY: Electrical and Computer Engineering

PHONE NO. (856) 256-5332 FAX NO. (856) 256-5241 EMAIL: [schmalzel@rowan.edu](mailto:schmalzel@rowan.edu)

FACULTY

SPONSOR

SIGNATURE:

DATE: \_\_\_\_\_

5. HAS THIS RESEARCH PROJECT BEEN CONSIDERED PREVIOUSLY BY THE IRB? YES  
\_\_\_\_\_ NO  X

IF YES, GIVE DATE OF LAST REVIEW: \_\_\_\_\_

6. SOURCE OF FUNDING (IF APPLICABLE):

\_\_\_\_\_ SBR GRANT

\_\_\_\_\_ UNIVERSITY GRANTS (INCLUDING FOUNDATION)

\_\_\_\_\_ CAREER DEVELOPMENT GRANT

X  EXTRAMURAL FUNDS

PLEASE INDICATE AGENCY NAME:  NJ Department of Transportation,  
Federal Highway Administration, and NJ State  
Police

7. ARE YOU WORKING WITH A RESEARCHER FROM ANOTHER INSTITUTION? IF SO, BE  
AWARE THAT YOUR CO-INVESTIGATOR MUST ALSO SUBMIT YOUR JOINT PROPOSAL  
TO THE IRB AT THE INSTITUTION THAT EMPLOYS HIM/HER. \_\_\_\_\_ YES  X  NO

8. DOES YOUR RESEARCH INVOLVE ANY OF THE FOLLOWING (CHECK ALL THAT  
APPLY)?

\_\_\_\_\_ minors \_\_\_\_\_ prisoners \_\_\_\_\_ pregnant women \_\_\_\_\_

\_\_\_\_\_ use of the investigators current students as subjects

\_\_\_\_\_ drugs or other controlled substances

\_\_\_\_\_ psychological or physiological stress above the level of normal everyday activities

\_\_\_\_\_ misleading or deceiving subjects about any aspect or purpose of the research

\_\_\_\_\_ collection of information which deals with sensitive aspects of the behavior (e.g., illegal  
activity, drug or alcohol use, sexual behavior)

\_\_\_\_\_ collection of information which would place subjects at risk of criminal or civil liability if  
it became known

\_\_\_\_\_ collection of information which could affect subjects' financial standing, employability,  
or reputation if it became known.

\_\_\_\_\_ examination of existing data, documents, or specimens that are not part of the public  
record

\_\_\_\_\_ children involved in your research without sensitive information about themselves or  
their families.

\_\_\_\_\_ collecting or studying existing data, documents, records, pathological specimens or  
diagnostic specimens, which are publicly available and from which participants cannot  
be identified by anyone other than the investigator(s).

9. WHAT IS THE OBJECTIVE OF THE RESEARCH?

\_\_\_\_\_ See Attached Sheet \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

---

10. DESCRIBE THE DESIGN OF THE RESEARCH INCLUDING WHAT WILL BE REQUIRED OF SUBJECTS (ATTACH ADDITIONAL SHEET IF NECESSARY):

\_\_\_\_\_ See Attached Sheet \_\_\_\_\_

---

11. UNDER WHICH OF THE FOLLOWING CATEGORIES ARE YOU APPLYING FOR EXEMPTION?

\_\_\_\_\_ 1. Research conducted in established or commonly accepted educational settings, involving normal educational practices such as, (i) research on regular and special educational instructional strategies, or (ii) research on the effectiveness of the comparison among instructional techniques, curricula, or classroom management methods.

\_\_\_\_\_ 2. Research involving the use of social sciences or educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior where (i) information is not obtained in such way that the participants can be identified directly or indirectly or (ii) the participants' responses, if they became known, could not place the participant at risk of criminal or civil liability or be damaging to the participants' financial standing, reputation, or employability. (All research involving survey and interview procedures is exempt when the participants are elected or appointed public officials or candidates for public office. However, confidentiality must be maintained when required by federal statute).

\_\_\_\_\_ 3. Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that participants cannot be identified.

\_\_\_\_\_ 4. Research and demonstration projects which are funded by a federal agency and determined to be exempt by the agency head and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

\_\_\_\_\_ 5. Exemption for collection or study of existing data: research involving collection or study of existing data, documents, records, if these data are non-identifiable and publicly available or information is recorded by the investigator in such a manner that subjects cannot be identified directly through identifiers linked to the subject (codes linking names to data are considered indirect identifiers).

\_\_\_\_\_ 6. Exemption for study of the department of health and human services: unless specifically required by the statute, research and demonstration projects which are conducted by or subject to the approval of the Department of Health and Human Services, and which are designed to study, evaluate, or otherwise examine:

\_\_\_\_\_ (a) programs under the Social Security Act or other public benefit or service programs

\_\_\_\_\_ (b) procedures for obtaining benefits or services under those programs;

- \_\_\_\_\_ (c) possible changes in or alternatives to those programs or procedures;
- \_\_\_\_\_ (d) possible changes in methods or levels of payment for benefits or services under those programs.

IF YOUR RESEARCH IS GIVEN EXEMPTION STATUS, THE FOLLOWING MUST BE STATED ON A COVER LETTER (ON DEPARTMENTAL LETTERHEAD) ACCOMPANYING ANY SURVEY OR QUESTIONNAIRE:

1. A statement that all participation is voluntary
2. A statement that you are conducting research and the reason for it (e.g., master's thesis, publication, etc.)
3. Purpose of the research - what you are investigating
4. A statement that all responses will be kept anonymous and confidential
5. A statement that participants need not respond to all questions
6. If participants are your own students, a statement that class standing will not be affected in any way based on participation
7. The name and telephone number of the Principal Investigator (PI) and faculty sponsor (if applicable)

**CLAIMS FOR EXEMPTION MAY NOT BE MADE FOR (A) RESEARCH INVOLVING CHILDREN, (B) AIDS-RELATED RESEARCH, (C) RESEARCH INVOLVING SUBSTANCE OR CHILD ABUSE OR (D) RESEARCH TO BE CONDUCTED AT THE V.A. (RESEARCH UNDER THESE CATEGORIES IS SUBJECT TO SPECIAL FEDERAL GUIDELINES.)**

**COMPLETE THE FOLLOWING ADDITIONAL QUESTIONS FOR A FULL IRB REVIEW**

12. DESCRIBE THE SUBJECTS WHO WILL BE PARTICIPATING (NUMBER, AGE, GENDER, ETC):

\_\_\_ For this research there will be 60+ participants of either gender of age 18+. \_\_\_

\_\_\_\_\_

13. HOW WILL SUBJECTS BE RECRUITED? IF STUDENTS, WILL THEY BE SOLICITED FROM CLASS?

\_\_\_ Students will be recruited through departmental postings and sign-up sheets. \_\_\_

\_\_\_\_\_

14. WHAT RISKS TO SUBJECTS (PHYSIOLOGICAL AND/OR PSYCHOLOGICAL) ARE INVOLVED IN THE RESEARCH?

\_\_\_ NONE \_\_\_

\_\_\_\_\_

15. IS DECEPTION INVOLVED IN THE RESEARCH? IF SO, WHAT IS IT AND WHY WILL IT BE USED?

\_\_\_\_\_ NO \_\_\_\_\_

16. WHAT INFORMATION WILL BE GIVEN TO THE SUBJECTS AFTER THEIR PARTICIPATION? IF DECEPTION IS USED, IT MUST BE DISCLOSED AFTER PARTICIPATION.

\_\_\_\_\_ There is no set information to be given, however any information requested \_\_\_\_\_  
\_\_\_\_\_ by the participants will be given. \_\_\_\_\_

17. HOW WILL CONFIDENTIALITY BE MAINTAINED? WHO WILL KNOW THE IDENTITY OF THE SUBJECTS? IF A PRE-AND POSTTEST DESIGN IS USED, HOW WILL THE SUBJECTS BE IDENTIFIED?

\_\_\_\_\_ The confidentiality will be maintained by using identification numbers for all recorded  
\_\_\_\_\_ data, with the name of the participants only located on the consent sheet where \_  
\_\_\_\_\_ the recording number will be. The only individuals with access to the consent \_  
\_\_\_\_\_ forms will be the PI and the faculty advisor of the PI \_\_\_\_\_

18. HOW WILL THE DATA BE RECORDED AND STORED? WHO WILL HAVE ACCESS TO THE DATA? ALL DATA MUST BE KEPT BY THE PRINCIPAL INVESTIGATOR FOR A MINIMUM OF THREE YEARS.

\_\_\_\_\_ The Data will be recorded by using a computer interface which will acquire \_\_\_  
\_\_\_\_\_ the required data. The data will then be stored on disk until all the data \_\_\_\_\_  
\_\_\_\_\_ analysis is complete. Following which the data will be stored on CD for \_\_\_\_\_  
\_\_\_\_\_ the required time interval. \_\_\_\_\_

**A.2 *Experimental Procedure***

**The Sensitivity of the Palm  
Experimentation Procedure**

Edward Guest  
Rowan University  
Electrical and Computer Engineering



## Background/Purpose

The use of a rotary haptic knob as an interface to a mobile data computer system has a large benefit to the user. The force feedback related to changes in menus and selection items allows the user to traverse menus and functions with minimal visual cues. A limiting factor to this interface is that there are no stationary or non-active feedback cues to what menu is active. To fully benefit from a force feedback interface a user should be able to “feel” what menu is active without looking at the screen. For this particular application the development of a secondary interface point that would be felt by the palm of the hand is being developed. In order to ensure this addition will give the desired effect, the following experimentation will be performed.

## Hypothesis

The palm of the hand can sense a change of an interface with a radius of 1.5cm to 2cm and 45° increments. See figure below for clarification.

