Magnetic Motion Tracking System

by

Christopher Otto

A Thesis
submitted to the Faculty of Graduate Studies,
in Partial Fulfilment of the Requirements for the degree of

Master of Science
in
Electrical and Computer Engineering

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Abstract

Current methodology such as constraint-induced therapy offers little to keep patients motivated to continue the duration of therapy. Other methods such as biofeedback via Virtual Reality using haptic or input devices using EMG both do not allow common objects to be instrumented to interface with low cost off-the-shelf gaming to motivate exercise, assessment and therapy. An embedded peripheral electronic device was created to interface between a pulsed DC magnetic six degree-of-freedom motion sensor and a USB compatible computer for purposes of instrumenting a wide range of objects and transforming them into a universal joystick or mouse device in order to play off-the-shelf commercial video games to make meaningful and multifunctional movements and exercises in practice and rehabilitation training fun and enjoyable.

Secondly, the Assessment Rehabilitation Tool (ART) was created to log the coordinates of a USB mouse and output of the peripheral electronic interface device synchronously drawing an on-screen bright cursor moving in predictable and random trajectories. With this tool the fidelity and responsiveness of the magnetic motion tracking sensor and peripheral electronic device could be measured against the standard computer mouse for both predictable and random motion trajectories typical of commercial video games.

Residual waveform cross-correlations showed an average error of 1.13±0.02% difference in correlation from a standard waveform between a USB mouse and the proposed system. The difference was 1.4±2.0% using non-standard objects including wands, a leather ball, and cart. Compared to the standard computer mouse the results show that the level difference is directly dependant on the object used and that some objects have distinct advantages in certain motions or axis. Overall it is shown that the sensor and embedded system compare in performance to a standard HID compliant mouse. This system has the accuracy and responsiveness that has not been previously possible, that allows a wide range of exercise activity to universally interface with off-the-shelf gaming products to motivate long-term rehabilitation therapy.
Keywords: Biofeedback, ...

Acknowledgements

This has been a long and rewarding journey. I have had an opportunity to harness my engineering skills that I have accumulated throughout time to direct it to such a worthwhile project. I can see many future and present scenarios where this type of technology can be applied to the benefit of those who struggle to regain lost functionality of their limbs and movement.

I would like to thank both Dr. Peters and Dr. Szturm for theirThesis1998 guidance, wisdom, and patience throughout this project. I would not have been able to partake in such a worthwhile and satisfying endeavor without your valued council. I sincerely thank you both for everything you have done.

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1 Introduction

1.1 Motivation

Chronic disabling neurological and musculo-skeletal disorders and injuries of the hand and arm affect millions of children, adults and older people worldwide. For example, As of 1993 there were approximately 40 million Americans classified as disabled [17]. Social cost is in the billions of dollars [17]. Current statistics on demographics and health status within North America and Europe show that the number of people with long-standing disabilities will increase in the next 20-30 years to 20% of the population over 60 and 10% of the population fewer than 60. The increasing numbers and the diversity and heterogeneity of these populations with disabilities and handicaps will require novel solutions and require that rehabilitation treatments be flexible and accommodate individual differences and rural and remote communities, and also be able to be used in a home setting.

The motivation of this thesis is to address the need of a key-missing piece in rehabilitation for finger-hand-arm functions. The goal of rehabilitation is to enhance and maximize functional recovery and the state of livelihood enjoyed before a given action, illness, or condition.

Much of daily life requires manipulation and handling of diverse objects, utensils and tools, many of which require a high degree of precision and are often unstable, i.e. small deviations from the correct behavior of the manipulated object leads to complete disruption of performance. For example, the safe transport of the soup to one's mouth is one of the challenges facing individuals with neurological and musculo-skeletal disorders and injuries.

Recovery from many neurological and musculo-skeletal disorders or injuries is often a long and difficult process. Thus a significant percentage of patients give up on their treatment and do not complete the rehabilitation process[[**?**]]. This substantially limits the amount of functional gains for the patient who is unwilling to endure the exercises on a prescribed regular basis[[**?**]]. Some therapies, such as constraint-induced therapy, directly force the patient to utilize the damaged appendage by removing the ability to use the unaffected hand or arm. While this technique can be effective, the motivation to endure this type of rehabilitation is trying on the willingness and patience to continue with treatment. It has been shown that the end result of a sustained task-specific treatment will yield improved results to the patient.

On the other side, there are treatments that incorporate more motivational technology. Biofeedback, force-feedback, virtual immersion are all examples of this philosophy[[26]]. The intended goal is a much more user-centric style of motivation to promote the successful completion of treatment.

However each one of these treatments lack the customization that will motivate and encourage a patient to continue treatment. Many of the techniques such as the virtual immersion systems/software and 3-degree-of-freedom manipulandums used in force feedback are expensive and not readily suitable for home use by the client. It is also the case that patients in remote rural and northern locations cannot access the same facilities as larger urban areas. It is not possible to place an expensive unit and system where each patient resides to further their respective treatment and encourage continued practice to achieve prolonged and improved results.

1.2 Purpose and Objectives

The purpose of this work was to provide a cost-effective therapy alternative for recovery of fine and gross finger-hand functions that:

a) are consistent with modern concepts of motor recovery and neuromuscular adaptation [23] which favor a task-specific [21], repetitive approach [31].

b) incorporates the beneficial properties of therapies such as virtual immersion, and biofeedback

Thus the development of a system that a) meets the above definition and b) can be shown that it is a feasible method by demonstrating its ability to facilitate its required function.

The first objective is to create a system that combines the beneficial properties of previous techniques and creates a functional, motivational, and cost effective system. To achieve this goal an embedded interface attached to a high precision six-degree-of-freedom position and orientation motion tracking sensor was created. The motion-tracking sensor employed is a pulsed DC magnetic-tracking sensor. This device mimics a standard joystick or mouse interface that can translate the sensor's information into the desired output.

The second objective is to demonstrate the ability of the miniature motion-tracking sensor and the developed interface device and show that it can perform the required interfacing between a therapeutic exercise independent of object geometry and material properties and a virtual game. It will also be necessary to show that against a qualified metric, that therapeutic exercise and natural movements using real objects through the embedded system can produce viable output that will allow the patent to participate in a virtual gaming experience and be competitive to retain motivation.

Lastly, the final objective will be to show that exercise motivation, or motivation to continue rehabilitation exercises is obtained and encouraged through the use of the embedded system that was developed.

1.3 Organization of Thesis

The introductory chapter described the motivation and research objectives of this thesis. Chapter 2 provides Basic ideas and notation and background on current techniques used to encourage motivation in rehabilitative exercise and products that are currently in the field that assist with this objective. A comparison of the results obtained are compared with similar systems in Chapter 3. Chapter 4 describes the detail of the function of the system developed for this thesis as well as the testing mechanism developed to provide a metric for the experiments performed. Chapter 5 discusses the experimental methodology to demonstrate the functionality of the sensor used and the thesis device against a testing metric with the Assessment Rehabilitation Tool (ART). Chapter 6 discusses the results of the experiments performed, and results of the field-testing are presented. Finally conclusions and future work are presented in Chapter 7.

2 Biofeedback: Basic Ideas and Notation

This section presents some fundamental concepts, methods and notation related to biofeedback.

This chapter discusses current rehabilitation methodologies including biofeedback, virtual reality or virtual immersion, and constraint induced therapy. Current products in the field are also discussed.