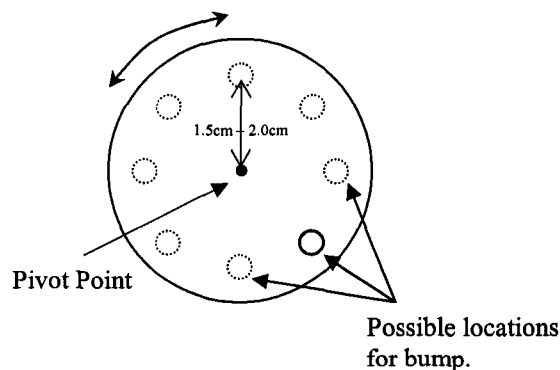


Figure – Basic Design of Interface

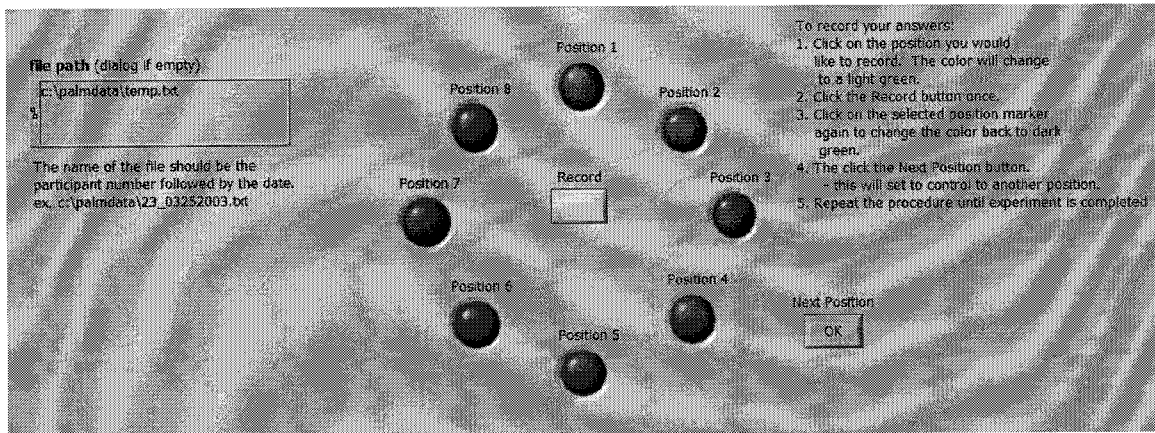
## Testing Base

The desired testing base for this experimentation would be approximately 60 people including both left and right handed individuals, male and female.

## Methods

To test the sensitivity of the palm I am suggesting the following experiments. First, have the subject fill out the attached questionnaire. Then explain to the individual the procedure and demonstrate the operation. There are two user interfaces that will be used throughout this experiment. One is the computer interface that will record the input and the other is the rotary palm indication simulator.

The computer interface is a LabVIEW vi(visual interface) which is shown below.



**Figure 2 - LabVIEW User Interface**

The rotary palm indication simulator will be located where the users right-hand can easily reach, but will be located behind a visual barrier. The simulator has the option of various radius for the indicator peg to be positioned. The user will begin by estimating which peg position they feel they will best be able to determine the various positions. The experimenter will then start the simulation on the computer and the first position will be indicated on the palm by the simulator.

The user will then select which position he/she thinks the simulator is in, changing the dark green circle to a light green circle. The user will then click on the record button to record the answer. Now, the user will click on the position indicator that is light green to return it back to the dark green state. When the user is ready for the next position, the user will click the next position button. This will send another random position number to the simulator which will then rotate to the desired position. The user will then repeat the previous procedure by selecting and recording the position they sense. The procedure will continue until the user has completed approximately 50 revolutions of the experiment. At this time the user will have the option to change the radius of the indicator peg or state that they feel that they are comfortable with the responses and do not think changing the radius will assist them any further.

### **Conclusions/Analysis**

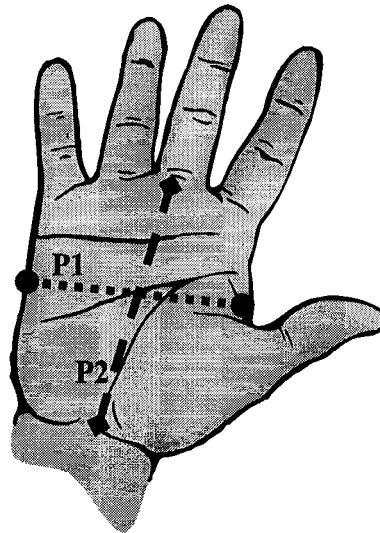
After completing the experiments with the subjects we can then compare the responses of the subjects to the recorded correct values. This data will give information such as the number of correct versus incorrect responses, the number of incorrect responses that varied by 1 position and by 2 positions. It will also give information relating the radius of the indicator peg and the number of correct versus incorrect values. All of this information will be further analyzed and used to find the optimal peg radius and degree increments for the positions.

### Participant Questionnaire

1. What is your age?
2. Are you male or female?
3. Are you right or left handed?
4. Is there any reason that the sensitivity of your hands could be compromised?  
(ex. Burns, broken bones, nerve damage, etc.)
5. Please measure the two distances shown below in cm. (of the right hand)

P1 =

P2 =



**Figure - Measurements of the Palm**

**A.3 Institutional Review Board Approval Form**

RECEIVED

MAR 12

INSTITUTIONAL REVIEW BOARD  
DISPOSITION FORM  
Government Grants and  
Sponsored Projects

Edward Guest Principal Investigator	_____	_____	Co-Principal Investigator (if applicable)
320 A Florence Ave. Address of Principal Investigator	_____	_____	Address of Co-Principal Investigator
Pitman, NJ 08028 City, State, and Zip Code	_____	_____	City, State, and Zip Code
(856) 598-0807    guest@leee.org Telephone #    Fax #    e-mail address	_____	_____	Telephone #    Fax #    e-mail address

TITLE OF RESEARCH    What can your palm distinguish?

\_\_\_\_\_

\_\_\_\_\_

**ADMINISTRATIVE DISPOSITION - DO NOT WRITE BELOW THIS LINE**

Your claim for exemption for the research study identified above has been reviewed. The action taken is indicated below:

- \_\_\_\_\_ APPROVED FOR EXEMPTION AS CLAIMED: CATEGORY # \_\_\_\_\_  
Note: Anything that materially changes the exempt status of this study must be presented to the IRB for approval before the changes are implemented. Such modifications should be sent to the IRB Office at the address above.
- \_\_\_\_\_ APPROVED FOR EXEMPTION - BUT NOT AS CLAIMED. Your claim for exemption does not fit the criteria for exemption designated in your proposal. However, the study does meet the criteria for exemption under CATEGORY # \_\_\_\_\_.
- \_\_\_\_\_ A determination regarding the exempt status of this study cannot be made at this time. Additional information is required.
- \_\_\_\_\_ Your proposal does not meet the criteria for exemption, and a full review will be provided by the IRB.

EXPEDITED REVIEW:     Approved     Denied

FULL REVIEW:     Approved     Approved with modifications     Denied

DENIED: \_\_\_\_\_

Kate Polster    See attached Committee Action Letter for additional comments  
Chair, IRB

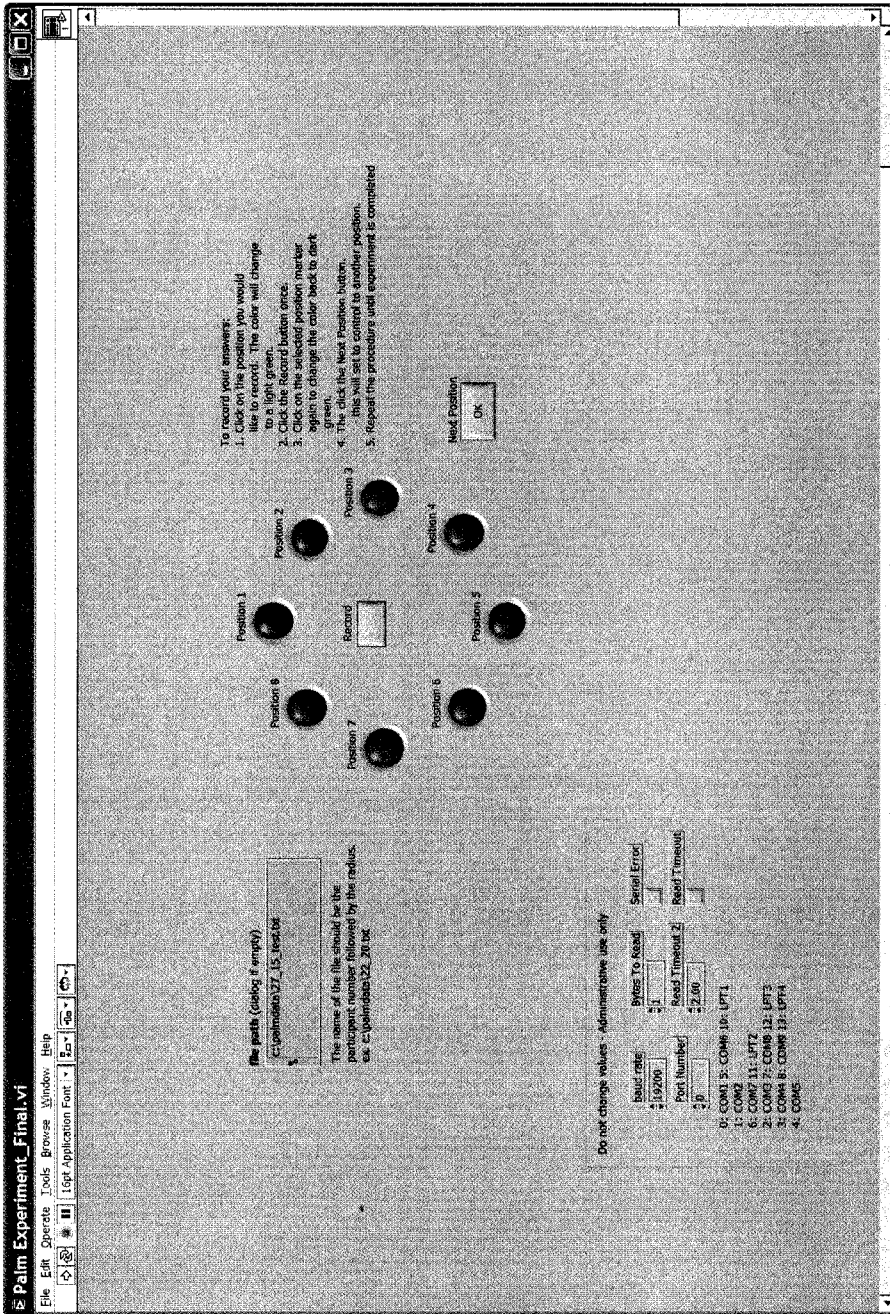
Jo Anderson  
Co-Chair, IRB

Date 4/4/03    Date 4/3/03

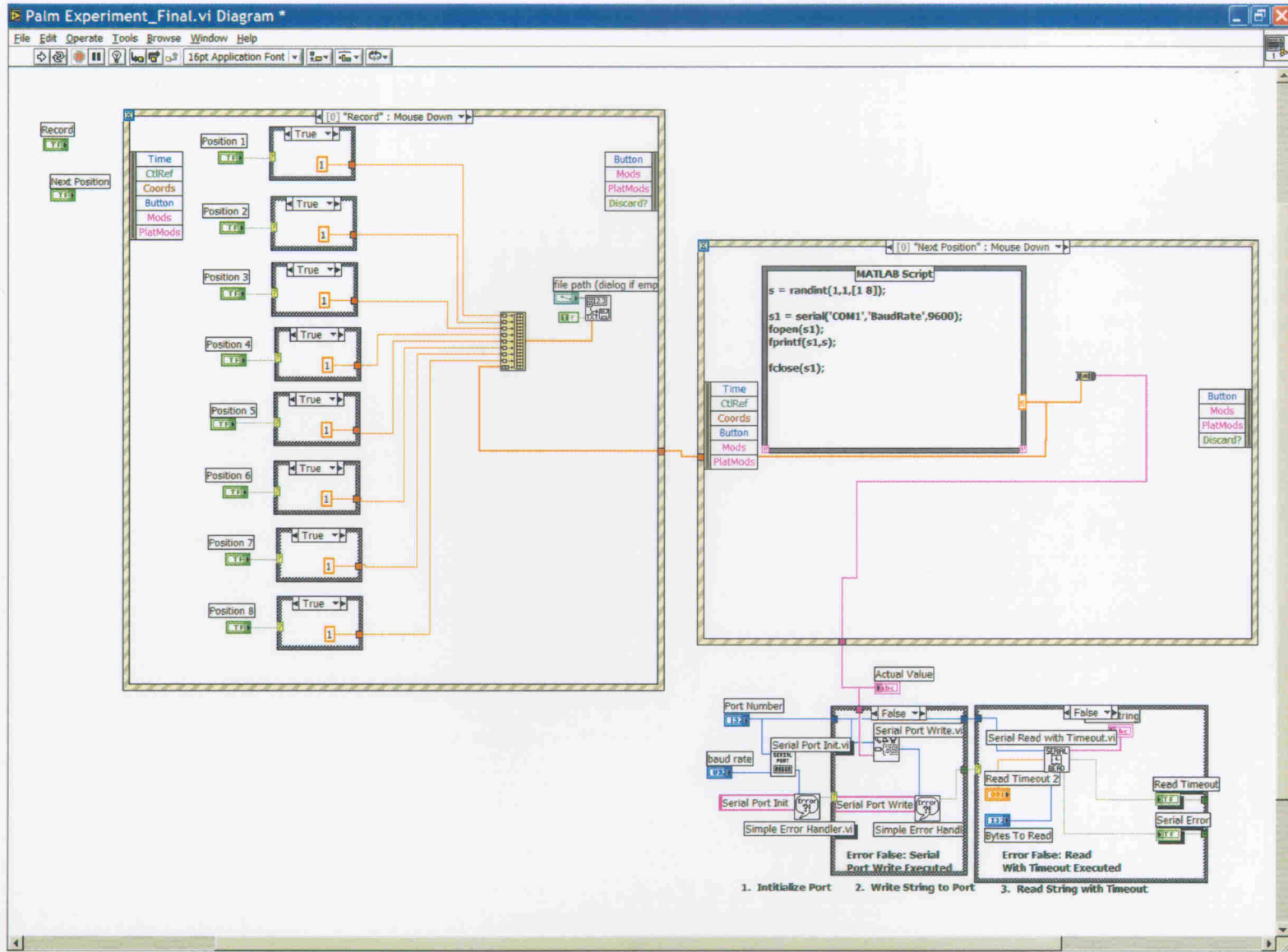
# Appendix B

## B.1 LabVIEW Recording Interface

### B.1.1 Front Panel







B.1.2 Diagram

## B.2 Tactile Feedback Indicator

### B.2.1 Dynamic C Control Code

```
/******  
HHDAEI.c  
Haptic  
Human  
Data  
Aquisition  
Experimental  
Interface  
Version .01A  
  
Don Nickles and Jon Morris for E. Guest  
  
This program receives data transmitted from the PC to Serial Port C input of  
the BL1800. The integer value of the ascii string corresponds to positions of  
the Guest Peg. The Guest Peg, for this example, has only eight possible  
positions. Upon boot, system will have user calibrate position using the  
STDIO window.  
  
Configuration of the serial RS232 port: 19200, 8N1  
  
Black wire connects to TX  
White wire connects to RX  
Gray is Ground  
  
*****/  
  
/******  
The input and output buffers sizes are defined here. If these  
are not defined to be (2^n)-1, where n = 1...15, or they are  
not defined at all, they will default to 31 and a compiler  
warning will be displayed.  
*****/  
#define CINBUFSIZE 15  
#define COUTBUFSIZE 15  
  
int iSerialBuffer; //8Bit serial string  
void isrRS232();  
int newvalue;  
int iCurrentPosition;  
  
int iSteps = 25; // number of steps between each position  
  
fStepperControl(int iPCPosition);  
void MoveMotor(int NumberOfPositons, int direction);  
  
main()  
{  
    //setup operating environment  
  
    iCurrentPosition = 1; // Initialize the position of the motor to the N  
    iSerialBuffer = 1;  
  
    WrPortI(SPCR, &SPCRShadow, 0x84); // Port A bitwise output  
  
    BitWrPortI(PADR, &PADRShadow, 1, 0); // enable the stepper motor drive  
    printf("Stepper Enabled\n");  
  
    serCopen(19200);  
    SetVectIntern(0x0E, isrRS232);  
    newvalue = 0;
```

```

        while (1)
        {
            if(newvalue)
            {
                fStepperControl(iSerialBuffer);
                newvalue = 0;
            }
        }
    } //end main

nodebug root interrupt void isrRS232()
{
    /* interrupt routine for Internal Interrupt 14 (RS232 interrupt register)
       This interrupt triggers when data is sent to the RS-232B port of the Rabbit
       RCM2300. At this time, the interrupt will receive the databyte, assign it
       to an integer value, and then relinquish processing to the main program.
    */

    iSerialBuffer = RdPortI(SCDR)-48;
    newvalue = 1;
    WrPortI(SCSR, NULL, 0x00);
}

fStepperControl(int IPCPosition)
{
    /* This function repositions the stepper motor to a new position, as defined
       by the passed parameter cDirection. Valid directions are:
       N, S, W, E
       NE, SE, NW, SW
       Stepper motor clock port:
       Stepper motor direction port:
       Stepper motor step port:
    */

    // WrPortI(SCCR, &SCCRShadow, 0x00); //disble serial C interrupts

    if(IPCPosition == iCurrentPosition);
    else
    {
        if(IPCPosition > iCurrentPosition)
        {
            if((IPCPosition - iCurrentPosition) > 4)
                MoveMotor(8-(IPCPosition-iCurrentPosition), 1);
            else
                MoveMotor(IPCPosition - iCurrentPosition, 0);
        }
        else
        {
            if((iCurrentPosition - IPCPosition) > 4)
                MoveMotor(8-(iCurrentPosition - IPCPosition), 0);
            else
                MoveMotor( (iCurrentPosition - IPCPosition), 1);
        }
    }

    iCurrentPosition = IPCPosition;
    printf("Current Position: %d\n", iCurrentPosition);
    //
}

void MoveMotor(int NumberOfPositions, int direction)
{
    int i;
    int j;

    BitWrPortI(PADR, &PADRShadow, direction, 2); //update direction bit