2.1 Current Rehabilitation Techniques

2.1.1 Biofeedback

Feedback in any process, whether that is in rehabilitation or design, is an important inclusive element. Biofeedback has long been used clinically to augment training [10, 18]. A biological signal is recorded, amplified/conditioned and presented in real-time in a simplified format to the subject, while the subject attempts to move or perform a task. Many different types of biological signals, such as, single muscle activity (EMG), center of foot pressure or motion signals can be used in biofeedback to help patients associate a given action to a visual or auditory stimulus to use as a feedback metric. Positive, enhanced feedback is provided when the patient performs a given task within predefined bounds.

One example is EMG biofeedback, where the electrical activity of a weak muscle is recorded and is presented through visual or auditory means. [15, 10]. The benefit of this association between the EMG signal and the augmented visual/auditory feedback is the strengthening or creation of awareness of a muscle contraction. Biofeedback has also been incorporated into balance exercises using signals recorded from a biomechanical force plate. The force signals are converted into center of foot pressure that represents a time varying record of relative standing position [18, 29, 27]. It has also been incorporated into postural training [28, 30, 27].

The benefit of association is to strengthen or create awareness of a given activity or performance level to help that patient regain or learn an activity [18]. Exercises and techniques can be limited as a motivational by that same association as the activity and feedback can be one-dimensional in nature.

2.1.2 Virtual Immersion

The application of virtual reality and robotic technology to rehabilitation is also gaining much attention and interest because of the potential to be cost effective models of health care delivery [24]. In particular for individuals and clients to perform their programs independently at home with monitoring done by developed computer software (expert systems) that can be distributed over the Internet (tele-rehabilitation) [16] and accessed by most everyone. The other important and highly valued component or property of these treatment approaches is that they can be self-motivating and thus more likely to achieve regular and long term practice. As with biofeedback there is still a focus on the activity and movement with added stimulus to enhance the exercises. An important finding is that intensive training can be achieved with these systems. Virtual reality and robotic technology has been found to have potential as a training device in stroke rehabilitation [24].

2.1.3 Constraint Induced Therapy

To contrast the above methods, one emerging method to improve sensory-motor recovery of the upper extremity after stroke is constraint-induced movement (CIM) therapy [19, 20]. The non-afflicted arm and hand is cast or constrained by a sling or cast forcing the subjects to use their affected arm and hand. CIM has been shown in controlled studies to produce a substantial long-term improvement in the amount of use of the paretic extremity that transfers into the real world environment [14]. CIM therapy is believed to produce its therapeutic effect through massed practice (large volume of practice) using behaviorally relevant tasks. Lack of motivation or interest has been shown to impair the potential effectiveness of such therapeutic exercise especially when a large volume of practice is essential as in cases of central nervous system disorders and long-standing musculo-skeletal conditions. On the other hand the use of meaningful and rewarding activities has been shown to improve a patient's motivation to practice [11].

2.2 Previous Work and Current Related Work in the Field

2.2.1 Haptic Devices

Haptic devices are devices that provide force-feedback by generating interactive resistance to movement. This is accomplished via a three-segment motorized robotic arm and requires an Intel-based computer for its controls. This allows a user to experience simulated movement of objects within a virtual environment. One of its primary uses is for 3D modeling.

The most popular commercial haptic device is the "Phantom" manipulandum from SensAble Technologies [6]. This technology uses proprietary interfaces and software to communicate and interact with its manipulandum. The scope of software that is able to take advantage of this device is very limited due to its custom interface. Any interactive therapy software must be highly customized to achieve a compatible connection.

2.2.2 Therapeutic Robotics

InMotion [2] therapeutic robots consist of complex servo controlled motorized external mechanical devices that attach to the shoulder, elbow and/or wrist which serve to move or assist movement of the respective limb segment(s). Many precautions and over-ride systems are required to ensure no excessive "hazardous" movements ever occur. Patients recover more than twice as rapidly as those not receiving robotic therapy [2].

Each system includes a small number of proprietary "video games" that stroke patients find engaging, and that are designed to guide and elicit therapeutically meaningful movement.

2.2.3 Optical Recognition

IREX [3] is an interactive virtual reality solution in physical therapy equipment. IREX submerges a patient into a computer-generated world producing isolated joint movement, combined joint movements and full body functional movement of both upper and lower extremities.

A small number of proprietary interactive computer games are at the core of the system. Camera technology, similar to that of the Eye-Toy [7], is required to capture the patient's image on a computer monitor, which allows the patient to see his or herself move and interact with objects in a virtual environment. This technology allows for interactivity between the camera output and the proprietary game used. It does not allow for subtle or rotational movements due to the resolution of those movements.

2.2.4 Biomechanics and Balance

Neurogames [5] uses three proprietary video games to enhance rehabilitation and training of balance and mobility. The input device is a large servo controlled moving platform and visual surround or a custom platform with biomechanical force plate.

2.2.5 EEG and EMG Biofeedback Systems

Thought Technologies [8] includes EMG and EEG as input biological signal. As with the other products a small number of proprietary game-like programs and other software are available for this product. The core of the technology is focused on biofeedback as the primary motivating feedback through these or highly customized assessment programs.

2.3 Computer Gaming as Biofeedback

The above devices listed all have some degree of feedback to their process. The most strikingly common element is that games are used as a motivator for rehabilitation. Like media, and art, games are a personal measure of a motivational and fun activity. Each of the techniques are unique in their approach but are all limited in the number of motivators in the form of games available. The system with the most available games is the IREX camera product.

Computer gaming has the potential to take motivation for rehabilitation to a new level. The fun and experiences associated with gaming are fundamentally different than enhanced signal biofeedback or moving inside a virtual environment. If the patient can be competitive and engaged in "fun through gaming" one will have motivated practice.

There are thousands of titles of computer game titles at relatively low cost with levels and activities for any preference that the patient may have. To be able to use off-the-shelf games as the motivating and feedback tool without compromising the performance and functionality of the game itself would allow an almost infinite choice for the patient to choose an activity that motivates them to exercise. The end result is being able to use these low cost, highly available off-the-shelf games in place of higher cost, limited production biofeedback programs, custom virtual reality environments or robotic arms and which have far greater flexibility for the patient and rehabilitation clinician.

3 Description of the Problem

This section describes the problem considered in this thesis contrasts previous work that has been attempted.

3.1 Description

Access to therapy is terminated once a level of function is achieved even if residual deficits remain[26]. Tinson [**?**] reported that individuals post stroke typically spent only 2060 minutes per day in formal therapy. Boredom, fatigue, lack of motivation and lack of cooperation in attending therapy will negatively affect exercise outcome[[**?**]]. Rehabilitation exercise requires very specific movements and coordination that is specific to each patient case. These movements are difficult and repetitive for the patient. Motivation to complete exercise suffers due to frustration and lack of stimulation[[**?**]]. Computer gaming used as enhanced biofeedback, more specifically low level proprietary games have been shown to increase motivation. These games are basic and expensive to produce. Furthermore they cannot be easily ported from one proprietary system to another making these systems expensive. There are thousands of commercial games available. Commercial games are cost effective and use standard interfaces. These same interfaces can also allow cost effective movement analysis.

It is not possible to use standard input devices such as a keyboard, joystick, or mouse to translate both linear and angular non-standard motion within a three-dimensional linear and angular space into a medium that requires standardized input.

3.2 Previous Work

There has been extensive research in biofeedback (see, *e.g.*, [25, 12, 13, 26, 22]).

EMG [25, 12, 13] The Biofeedback

4 Proposed Method of Solution

In this chapter the proposed method of solution as well as design requirements that arose from analysis of the objective and previous work in the field are discussed. The overall requirements, design and implementation of the testing suite to test the embedded system's functionality are discussed.

4.1 Thesis Design

Before discussing the main points of the thesis design it is necessary to discuss some points on previous work on other possible methodologies that could be potential solutions to the thesis objectives. Biofeedback and virtual reality do add a needed motivational and feedback mechanism to therapy [10]. The difference with using traditional video gaming as the motivating technique is that any design for an interface hardware or otherwise must be able to actively control a virtual environment that was not designed to be controlled by anything other than a keyboard, joystick, mouse, or combination thereof.

Previous work in the field revealed necessary points that a system would need to have to successfully carry out the overall stated thesis objectives. The first point is that the system would have to be a hardware embedded device and not a software driver. The primary reason for this requirement is that if properly managed hardware is a separate entity from any given operating system, it allows the freedom of moving the interface between any computer platform to any other computer platform. As a consequence of this choice the universality of connectivity becomes a necessity. This refinement means that it is necessary to standardize any output signals from the device in order to maximize the potential use of the interface. Previous works in the field have hardware devices with proprietary interfaces. Although functional, the interfaces are only useful in conjunction with specialized software drivers or programs. To truly allow simple operation on any platform, proprietary interfaces are therefore not a viable solution for the aforementioned reasons. Gaming systems and programs are not able to take advantage of proprietary interfaces easily, at least not without direct custom software drivers.

Custom software drivers would also have difficulty with gaming environments that require intensive use of the resources of a given computer platform. On the Microsoft Windows platform there are provisions to make some custom serial drivers using the Accessibility API. This API allows for a custom serial device to act as a mouse. The primary reason for not using a similar API on various platforms is that this API isn't universal across many platforms and is certainly not accessible on other hardware entertainment consoles where such software is not readily available.

4.2 Embedded System Design

From the previous design exercise the following criteria were formed:

1. The interface needs to be an embedded controller versus platform-centric software.
2. The interface requires a durable sensor capable of distinguishing fine motion and the ability to translate that motion into understandable standard output signals.
3. The interface should have a standardized universal output that can act as standard input devices such as a mouse, joystick, or keyboard.
4. Given that the control target (Video Game) is not known, the interface needs to have provisions to adjust the output control and provide control assistance where needed.

4.2.1 Microchip 18F458 Processor

To answer the first objective, a peripheral based on the Microchip PIC (18F458) with embedded interface software and essential algorithms was envisioned. The PIC microcontrollers are versatile and easy to use. The controllers allow for ample program memory and interface options for analog controls, serial communication, and digital interfacing.

4.2.2 mini-Bird DC Magnetic Sensor

The second objective is to find a versatile sensor capable of detecting fine movement for hand and finger exercises. The choice is a DC magnetic sensor made by Ascenion Technologies [1] called the mini-Bird (Table 1).

This device utilizes the mini-Bird, a low pulse DC magnetic field that can detect precise motions from a small, wired sensor in a generated magnetic field. Individual movement axis and angles can be tracked independently in six degrees of freedom. The sensor can be attached to various objects because of its durability and small size. The primary feature of this

technique is that is the physical object that requires manipulation through exercises is what is read and processed via the interface with very fine precision allowing for 360 degrees of trackable movement within its 90 cm. field.

4.2.3 HID Protocol using USB

The third, and one of the more important points, is that the controller software will be used to condition and transform position and orientation data from the magnetic sensor into a representation that can emulate a mouse or joystick, etc. (Figure 1). In this manner

Table 1: mini-BIRD Magnetic Sensor Specifications [1]

Degrees of freedom:	6 (Position and Orientation)
Translation range:	Model 500: ±45.7cm in any direction
Angular range:	Attitude: ±180 ° Azimuth & Roll, ±90 ° Elevation
Static Accuracy:	Position: 1.8mm RMS Orientation: 0.5 ° RMS
Static Resolution:	Position: 0.5mm Orientation: 0.1 ° @ 30.5cm
Measurement rate:	Up to 120 measurements/second
Outputs:	X, Y, Z positional coordinates and orientation angles

it will be compatible with game controller input devices (2D or 3D), and able to play all commercially available computer games (including many new virtual reality applications) by movement of a wide-range of objects (attaching the sensor to the object) or by moving a finger (attaching the sensor to finger).

USB, or the universal serial bus, is a well-known standard that is cross-compatible with many PC and Apple computers. The device interoperability is allowed via USB from the HID, or Human Interface Device, protocol. The HID protocol allows for USB devices to identify and enumerate themselves by handshaking with the host hub or computer using a device descriptor. The data exchanged are referred to as reports. The device is responsible for identifying itself as an HID device, and support Interrupt transfers [9]. The descriptors identifies the endpoints to the host, or point of communication for the device. Setup information is always sent via endpoint 0.

The device, or peripheral, identifies its particular class, configuration, and detailed packet information on how the device communicates. The protocol is flexible enough to allow various configurations of on a standard class. A mouse or joystick, for example, can have two or five buttons, each defined as analog or digital all strictly dependent on the HID descriptor. This allows a great deal of flexibility in design and becomes a very useful tool for embedded designers to utilize standard HID compliant device drivers found on most common operating systems.

4.2.4 System Details

The translation device consists of:

1. Serial mini-Bird Input Interface
2. PS/2 Keyboard/Mouse Input/Output Device
3. USB Input/Output Device

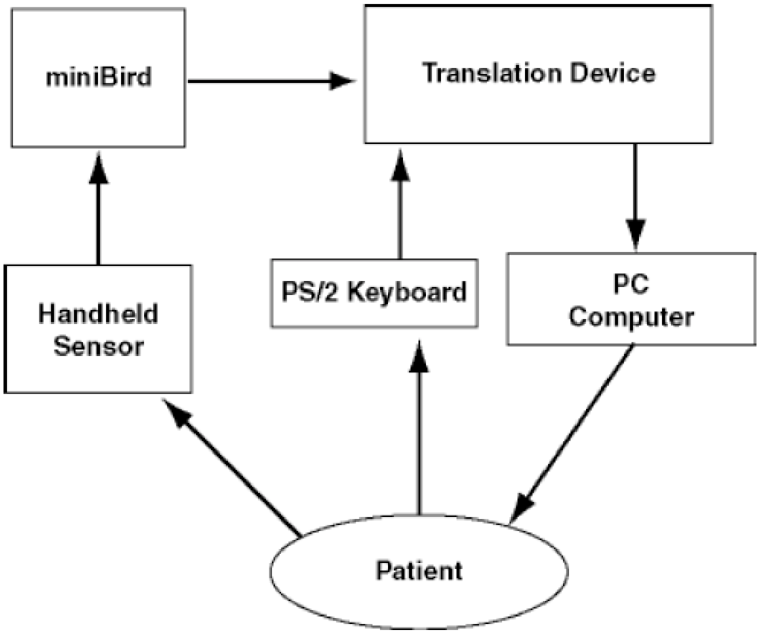


Figure 1: Functional System Overview

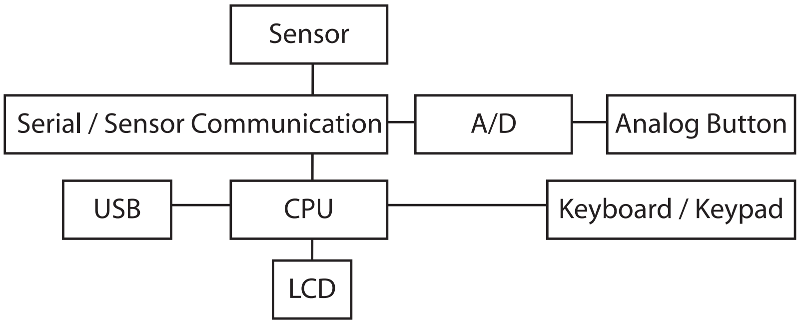


Figure 2: Component Diagram showing the different Units of the Firm ware which corresponds to the flow charts.