```



```

printf("Moving Motor %d steps\n", NumberOfPositions);

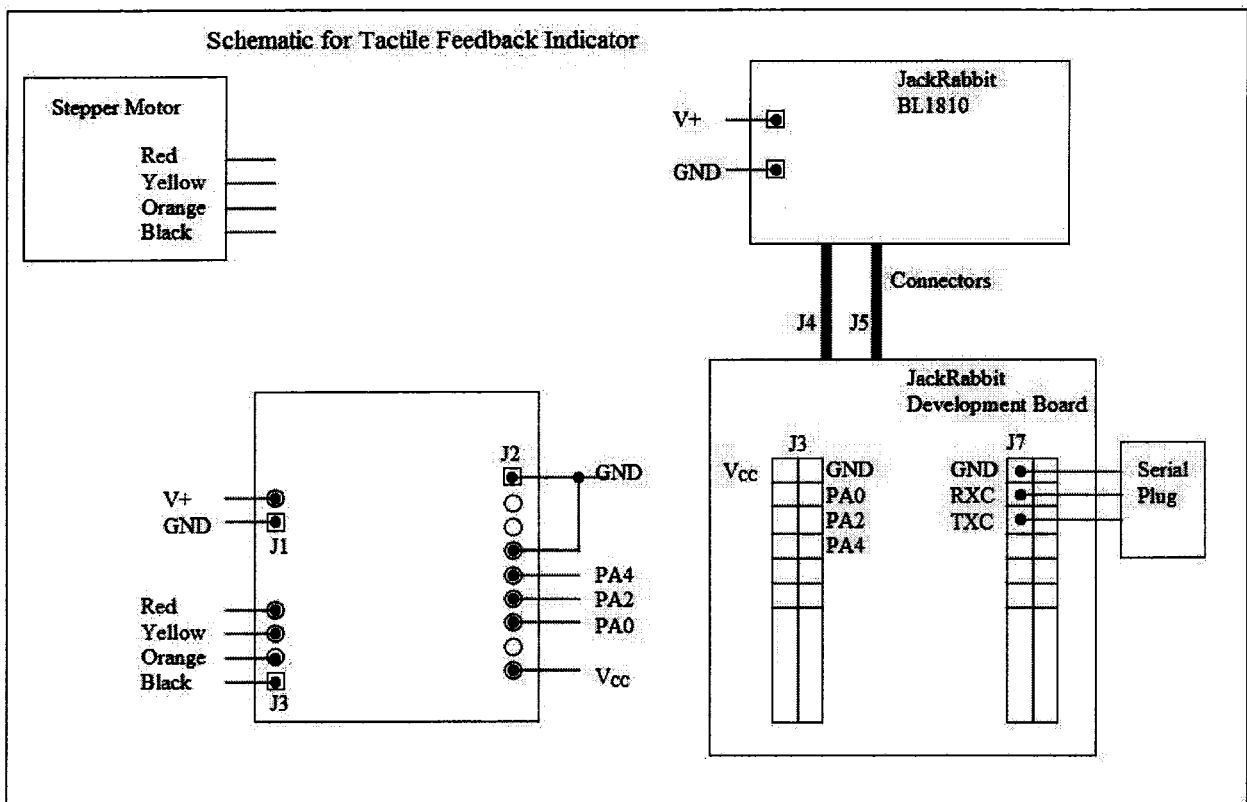
for (i=0; i < NumberOfPositions * ISteps; i++)
{
    BitWrPortI(PADR, &PADRShadow, 1, 4);           // clock on
    for(j=0; j < 800; j++);
    BitWrPortI(PADR, &PADRShadow, 0, 4);           //clock off;
    for(j=0; j < 800; j++);
}
printf("Motor Moved\n");

BitWrPortI(PADR, &PADRShadow, 1,4);               // make sure clock is on

WrPortI(SCDR, NULL, 'A');
}

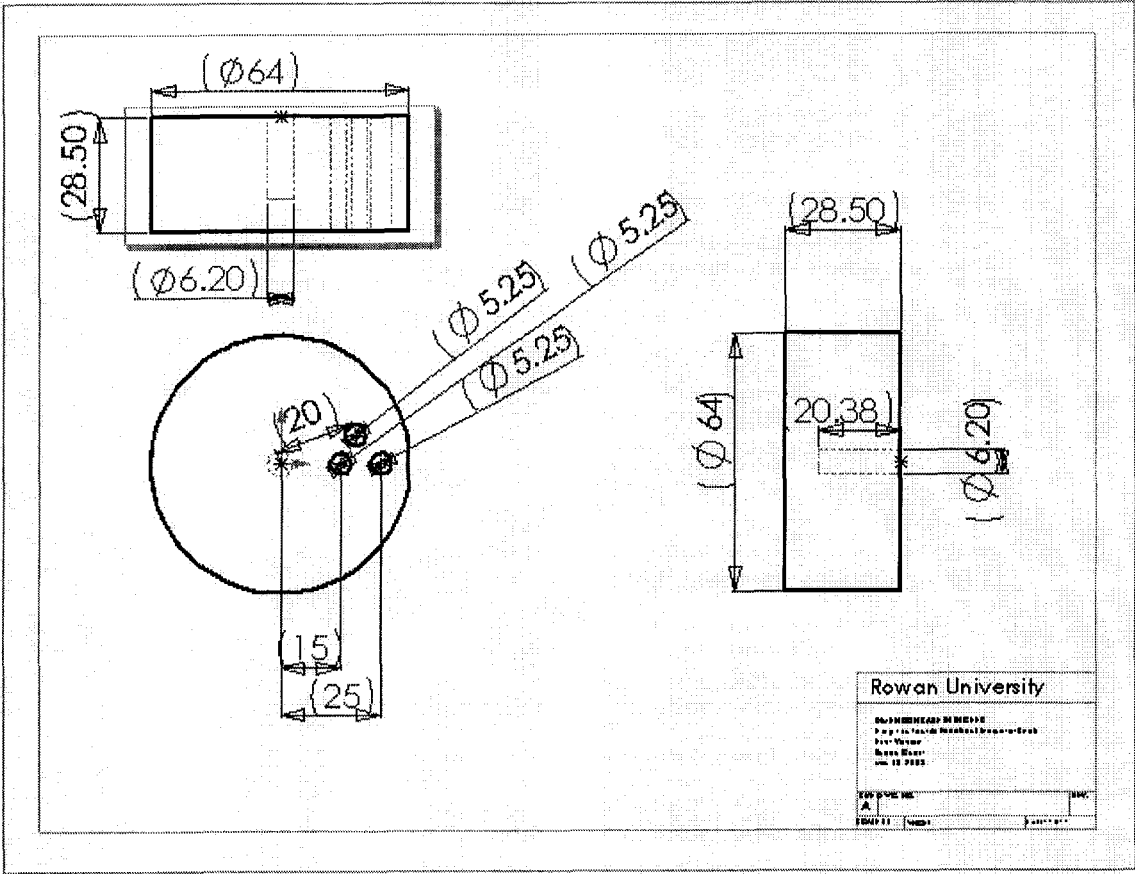
```