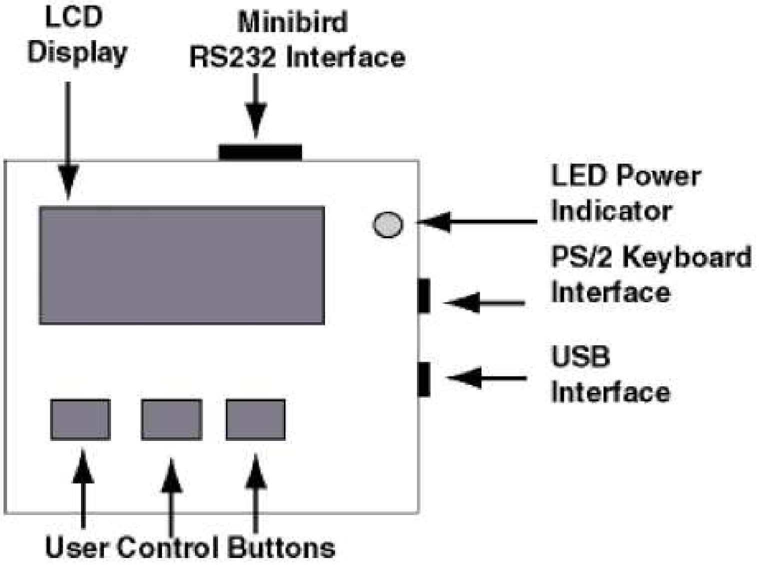


Figure 3: Embedded Device Diagram

4. LCD Screen for user configuration
5. Future module additions to interface with different sensors

The design of the system (Figure 2) allows for a working PS/2 keyboard to be hooked up simultaneously as the mini-Bird. This allows for the unit to be a complete keyboard replacement if necessary. This way the Microsoft Windows OS will treat the unit as a plug-n-play device to greatly reduce installation difficultly. The unit is universally compatible with Windows (98/2000/XP), Apple, and Linux operating system with a 2.4 kernel, or 2.2 kernels with USB extensions.

The basic idea is to promote and achieve ”full” active movements of the fingers, hands and arms while manipulating real objects in real ways using behaviorally relevant tasks. Finger-hand function was targeted and not just arm, thus the control problems we are tackling are orders of magnitude more difficult because of fineness of scale, number of degrees-of–freedom and wide range of geometric and material properties of objects utensils and tools to handle and manipulate.

Geometric properties are specific to particular objects, and are divided into size, shape and weight (fixed, viscous or fluid). Material properties are independent of any one sampled object and are differentiated into texture, roughness, smooth, slippery, sticky, compliant, etc. Many repetitions of these functional movements with objects performed in a controlled randomized manner are critical to recovery. By making practice fun, i.e. coupling movement to game controls, we can achieve a large volume of practice. In addition signal manipulation algorithms are available which can augment limited or abnormal movements in many ways. Besides the ability to select which object to use and which combination of sensor position/orientation signals to use for tracking (6 degrees of freedom), we can scale and amplify movement signals for those who have small or very small movements; offset signals in cases where only one direction of movement is possible; smooth tremor and jerky movements; and a variety of other important movement transformations.

Device configuration The output of the device is able to dynamically select the combinations of mouse and joystick outputs. For each function there are test modes to ensure that there is proper communication between the device and the computer or console.

Facilitators and end users are able to select the desired output sent by the device. Tracking of each of the forms of movement from the mini-Bird are independently configurable. Given that the operating system just sees the device as a regular peripheral (mouse, joystick or game pad, any special settings within any gaming environment also can be applied in conjunction with the variety of options designed to make the game playable for patients with restricted movement. This allows a great flexibility of options that can be individualized for each patient. The USB controller used is a PIC16C765. It is limited to one setup endpoint (0) and two data endpoints (1 and 2). This limitation only allows for two out of the three prepared devices to be present on the device at one time. The current configuration is joystick and mouse.

Movement configuration The six-degree-of-freedom DC magnetic motion-sensor is able to detect and relay position on an X, Y, and Z-axis along with orientation in pitch, yaw, and roll directions. The facilitator, or therapist, is able to change the parameters of the device via the control console on the device. Thus various configurable combinations of linear and/or angular motion (Algorithm 2) about any axis can be used as input to the device to be translated into the desired game controller (mouse, joystick game pad). The facilitator can adjust a movement range with a central point. The central point can be adjusted to allow for an area in which all movement, relative or otherwise, is nullified, similar to a stop-band filter. Utilizing this method, any type of movement along various axes can be easily controlled by the patient.

$$f(x) = \left((x_t - x_{t-1}) \bullet \frac{1}{2^{(s-10)+4}} \right) - 127 \tag{1}$$

$$f(y) = \left((y_t - y_{t-1}) \bullet \frac{1}{2^{(s-10)+4}} \right) - 127 \tag{2}$$

Algorithm 1: Digital Joystick / Keyboard Translation Output

```
Input  : Axis Position Coordinate $x$, Axis Low Threshold $\bar{x_l}$, Axis Upper
         Threshold $\bar{x_u}$
Output: Output Positional Direction State $direction$
if $\bar{x_l} \leq x \leq \bar{x_u}$ then
    $direction = None$
else
    if $\bar{x_u} \leq x$ then
        $direction = PositionHighState$
    else
        $direction = PositionLowState$
    end
end
```

Algorithm 2: Digital Joystick / Keyboard Rotation Output

```
Input  : Axis Position Coordinate $\theta$, Axis Low Rotation Threshold Angle $\bar{\theta_l}$, Axis
         Upper Rotation Threshold Angle $\bar{\theta_u}$
Output: Output Positional Direction State $direction$
if $\bar{\theta_l} \leq \theta \leq \bar{\theta_u}$ then
    $direction = None$
else
    if $\bar{\theta_u} \leq \theta$ then
        $direction = PositionHighState$
    else
        $direction = PositionLowState$
    end
end
```

Scale Configuration This system allows for the range of movement given by the miniBird to be scaled fitting the range of the patient undergoing a given exercise. Each patient has different ranges of capable motion and that is addressed by this scaling ability. The system allows the facilitator to adjust the parameters of the motion to reflect the range of

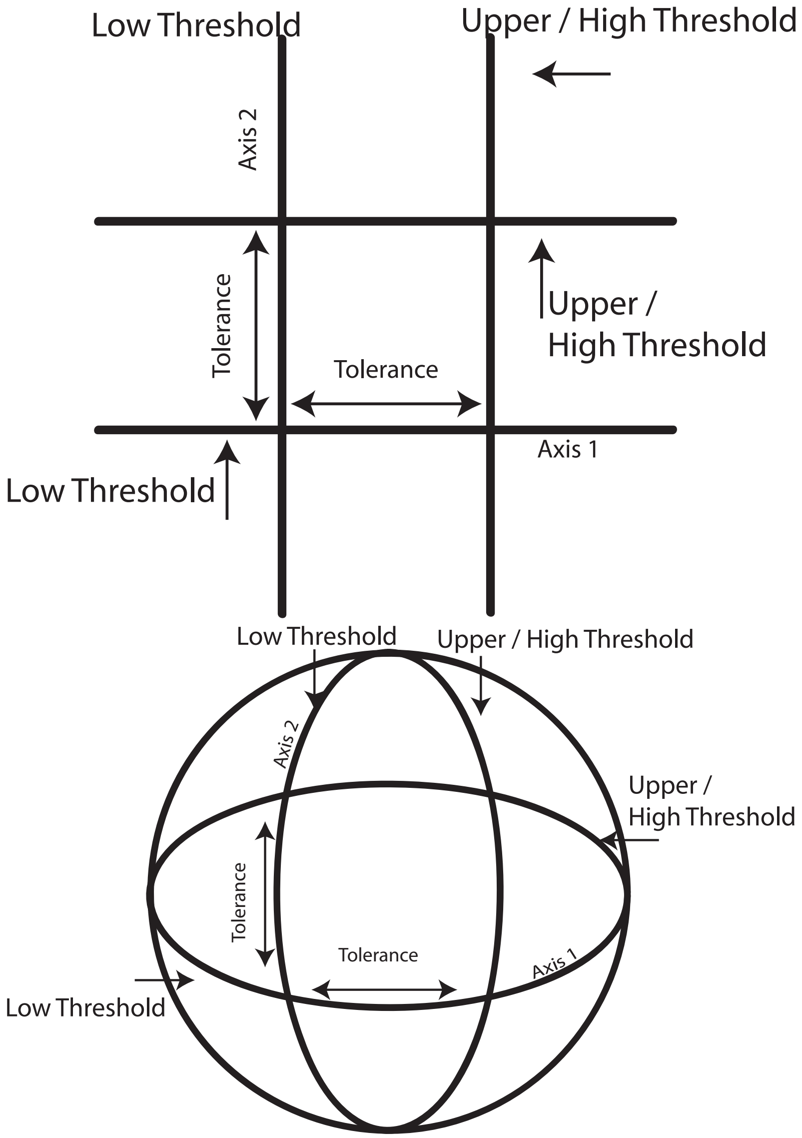


Figure 4: Diagrams of how the tic tac toe grid forms with the Tolerance middle sized by the upper and lower tolerance in space (MENU F2)

Algorithm 3: Analog Joystick Translation Output

```
Input  : Axis Position Coordinate $x$, Axis Low Threshold $\bar{x_l}$, Axis Upper
         Threshold $\bar{x_u}$
Output: Output Positional Direction State $out$ where $out \epsilon Z$
if $\bar{x_l} \leq x \leq \bar{x_u}$ then
    $out = 128$
else
    if $\bar{x_u} \leq x$ then
        $out = \frac{x - x_u * 255}{2^{(n-10)+4}}$
    else
        $out = \frac{x_l - x * 255}{2^{(n-10)+4}}$
    end
end
```

motion required by the video game being played on the computer or console. Each axis is separately configurable and scalable via the console.

$$S(n) = \frac{1}{2^{(n-10)+4}} \tag{3}$$

Diagnostic Inputs / Outputs Via the diagnostic console it is possible to test output and input signals. This allows simulation of the output to verify that it is compatible with the video game(s) being used. As all configurations are dynamic, meaning changeable at any time, it is important that the ability to verify the settings of the system exists. The diagnostic console is able to display the current settings used, as well as view and test input directly from the mini-BIRD in a built in serial terminal.

Input / Output Assists The device is also capable of providing secondary output assistance. Within various genres of games, there is a need for the user to hold down an acceleration control in racing games, or a fire button for first-person or arcade-style games. Recognizing this need, the device allows for 8 output buttons to be pressed at independent, dynamically configurable intervals of the current set reporting speed.

An analog button device has also been added to enhance the ability of game play and refine the control level allowable by the system. The device is a small pressure pad that responds to touch. The variability of the pressure required ranges from very sensitive to extremely non-sensitive. The advantage is that it allows both weak and strong patients be able to control one aspect of the game without pressure strength being a factor in control.

$$f(t_i) = t_i \bullet (10 - n_i) \tag{4}$$

Specific System Functionality and variations The magnetic field generator is placed within the area that the patient is performing the exercises. This is usually done within easy view of a monitor. The magnetic sensor is then placed on the object that is tasked for manipulation by the patient in the context of rehabilitation. The sensor control box is attached to the translation device. In turn the translation device is attached to a personal computer, video game console or any input device that will accept the signals as desired.

Menu and Configuration System The translation device has an extensive menu system to configure and customize system parameters to best meet the needs of the client. This menu system performs the following tasks:

1. Tests the connection between both the mini-Bird and gaming device.

2. Sets the desired output emulation of the device (joystick, mouse, and combinations)

3. Sets the desired axis / rotational axis of movement. The patient or therapist can decide if they want multi-axial or single axis, or combinations of rotational axis and single axis input to be translated into the selected output device for the console.

4. Sets the scale of the input to match the needs of the patient. The scales are separately configurable for each axis desired to yield the best results for the patient, and best response from the gaming console/ pc console to the exercises.

5. The device can now set secondary outputs to assist the patient. Some games require some other secondary control, such as acceleration, braking, weapon firing, etc. This feature allows the translation device to control the output and frequency by which it is activated. Several buttons are independently configurable in both frequency and activation. The therapist can then set the device to output the correct controls that the video game requires as input for proper functioning of the game.

6. The patient/therapist can view the settings and change them at any time as the device can be interrupted to select upgraded settings.

5 Experiments

This chapter discusses the testing methodology used to complete the secondary thesis objective. To complete this objective the overall thesis design and functionality are tested. As the system depends on the quality of the sensor in use, the mini-Bird sensor is separately measured against a known signal on various different coordinate planes. The functionality of the combined system, emulating a HID compliant mouse, is observed and compared to the output of a standard HID compliant mouse under the same testing environment.

Although the system is capable of acting as a joystick interface, the following experiments measure the accuracy and precision of the mouse segment only. As the ART program is written in Java, and there is not, as of yet, any reliable joystick interface libraries for Java that would result in the creation and completion of a fair and objective test. In either case data taken from the mouse component will show that the sensor and interface are sensitive enough to handle movement and translate into useful peripheral input signals as the joystick uses the same sensor and interface.

5.1 Subjects

Sixteen subjects volunteered to participate in this study and gave informed consent. Ethics approval was granted prior to recruiting subjects by The University of Manitoba, Faculty of Medicine, Ethics Committee.

5.2 Testing the Sensor

To verify that the sensor is game capable it must be shown that the response time and accuracy of the sensor is within a tolerable and reasonable limit such that the reading and input of the device will be reactive enough to fulfill the primary need of playability.

Given that the device is capable of moving and reacting within six degrees of freedom, it is necessary to test the ability of the sensor to mimic patterns that a standard input apparatus would be able to match.

Using the custom A.R.T. program, a large square cursor was moved sinusoidally either horizontally from left to right edge of the display and vertical from the top to bottom of the display. The sine wave was configured to 0.5 Hz, with a cursor speed of a 20 milliseconds delay with data samples taken every 20 milliseconds.

The mini-Bird interface system was attached directly to the serial port on the testing computer so that the A.R.T. program would record the position of the magnetic motion-tracking sensor directly.

The motion-tracking sensor was attached to a computer mouse which itself was attached to the computer. This permitted synchronous recording of the position of the magnetic motion tracking sensor and computer mouse. This was done to place the measuring device on a known and familiar tracking object, and secondly to allow the mouse cursor to be used to track the A.R.T. cursor.

Using a keyboard trigger to start the wave in motion, each of the subjects were required to use the instrumented mouse to move a second cursor to overlap the on-screen cursor (reference) which was moving sinusoidally. The reference cursor was a different color from the tracking cursor.

The A.R.T. program would then record and log position data of the reference on screen cursor, the mouse, and the magnetic motion tracking sensor.

Three different trials were performed:

1. Tracking a horizontally moving reference cursor
2. Tracking a vertically moving reference cursor
3. Tracking a vertically moving reference cursor except the mini-BIRD magnet was rotated 90 degrees to use the mini-BIRD z-axis.