## B.2.2 Schematic

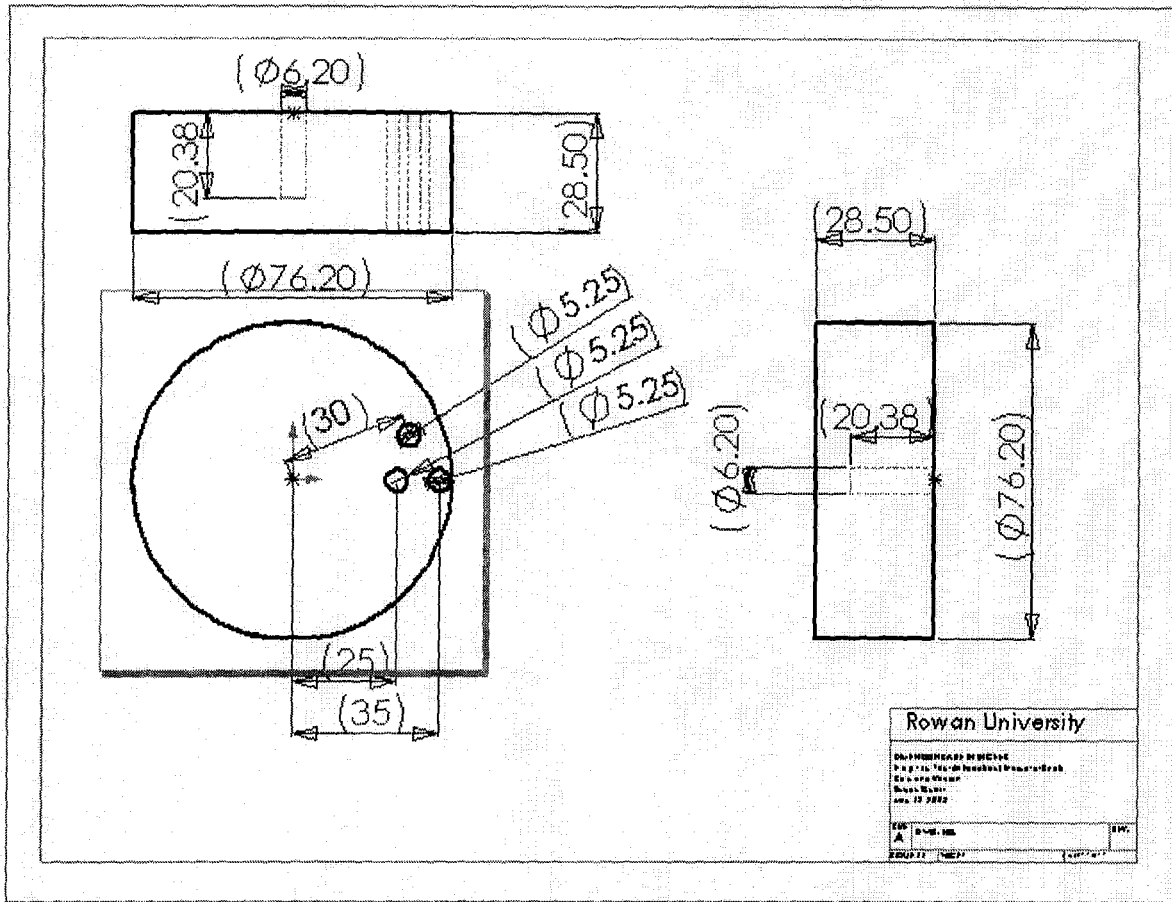


**B.3 Construction of Test Setup**

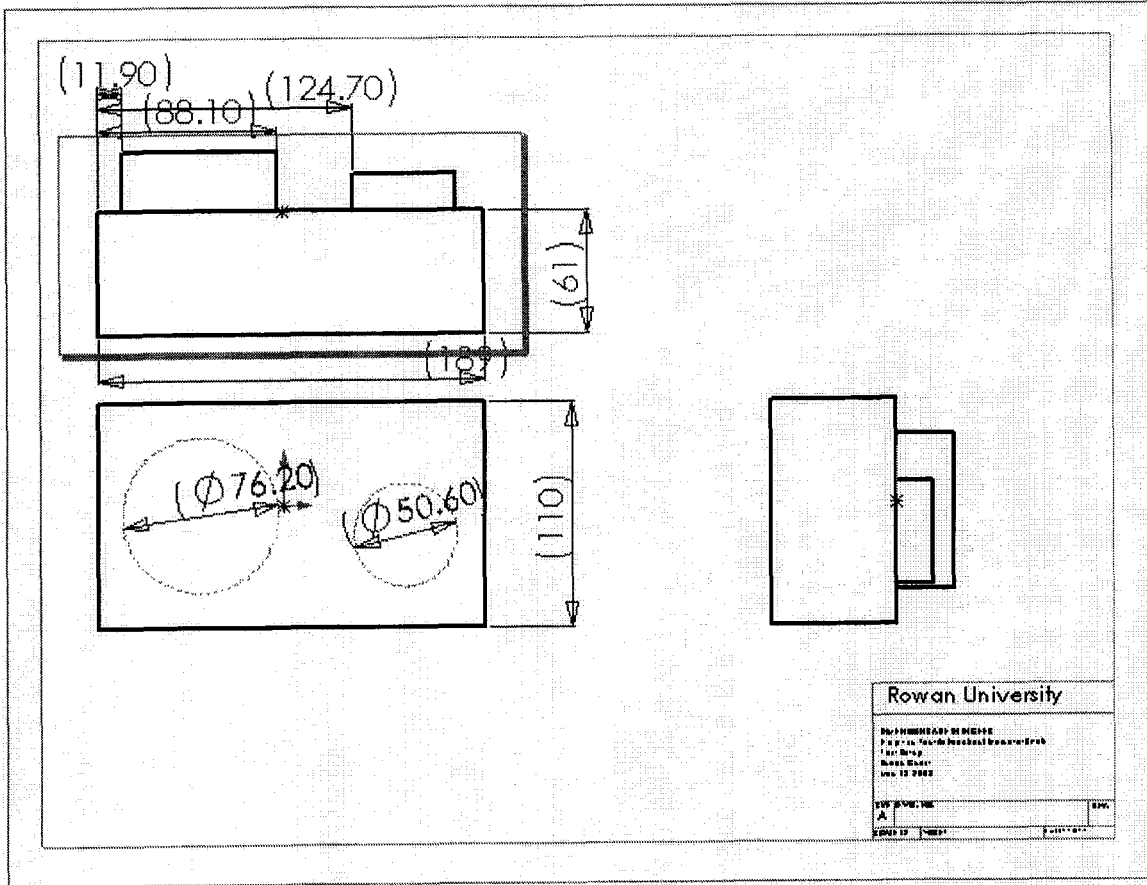
**B.3.1 First Knob Design**



### B.3.2 Second Knob Design



### B.3.3 Test Design



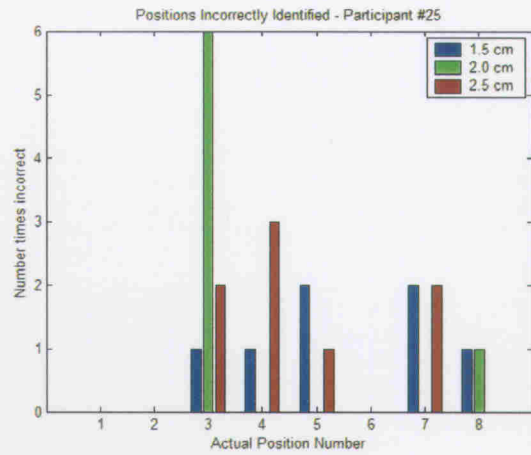
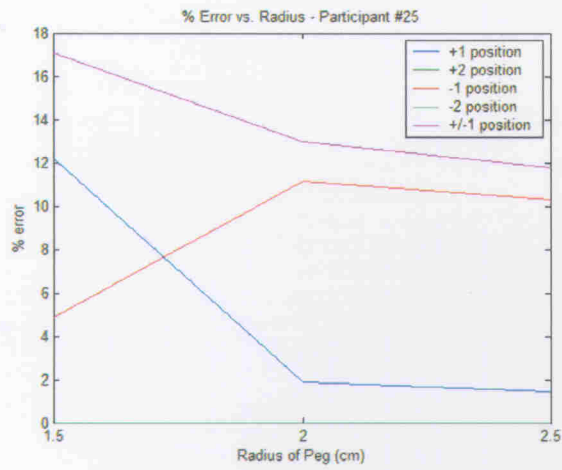
# Appendix C

## C.1 Individual Results

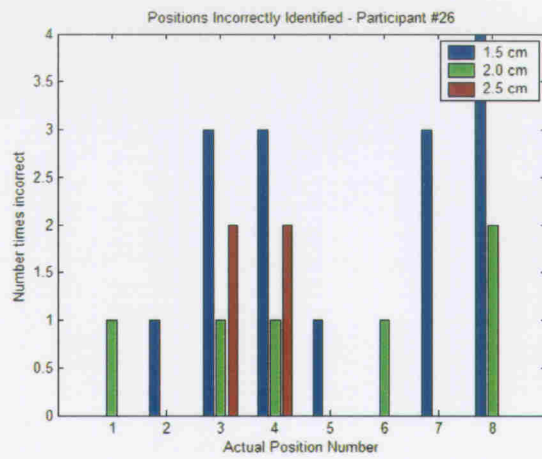
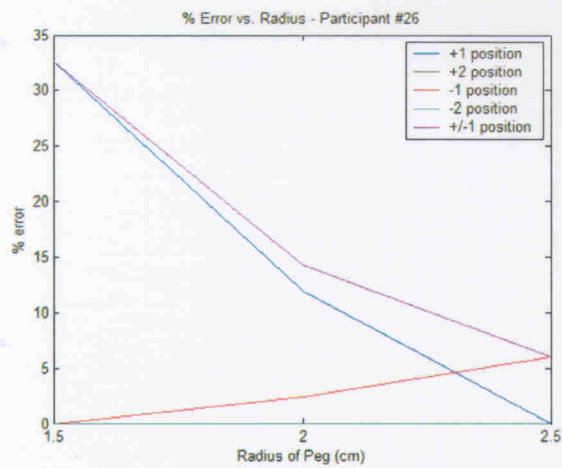
### C.1.1 First Experimental Trials

Numbering started at 25.

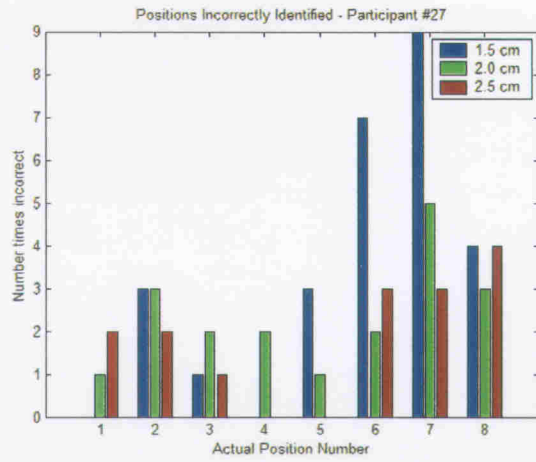
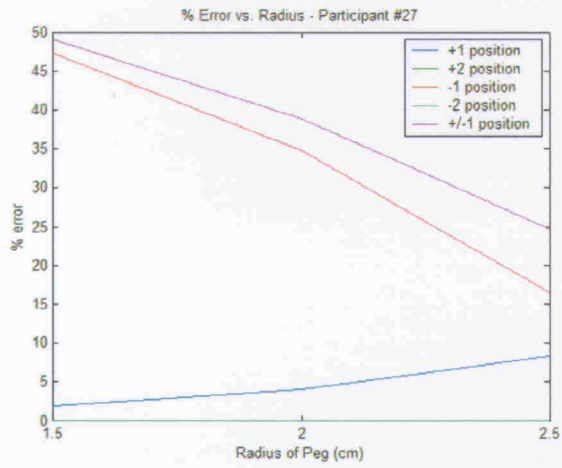
#### Participant #25



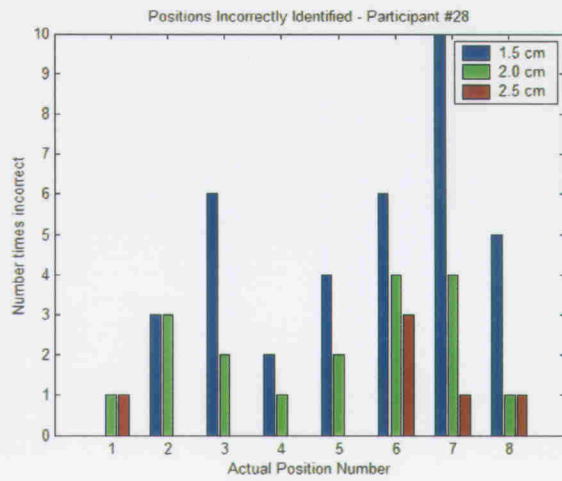
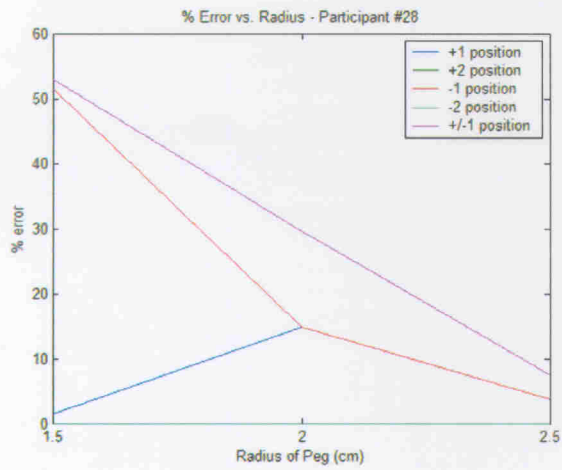
#### Participant #26



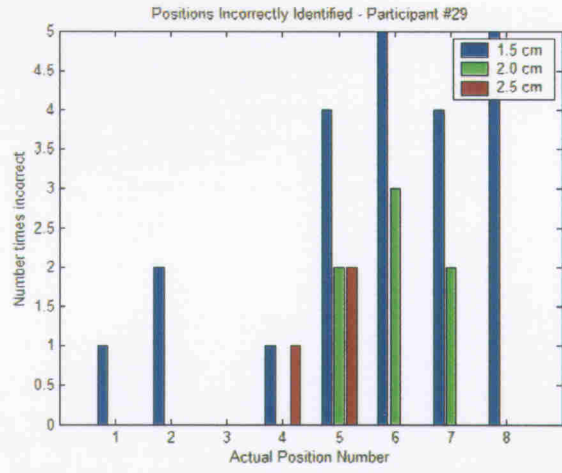
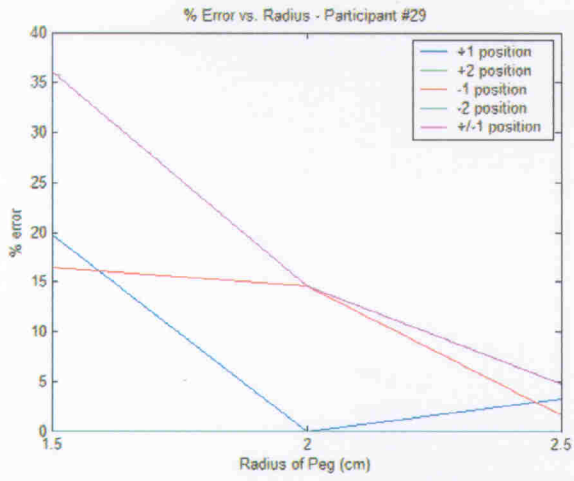
## Participant #27



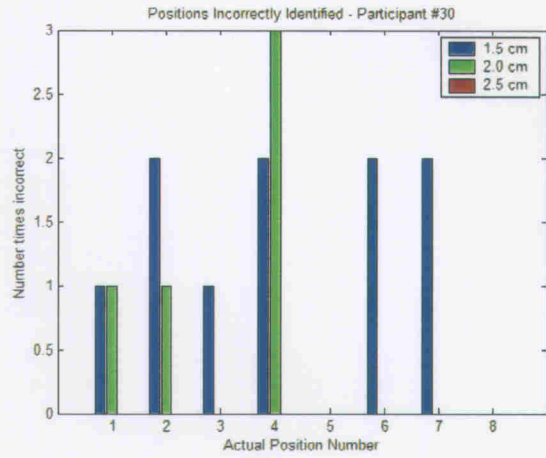
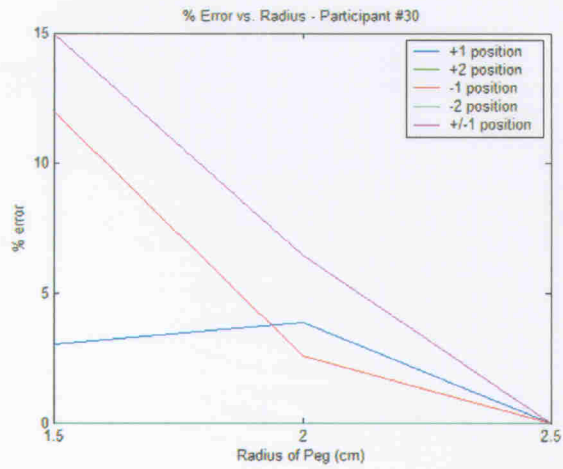
## Participant #28



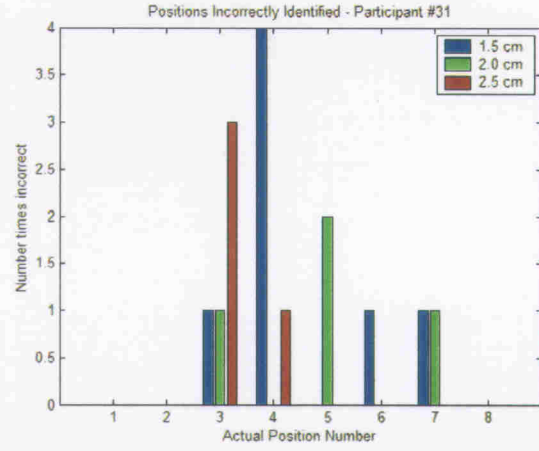
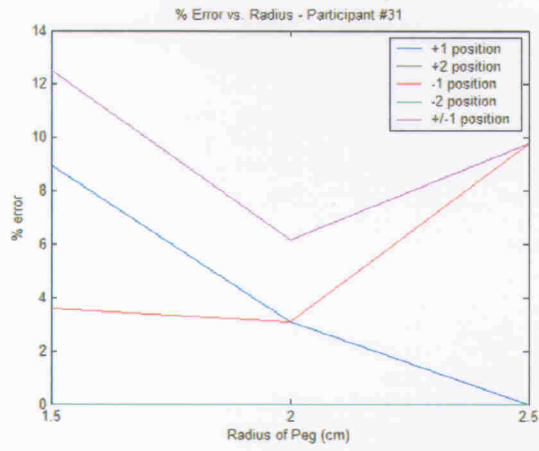
## Participant #29



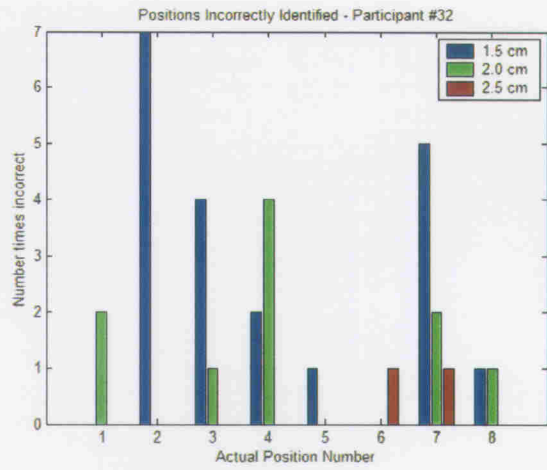
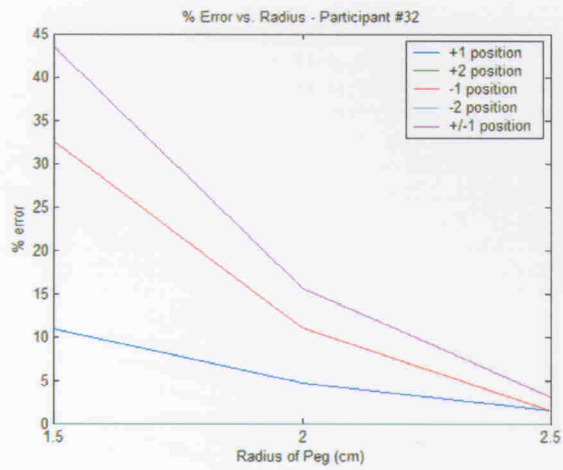
## Participant #30



Participant #31

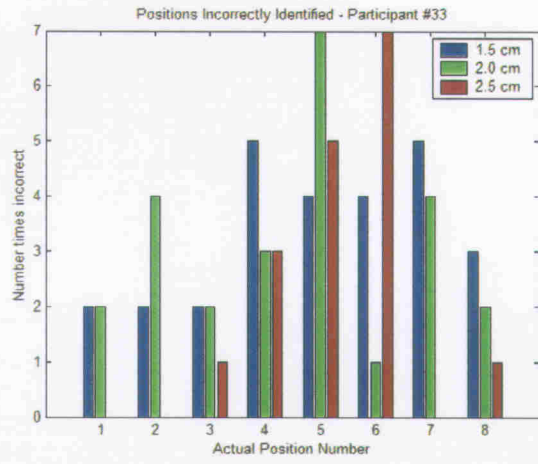
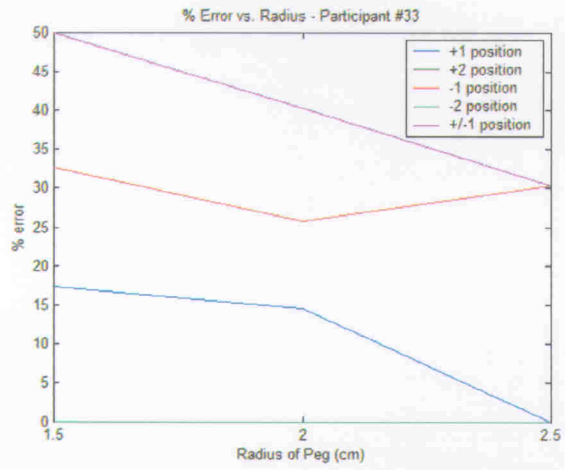


Participant #32



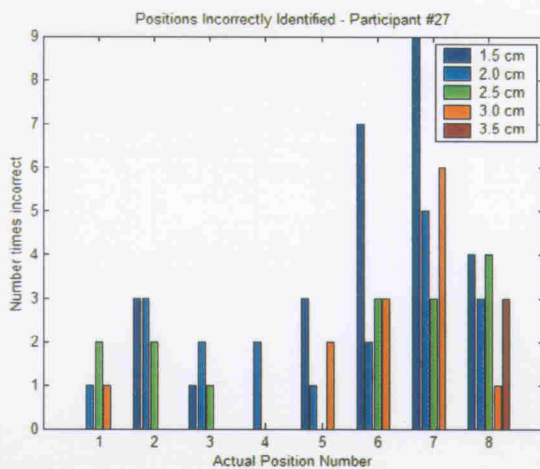
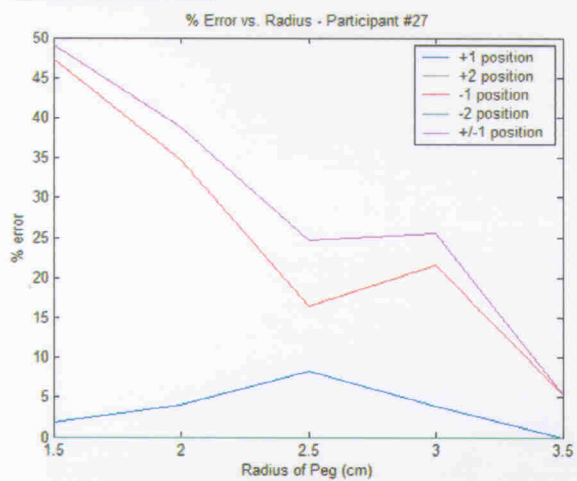


# Participant #33

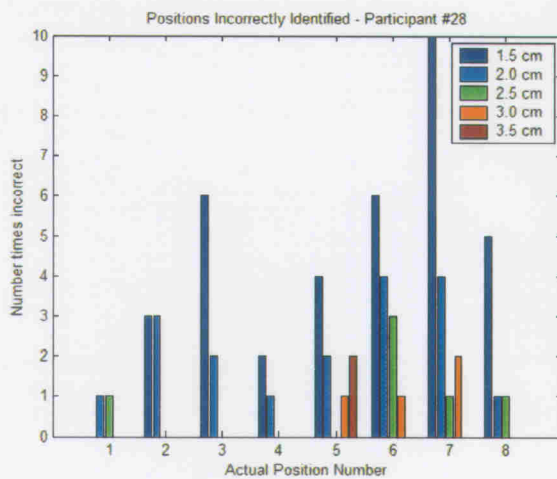
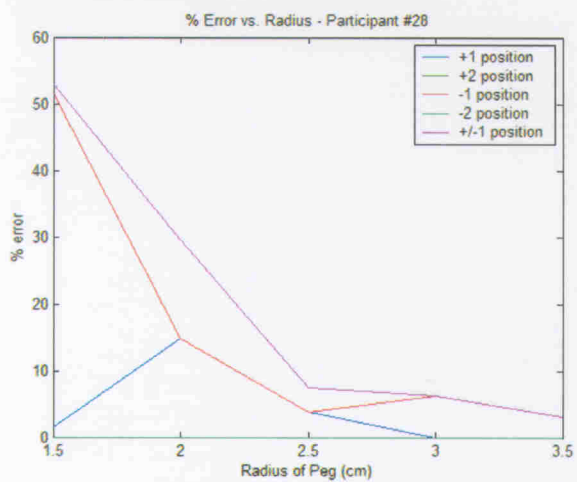


## C.1.2 Second Experimental Trials

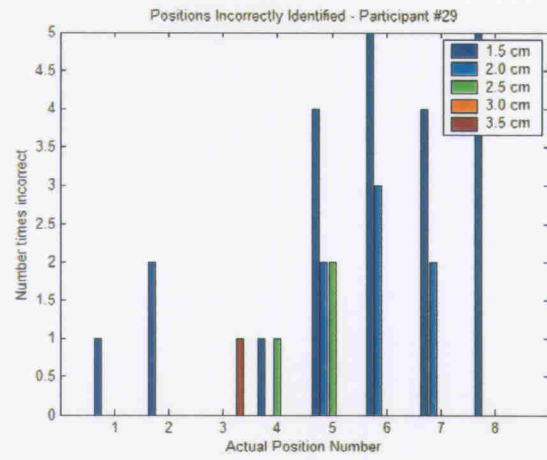
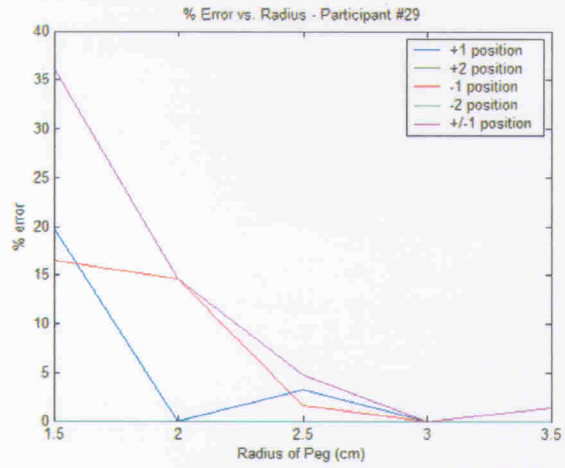
### Participant # 27