5.3 Testing the Embedded Device

The purpose of this experimental test is to compare the accuracy, precision, and functionality of the a standard USB tracking mouse with position data of the magnetic motion tracking system and the emulated mouse position data translated by the embedded system.

Given that most games use sprite or polygon intersection to determine success or failure of the gaming objective, two experiments were formulated to test performance using this concept. Games have two primary elements in common, predictable and random. Different classes of games such as racing, or arcade style games rely on a combination of these predictive and random elements.

As described above in section 4.2, this second set of experiments will quantify and compare the ability to track the reference on-screen cursor using a second cursor driven by the feedback signal obtained from a standard USB mouse or the magnetic tracking sensor via the embedded interface.

The cursors have a width and height of 50 pixels compared to the 640 by 530 screen size. Game sprites, objects, and objectives are rarely one pixel wide and both the player and objective have some degree of width and height. The size of the cursor was approximated to simulate a reasonable size of a game sprite or avatar. The percentage of samples where there is an intersection of the coordinates of reference and feedback cursors will be taken as an index of performance.

Position data of the reference cursor, the mouse controlled cursor and the embedded interface controlled cursor will be recorded. Since the recording data is mouse x-y position versus the waveform x-y position on the same graphical panel the data will be an absolute measure of mouse position to waveform position on an exact scale in pixels. Sine wave motions were utilized as a standard for measuring accuracy along a predictable pattern centered on the middle of the display screen both vertically and horizontally.

5.3.1 Embedded Interface Comparison

The primary method of the experiment to further test functionality is to compare various instrumented objects that would be used in rehabilitation against the input from a standard mouse. The A.R.T. program reads in mouse movement within this testing mode. Thereby it is possible to use a standard USB mouse as a reference game controller and object to compare with the embedded interface and magnetic motion-tracking sensor. The embedded device is designed to emulate standard mouse output, thus it is appropriate to compare the output from the embedded device and a standard HID compliant mouse.

To accomplish this goal the magnetic motion-tracking sensor was attached to an unplugged HID compliant USB mouse where in this case the mouse was the instrumented object. The same mouse was then plugged into the testing machine and tracked separately. Five subjects were required to follow the tracked cursor to the best of their abilities using both devices.

The on screen reference cursor motion to be tracked was a sine wave of 0.2 Hz, screen height of 70%, and a cursor speed of 20 milliseconds through the A.R.T. program. In addition to the predictable sine wave, a random waveform trajectory was also used to drive the reference cursor. In random mode, these waveforms were randomized to switch or continue direction every 50 cycles. The randomness of the wave was calculated using the random function within the standard Java utility library. Waveform results and intersection data were recorded for both X and Y-axis using predictable and random settings.

Cross correlation functions were computed between the data of the on screen reference cursor position and the second feedback cursor defining object position. The peak r-value and corresponding phase shift values of the cross correlation function were determined to quantify the maximum correlation and lag between the reference and measured signals.

The purpose of this metric is to show the quality of the object motion compared to the reference signal generated by the A.R.T. software. This was determined for both predictive and random modes along each axis for both the USB mouse and embedded system.

5.3.2 Non-standard Object Center of Area Comparison

To further this comparison it is necessary to demonstrate and contrast different core objects with the sensor attached:

1. Leatherette Soccer ball
2. Flat bed Lego cart with 4 wheels
3. One inch dowel diameter of 8 inches long as a wand

The objects differ considerably in their properties and relative to a mouse each of these objects has a level of mechanical disadvantage and advantage that is obtained by its use in a preferred direction dictated by its function.

The ball and cart were typically used to perform motions away and towards the body while the wand amplified wrist movement from side to side. Both the cart and the ball allow a patient to rest the weight of the limb while promoting motion while giving mechanical leverage to any motion produced.

The purpose of this experiment is to show that different objects will yield a similar level and degree of cursor control to that of a standard game controller, i.e. optical mouse.

Position data of the mouse and the instrumented objects were recorded for both predictable and random settings. The peak r-value and corresponding phase shift values of the cross correlation function were determined.

5.4 Field Testing

The hardware component was subjected to testing in a clinical setting. A sampling of sixteen people with chronic conditions ranging from a single stroke, acquired or traumatic brain injury, and spinal cord injury that had symptoms ranging from light to severe were used in this study. The range of people with chronic neurological conditions that participated were male subjects, 15-78 years of age, and female subjects, 28-84 years of age.

Figure 5: Photograph of the range of objects that were used in rehabilitation during field testing

6 Analysis

This section considers the test results obtained from the functional experiments described in

6.1 Testing the Sensor

The time-series position data obtained during the on screen cursor tracking tasks was normalized to scale with the screen data using Matlab 7.0.4.365 (R14). On each graph the normalized screen data, and recorded sensor data are shown. The data collected was within the relative X, Y, and Z-axis to the magnet (Figure 6).