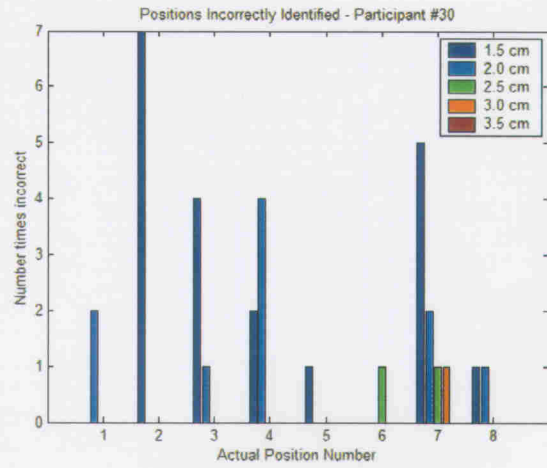
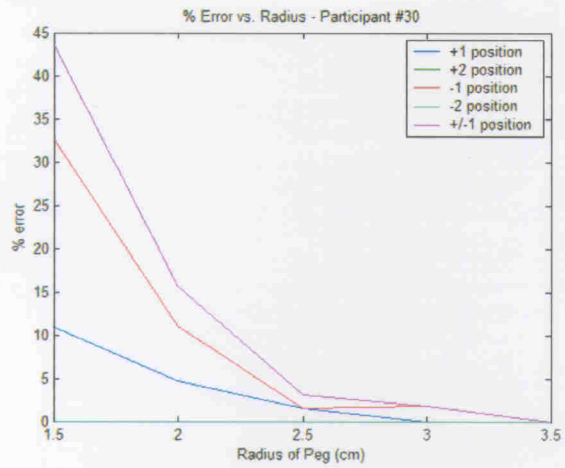
### Participant # 28



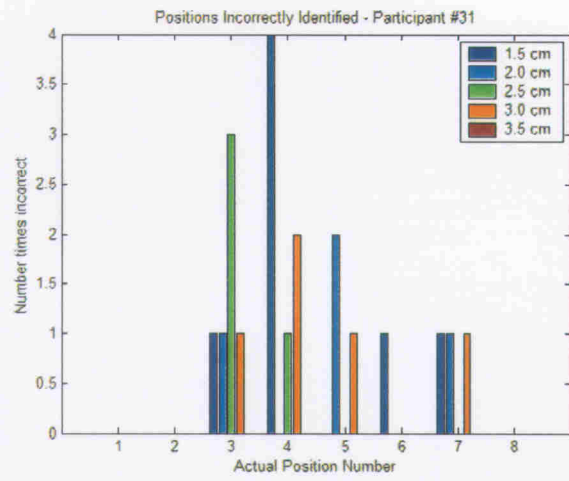
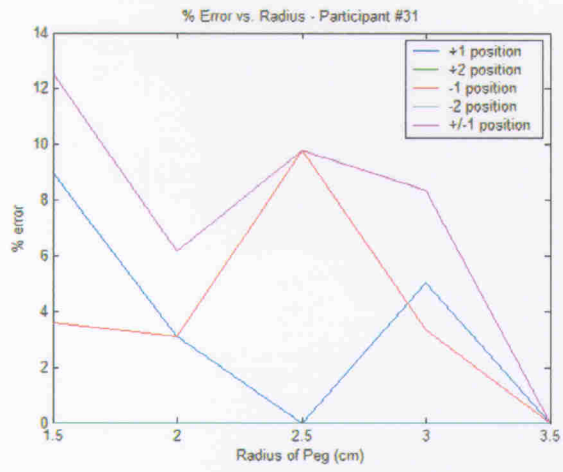
### Participant # 29



### Participant # 30



## Participant # 31



## C.2 Matlab Code for Results

### C.2.1 Individual Analysis

#### C.2.1.1 First Series

```
% Data Analysis of Palmdata
% 4/08/03

clear all; close all;

%part_num=22;
part_num = input('What participant number do you want to look at? ');

% ***** A - 1.5 cm *****
all_data = dlmread([num2str(part_num) '_15.txt'],' ');
guess_all = all_data(:,1:8);
correct = all_data(:,9);
bar_graph = [ 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ;];

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
    if diff ~= 0,
        bar_graph(correct(index),1)=bar_graph(correct(index),1)+1;
    end
end

missed_a = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==-1))
length(find(missed_by==2)) (length(find(missed_by==1))+length(find(missed_by==-1)))];
missed_per_a = (missed_a / length(missed_by)).*100;

% ***** B - 2.0 cm *****
clear all_data guess_all correct Y guess missed_by;
all_data = dlmread([num2str(part_num) '_20.txt'],' ');
guess_all = all_data(:,1:8);
correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
end
```

```

    if diff ~= 0,
        bar_graph(correct(index),2)=bar_graph(correct(index),2)+1;
    end
end

missed_b = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==3))
length(find(missed_by==4)) (length(find(missed_by==1))+length(find(missed_by==2))+length(find(missed_by==3))+length(find(missed_by==4)))];
missed_per_b = (missed_b ./ length(missed_by)).*100;

% ***** C - 2.5 cm *****
clear all_data guess_all correct Y guess missed_by;
all_data = dlmread([num2str(part_num) '_25.txt'],'');
guess_all = all_data(:,1:8);
correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
    if diff ~= 0,
        bar_graph(correct(index),3)=bar_graph(correct(index),3)+1;
    end
end

missed_c = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==3))
length(find(missed_by==4)) (length(find(missed_by==1))+length(find(missed_by==2))+length(find(missed_by==3))+length(find(missed_by==4)))];
missed_per_c = (missed_c ./ length(missed_by)).*100;

plot_1 = [missed_per_a(1,2) missed_per_b(1,2) missed_per_c(1,2)];
plot_2 = [missed_per_a(1,3) missed_per_b(1,3) missed_per_c(1,3)];
plot_3 = [missed_per_a(1,4) missed_per_b(1,4) missed_per_c(1,4)];
plot_4 = [missed_per_a(1,5) missed_per_b(1,5) missed_per_c(1,5)];
plot_5 = [missed_per_a(1,6) missed_per_b(1,6) missed_per_c(1,6)];
t=[1.5 2.0 2.5];

plot(t,plot_1,t,plot_2,t,plot_3,t,plot_4,t,plot_5);
legend ('+1 position','+2 position','-1 position','-2 position','+/-1 position');
xlabel('Radius of Peg (cm)');
ylabel('% error');
title([' % Error vs. Radius - Participant #' num2str(part_num) ]);

figure;
bar(bar_graph);
title(['Positions Incorrectly Identified - Participant #' num2str(part_num) ]);
ylabel('Number times incorrect');
xlabel('Actual Position Number');
legend('1.5 cm','2.0 cm','2.5 cm');

```

### C.2.1.2 Second Series

% Data Analysis of Palmdata  
 % 4/08/03

clear all; close all;

```

%part_num=22;
part_num = input('What participant number do you want to look at? ');

% ***** A - 1.5 cm *****
all_data = dlmread([num2str(part_num) '_15.txt'],' ');
guess_all = all_data(:,1:8);
correct = all_data(:,9);
bar_graph= [ 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0;];

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
    if diff ~= 0,
        bar_graph(correct(index),1)=bar_graph(correct(index),1)+1;
    end
end

missed_a = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==-1))
length(find(missed_by==2)) (length(find(missed_by==1))+length(find(missed_by==-1)))];
missed_per_a = (missed_a ./ length(missed_by)).*100;

% ***** B - 2.0 cm *****
clear all_data guess_all correct Y guess missed_by;
all_data = dlmread([num2str(part_num) '_20.txt'],' ');
guess_all = all_data(:,1:8);
correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
    if diff ~= 0,
        bar_graph(correct(index),2)=bar_graph(correct(index),2)+1;
    end
end

missed_b = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==-1))
length(find(missed_by==2)) (length(find(missed_by==1))+length(find(missed_by==-1)))];
missed_per_b = (missed_b ./ length(missed_by)).*100;

% ***** C - 2.5 cm *****
clear all_data guess_all correct Y guess missed_by;
all_data = dlmread([num2str(part_num) '_25.txt'],' ');
guess_all = all_data(:,1:8);
correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

```

```

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
    if diff ~= 0,
        bar_graph(correct(index),3)=bar_graph(correct(index),3)+1;
    end
end

missed_c = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==-1))
length(find(missed_by==-2)) (length(find(missed_by==1))+length(find(missed_by==-1)))];
missed_per_c = (missed_c ./ length(missed_by)).*100;

% ***** D - 3.0 cm *****
clear all_data guess_all correct Y guess missed_by;
all_data = dlmread([num2str(part_num) '_30.txt'],' ');
guess_all = all_data(:,1:8);
correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
    if diff ~= 0,
        bar_graph(correct(index),4)=bar_graph(correct(index),4)+1;
    end
end

missed_d = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==-1))
length(find(missed_by==-2)) (length(find(missed_by==1))+length(find(missed_by==-1)))];
missed_per_d = (missed_d ./ length(missed_by)).*100;

% ***** D - 3.5 cm *****
clear all_data guess_all correct Y guess missed_by;
all_data = dlmread([num2str(part_num) '_35.txt'],' ');
guess_all = all_data(:,1:8);
correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
end