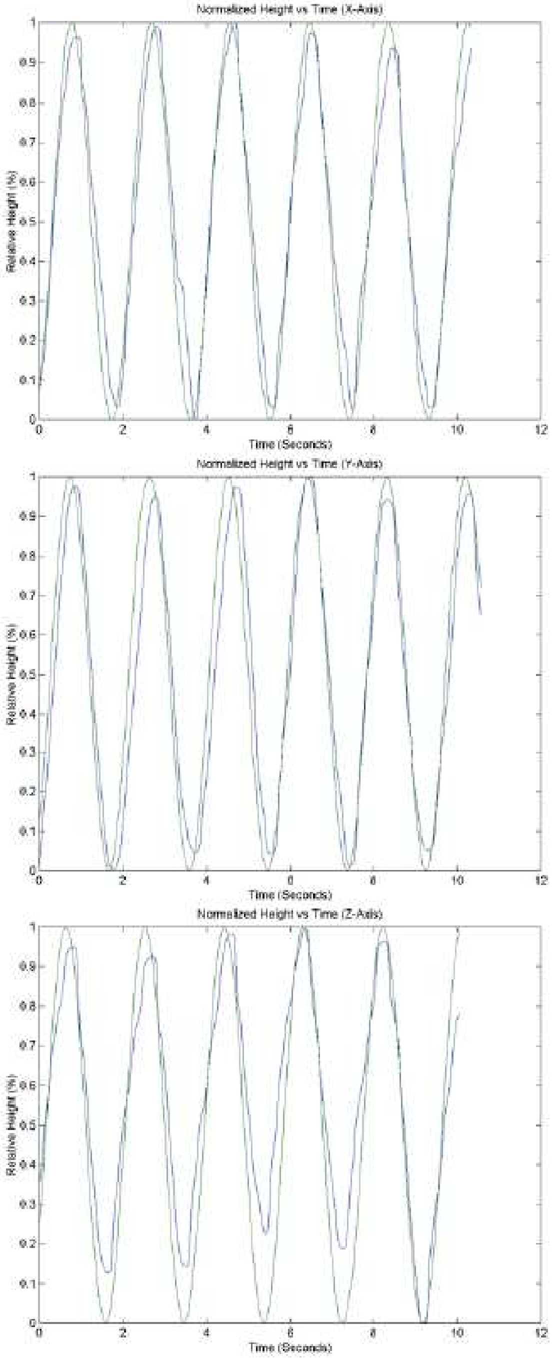


Figure 6: Sensor Plots for X, Y, and Z-axis

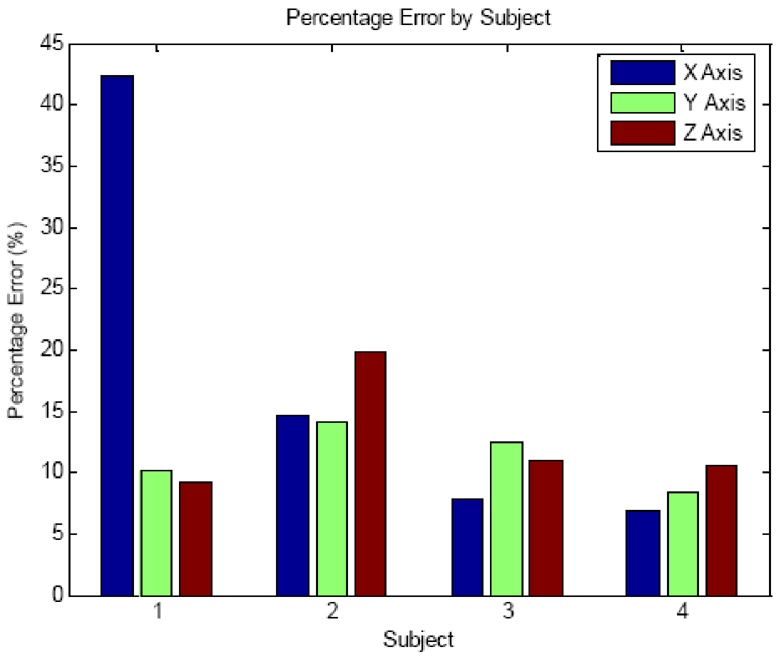


Figure 7: Percentage Error X, Y, Z-axis by Subject

In cases of the Y and Z plot the data in addition to being normalized has been rotated 90 degrees as the motion was measured along a perpendicular axis.

The percentage error is the mean residual difference from subtraction of the two comparison normalized signals (Figure 7). Within experimental error, the quality of the sensor signal is directly dependant on the subject as can be seen with the over 40% error for the X-axis of the first subject. However, the best subject has error as low at 6.8% deviation from the reference standard signal.

The difference between these sensor plots (Figure 7) and the previous set of plots is that the magnetic sensor was rotated 90 degrees during the taking of these readings. The purpose of the rotation is to capture data on a different axis than would normally be used. This technique allows the on-screen cursor tracking task to be performed horizontally and vertically to show that the magnetic motion-tracking sensor can effectively be used on different axial planes without loss of resolution. The results shown in Figure 8 confirm these findings. As with the previous readings the sensor error is dependant upon the ability of the subject. The best reading was found to be along the X-axis with a 4.8% deviation from the standard wave. There were still high degrees of error with a maximum of 29.8% deviation found in the X-axis (Figure 9).

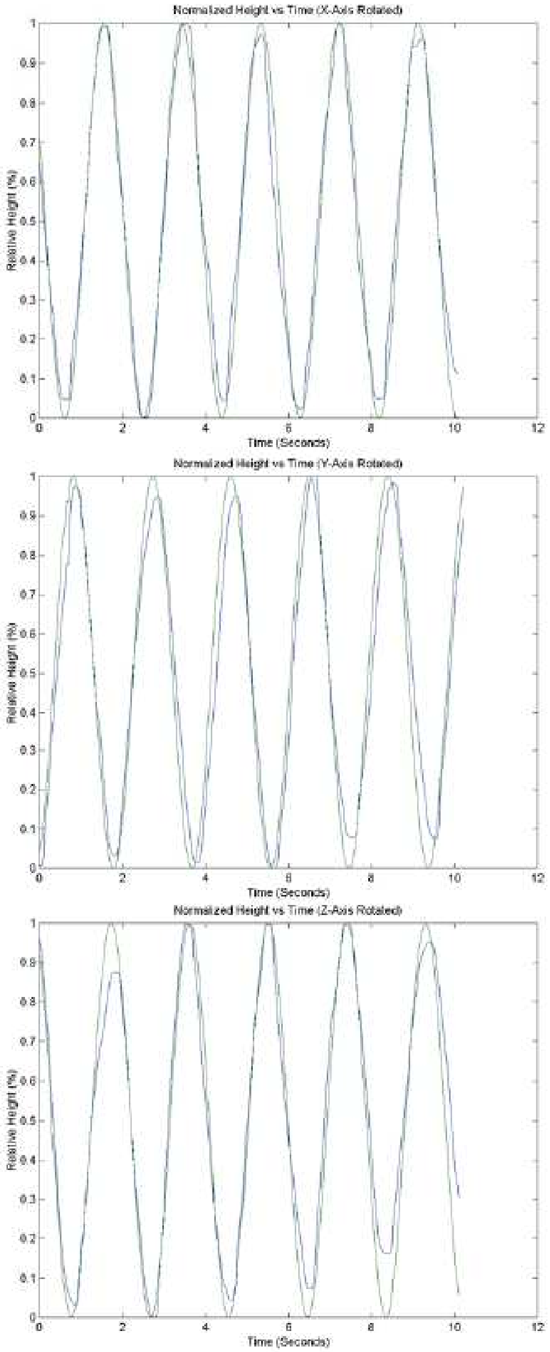


Figure 8: Sensor Plots for X, Y, and Z-axis Rotated 90 Degrees

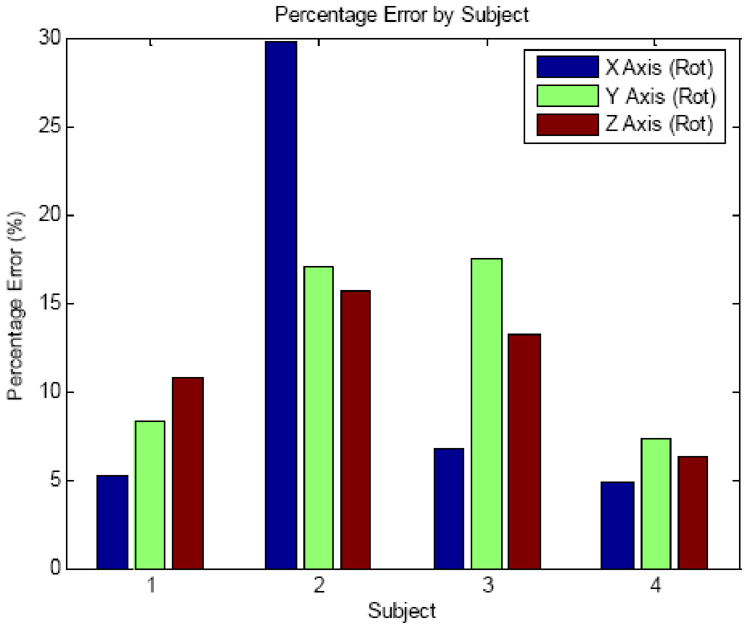


Figure 9: Percentage Error by Subject for X, Y, and Z-axis Rotated 90 Degrees

6.2 Embedded System Experimental Results

6.2.1 USB Mouse Comparison

Four separate tests were performed on the embedded hardware with the magnetic motion-tracking sensor as input:

1. Tracking a predictable sine wave along the X-axis (on-screen horizontal)
2. Tracking a random moving waveform along the X-axis (on-screen horizontal)
3. Tracking a predictable sine wave along the Y-axis (on-screen vertical)
4. Tracking a random moving waveform along the Y-axis (on-screen vertical)

The results show that a comparison of tracking performance using a computer mouse directly and the embedded device were similar as evident from the peak cross correlation r-values and phase values of the waveform data. The results presented (Table 2) show the largest difference of 2.032±0.02% correlation with the Y-axis random mode and minimal difference of 0.462±0.001% in the predictable X-axis mode with an overall average difference between mouse and system cross-correlation of 1.13±0.02%.