```



```

if diff ~= 0,
    bar_graph(correct(index),5)=bar_graph(correct(index),5)+1;
end
end

missed_e = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==-1))
length(find(missed_by==2)) (length(find(missed_by==1))+length(find(missed_by==-1)))];
missed_per_e = (missed_e ./ length(missed_by)).*100;

plot_1 = [missed_per_a(1,2) missed_per_b(1,2) missed_per_c(1,2) missed_per_d(1,2) missed_per_e(1,2)];
plot_2 = [missed_per_a(1,3) missed_per_b(1,3) missed_per_c(1,3) missed_per_d(1,3) missed_per_e(1,3)];
plot_3 = [missed_per_a(1,4) missed_per_b(1,4) missed_per_c(1,4) missed_per_d(1,4) missed_per_e(1,4)];
plot_4 = [missed_per_a(1,5) missed_per_b(1,5) missed_per_c(1,5) missed_per_d(1,5) missed_per_e(1,5)];
plot_5 = [missed_per_a(1,6) missed_per_b(1,6) missed_per_c(1,6) missed_per_d(1,6) missed_per_e(1,6)];
t=[1.5 2.0 2.5 3.0 3.5];

plot(t,plot_1,t,plot_2,t,plot_3,t,plot_4,t,plot_5);
legend ('+1 position','+2 position','-1 position','-2 position','+/-1 position');
xlabel('Radius of Peg (cm)');
ylabel('% error');
title([' % Error vs. Radius - Participant #' num2str(part_num) ]);

figure;
bar(bar_graph);
title(['Positions Incorrectly Identified - Participant #' num2str(part_num) ]);
ylabel('Number times incorrect');
xlabel('Actual Position Number');
legend('1.5 cm','2.0 cm','2.5 cm','3.0 cm','3.5 cm');

```

## C.2.2 Overall Analysis

### C.2.2.1 First Series

```
% Data Analysis of Palmdata
% 4/08/03

clear all; close all;

num_start = input('Enter starting number: ');
num_end = input('Enter ending number: ');
sum_a=[0 0 0 0 0];
sum_b=[0 0 0 0 0];
sum_c=[0 0 0 0 0];
bar_graph = [ 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ;];
sum_bar = [ 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ; 0 0 0 ;];

for part_num = num_start:num_end,

% ***** A - 1.5 cm *****
all_data = dlmread([num2str(part_num) '_15.txt'],' ');
guess_all = all_data(:,1:8);
correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
    if diff ~= 0,
        bar_graph(correct(index),1)=bar_graph(correct(index),1)+1;
    end
end

missed_a = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==-1))
length(find(missed_by==2)) (length(find(missed_by==1))+length(find(missed_by==-1)))];
missed_per_a = (missed_a ./ length(missed_by)).*100;

% ***** B - 2.0 cm *****
clear all_data guess_all correct Y guess missed_by;
all_data = dlmread([num2str(part_num) '_20.txt'],' ');
guess_all = all_data(:,1:8);
correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
end
```

```

        missed_by(index,1)=diff;
    end
    if diff ~= 0,
        bar_graph(correct(index),2)=bar_graph(correct(index),2)+1;
    end
end

missed_b = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==-1))
length(find(missed_by==2)) (length(find(missed_by==1))+length(find(missed_by==-1)))];
missed_per_b = (missed_b ./ length(missed_by)).*100;

% ***** C - 2.5 cm *****
clear all_data guess_all correct Y guess missed_by;
all_data = dlmread([num2str(part_num) '_25.txt'],' ');
guess_all = all_data(:,1:8);
correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
    if diff ~= 0,
        bar_graph(correct(index),3)=bar_graph(correct(index),3)+1;
    end
end

missed_c = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==-1))
length(find(missed_by==2)) (length(find(missed_by==1))+length(find(missed_by==-1)))];
missed_per_c = (missed_c ./ length(missed_by)).*100;

sum_a = sum_a + missed_per_a;
sum_b = sum_b + missed_per_b;
sum_c = sum_c + missed_per_c;
sum_bar = sum_bar + bar_graph;
end

avg_sum_a = sum_a ./ (num_end-num_start+1);
avg_sum_b = sum_b ./ (num_end-num_start+1);
avg_sum_c = sum_c ./ (num_end-num_start+1);

plot_1 = [avg_sum_a(1,2) avg_sum_b(1,2) avg_sum_c(1,2)];
plot_2 = [avg_sum_a(1,3) avg_sum_b(1,3) avg_sum_c(1,3)];
plot_3 = [avg_sum_a(1,4) avg_sum_b(1,4) avg_sum_c(1,4)];
plot_4 = [avg_sum_a(1,5) avg_sum_b(1,5) avg_sum_c(1,5)];
plot_5 = [avg_sum_a(1,6) avg_sum_b(1,6) avg_sum_c(1,6)];
t = [1.5 2.0 2.5];

plot(t,plot_1,t,plot_2,t,plot_3,t,plot_4,t,plot_5);
legend ('+1 position','+2 position','-1 position','-2 position','+/- 1 position');
xlabel('Radius of Peg (cm)');
ylabel('% error');
title('% Error vs. Radius - All Participants');

figure;
bar(bar_graph);
title('Positions Incorrectly Identified - All Participants');
ylabel('Number of times misidentified');
xlabel('Actual Position Number');
legend('1.5 cm','2.0 cm','2.5 cm');

```

## C.2.2.2 Second Series

```
% Data Analysis of Palmdata
% 4/08/03

clear all; close all;

sum_a=[0 0 0 0 0];
sum_b=[0 0 0 0 0];
sum_c=[0 0 0 0 0];
sum_d=[0 0 0 0 0];
sum_e=[0 0 0 0 0];
bar_graph = [ 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0;];
sum_bar = [ 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0; 0 0 0 0 0;];

num_start = input('Enter starting number: ');
num_end = input('Enter ending number: ');

for part_num = num_start:num_end,

% ***** A - 1.5 cm *****
all_data = dlmread([num2str(part_num) '_15.txt'],' ');
guess_all = all_data(:,1:8);
correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
    if diff ~= 0,
        bar_graph(correct(index),1)=bar_graph(correct(index),1)+1;
    end
end

missed_a = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==-1))
length(find(missed_by==2)) (length(find(missed_by==1))+length(find(missed_by==-1)))];
missed_per_a = (missed_a ./ length(missed_by)).*100;

% ***** B - 2.0 cm *****
clear all_data guess_all correct Y guess missed_by;
all_data = dlmread([num2str(part_num) '_20.txt'],' ');
guess_all = all_data(:,1:8);
correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
    if diff ~= 0,
```

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        bar_graph(correct(index),2)=bar_graph(correct(index),2)+1;
    end
end

missed_b = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==3))
length(find(missed_by==4)) (length(find(missed_by==1))+length(find(missed_by==2))+length(find(missed_by==3)))]);
missed_per_b = (missed_b ./ length(missed_by)).*100;

% ***** C - 2.5 cm *****
clear all_data guess_all correct Y guess missed_by;
all_data = dlmread([num2str(part_num) '_2.5.txt'],'');
guess_all = all_data(:,1:8);
correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
    if diff ~= 0,
        bar_graph(correct(index),3)=bar_graph(correct(index),3)+1;
    end
end

missed_c = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==3))
length(find(missed_by==4)) (length(find(missed_by==1))+length(find(missed_by==2))+length(find(missed_by==3)))]);
missed_per_c = (missed_c ./ length(missed_by)).*100;

% ***** D - 3.0 cm *****
clear all_data guess_all correct Y guess missed_by;
all_data = dlmread([num2str(part_num) '_3.0.txt'],'');
guess_all = all_data(:,1:8);
correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
    if diff ~= 0,
        bar_graph(correct(index),4)=bar_graph(correct(index),4)+1;
    end
end

missed_d = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==3))
length(find(missed_by==4)) (length(find(missed_by==1))+length(find(missed_by==2))+length(find(missed_by==3)))]);
missed_per_d = (missed_d ./ length(missed_by)).*100;

% ***** E - 3.5 cm *****
clear all_data guess_all correct Y guess missed_by;
all_data = dlmread([num2str(part_num) '_3.5.txt'],'');
guess_all = all_data(:,1:8);

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correct = all_data(:,9);

[Y,guess]=max(guess_all');
guess=guess';

for index=1:length(correct),
    diff=guess(index)-correct(index);
    if abs(diff) > 4,
        if diff > 0,
            missed_by(index,1)=diff-8;
        else
            missed_by(index,1)=8-abs(diff);
        end
    else
        missed_by(index,1)=diff;
    end
    if diff ~= 0,
        bar_graph(correct(index),5)=bar_graph(correct(index),5)+1;
    end
end

missed_e = [length(find(missed_by==0)) length(find(missed_by==1)) length(find(missed_by==2)) length(find(missed_by==-1))
length(find(missed_by==-2))] / (length(find(missed_by==1))+length(find(missed_by==-1)));
missed_per_e = (missed_e ./ length(missed_by)).*100;

sum_a = sum_a + missed_per_a;
sum_b = sum_b + missed_per_b;
sum_c = sum_c + missed_per_c;
sum_d = sum_d + missed_per_d;
sum_e = sum_e + missed_per_e;
sum_bar = sum_bar + bar_graph;

end

avg_sum_a = sum_a ./ (num_end-num_start+1);
avg_sum_b = sum_b ./ (num_end-num_start+1);
avg_sum_c = sum_c ./ (num_end-num_start+1);
avg_sum_d = sum_d ./ (num_end-num_start+1);
avg_sum_e = sum_e ./ (num_end-num_start+1);

plot_1 = [avg_sum_a(1,2) avg_sum_b(1,2) avg_sum_c(1,2) avg_sum_d(1,2) avg_sum_e(1,2)];
plot_2 = [avg_sum_a(1,3) avg_sum_b(1,3) avg_sum_c(1,3) avg_sum_d(1,3) avg_sum_e(1,3)];
plot_3 = [avg_sum_a(1,4) avg_sum_b(1,4) avg_sum_c(1,4) avg_sum_d(1,4) avg_sum_e(1,4)];
plot_4 = [avg_sum_a(1,5) avg_sum_b(1,5) avg_sum_c(1,5) avg_sum_d(1,5) avg_sum_e(1,5)];
plot_5 = [avg_sum_a(1,6) avg_sum_b(1,6) avg_sum_c(1,6) avg_sum_d(1,6) avg_sum_e(1,6)];
t = [1.5 2.0 2.5 3.0 3.5];

plot(t,plot_1,t,plot_2,t,plot_3,t,plot_4,t,plot_5);
legend ('+1 position','+2 position','-1 position','-2 position','+/-1 position');
xlabel('Radius of Peg (cm)');
ylabel('% error');
title('% Error vs. Radius - All Participants');

figure;
bar(bar_graph);
title('Positions Incorrectly Identified - All Participants');
ylabel('Number of times misidentified');
xlabel('Actual Position Number');
legend('1.5 cm','2.0 cm','2.5 cm','3.0 cm','3.5 cm');

```