The group average of the percentage of time that the standard computer mouse intersected the generated cursor (Figure 9) was higher for a standard computer mouse than using the instrumented mouse through the embedded system. Both predictive modes had a group average of over 89% of time intersecting the cursor during the experiment. The

Table 2: Embedded system group average percent correlation, lag, and difference between mouse and interface correlation

Experiment Performed	Peak r-value (%)	Peak Phase Difference (Degrees)	Difference Correlation (%)
Mouse Predictable X	99.821±0.001	0	
Interface Predictable X	99.359±0.001	0.6±0.8	0.462±0.001
Mouse Random X	99.085±0.002	2.4±0.8	
Interface Random X	97.662±0.006	7.4±2.3	1.423±0.006
Mouse Predictable Y	99.702 .0.001	0.4±0.5	
Interface Predictable Y	99.115±0.004	1.6±1.3	0.587±0.004
Mouse Random Y	98.977±0.001	2.2±0.5	
Interface Random Y	96.945±0.017	7.6±2.6	2.032±0.02

group average of time intersecting the cursor in random mode was 67.1±7.2% along the X-axis and 79.9±7.6% along the Y-axis.

The difference between the group average of the predictive modes in the X and Y-axis of the standard computer mouse and instrumented mouse through the embedded system were 9.3±5.2% along the X-axis and 7.9±8.7% along the Y-axis. The difference in group average of the random modes, in both X and Y axis, were 18.3±7.6% along the X-axis and 11.8±3.0%. along the Y-axis.

The differences in percentage of intersection between the predictive X and Y-axis of magnetic-tracking sensor via the embedded system and the standard computer mouse were less than the random tests. The differences in this score in the random modes can be attributed to a 7.4±2.3-degree phase difference (102 ms lag) and a 7.6±2.6-degree difference (105 ms lag) in phase at the peak r-value versus a maximum of a 1.6±1.3 (22 ms) phase difference found in the predictive experiments.

The first reason for the difference between the native mouse performance and the embedded system is that the embedded system sends positional data at a rate of 50 milliseconds. A normal mouse sends updates more frequently making it somewhat more sensitive and in turn will perform better with a higher reaction speed especially in the random case. The predictable case is far closer since most of the action is a linear motion back, forward, up or down on the screen. Secondly, the embedded system reads the positional output linearly whereas specific mouse drivers will assist with acceleration that assists in fast direction changing, such as with the random tests.

6.2.2 Non-standard Object Comparison

Not all objects will behave like an ergonomically designed mouse. Depending on the geometric and material properties of the object, different directions and movement will facilitate a distinct advantage or disadvantage (Figure 10). The ball, cart, and wand give a mechanical advantage that mimics and amplifies motion. The ball and the cart also have an inertial component that assist with controlling movement in one direction, but will add a small degree of lag to change motion very quickly. The mouse without hardware or software acceleration is a linear device without the mechanical aid or lag of the other objects. Using these objects some of that linear disadvantage is almost eliminated in the predictive case.

All objects faired best in the predictive mode along the Y-axis and X-axis respectively whereas both the mouse had a higher degree of success in the randomized modes. The minimum difference was 0.24±0.002% using the wand in following a predictable pattern with a maximum of 2.588±0.010% using the Lego cart following a random mode. The average overall difference between the cross correlation of the magnetically-tracked

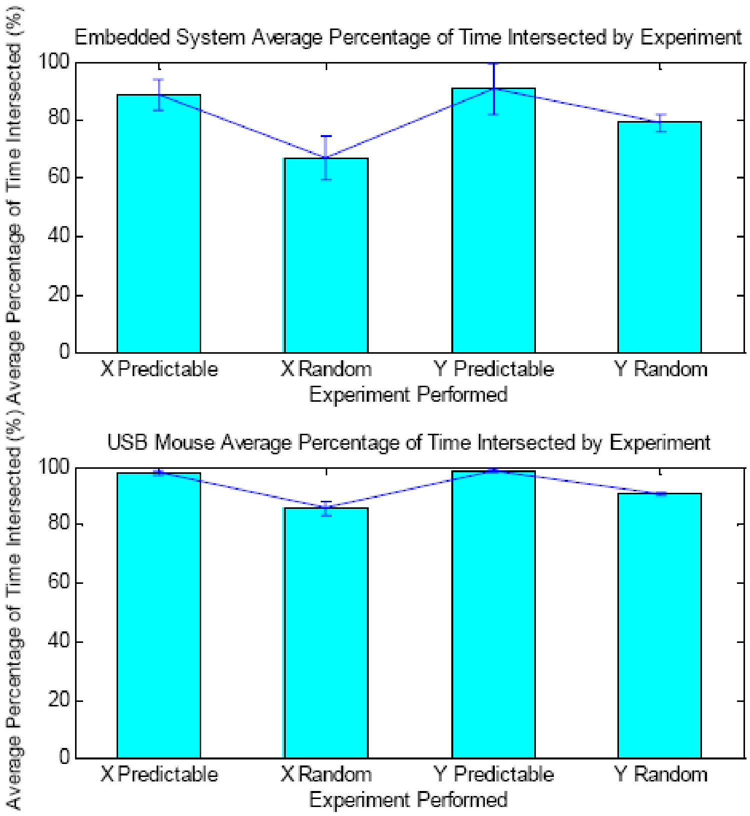


Figure 10: Average percentage of time of intersected by object showing the cursor intersection times showing the system compared to a HID mouse.

Table 3: Freehand group average percent correlation, lag, and difference between mouse (Table 1) and interface correlation

Experiment Performed	Percent Correlated (%)	Lag (Degrees)	Difference Correlation (%)
Ball Predictable X	99.462±0.002	0±0.1	0.24±0.002
Ball Random Y	96.389±0.010	6.6±2.1	2.588±0.010
Cart Predictable Y	99.361±0.002	0.8±0.7	0.341±0.002
Cart Random Y	97.042±0.010	9.6±1.7	1.935±0.010
Wand Predictable X	99.246±0.005	0.2±.04	0.575±0.005
Wand Random X	96.508±0.017	4.8±1.6	2.577±0.017

mouse via the embedded interface and the standard computer mouse in the random experiments was 2.37±0.02%. The average overall difference between the magnetically-tracked mouse via the embedded interface and the standard computer mouse was 0.385±0.005% with the predictable mode experiments.

The predictive modes all fared approximately equal or better than its mouse counterpart in its respective axis. The performance of the instrumented ball via the embedded system differed from the standard mouse by 1.4±2.0% along the Y-axis, while the cart differed by 3.6±3.7% along the Y-axis. The properties of the ball and cart, especially in predictive modes offered some degree of acceleration that resembled a standard computer mouse. The performance in the predictive modes of the cart and ball surpassed the performance of the instrumented mouse by having an average of 4.3% (cart) and 6.5% (ball) increase in time intersecting the test cursor. The wand was just under a 0.75% difference from the mouse instrumented with the sensor at 88.0±10.0%. The error value was much higher for the wand due to varying ability for the study group to use this object. The range of values was between a low of 71% intersection and as high as 99% intersection with the majority of the group at a score of 94% or higher (Figure 11).

The random mode results were more uniform with an average intersection of 70.7±4.8% group average intersections. On average the intersection percentages were lower than the instrumented mouse, the wand showed a 2.8% increase in performance in the random tests when compared to the embedded device instrumented with a mouse.

The phase differences at the peak r-value were lower for all the objects with the exception of the cart in the random test showing 9.6±1.7 degree phase difference or 133 ms lag with the lowest being the wand at a 4.8±1.6 degree or 67 ms phase difference. This contrasts the phase difference of under 1 degree at peak r-value in the predictive tests. Much of the differences in performance can be attributed to the unfamiliarity of using a device like the ball, cart, or wand as a input device especially in the random testing.

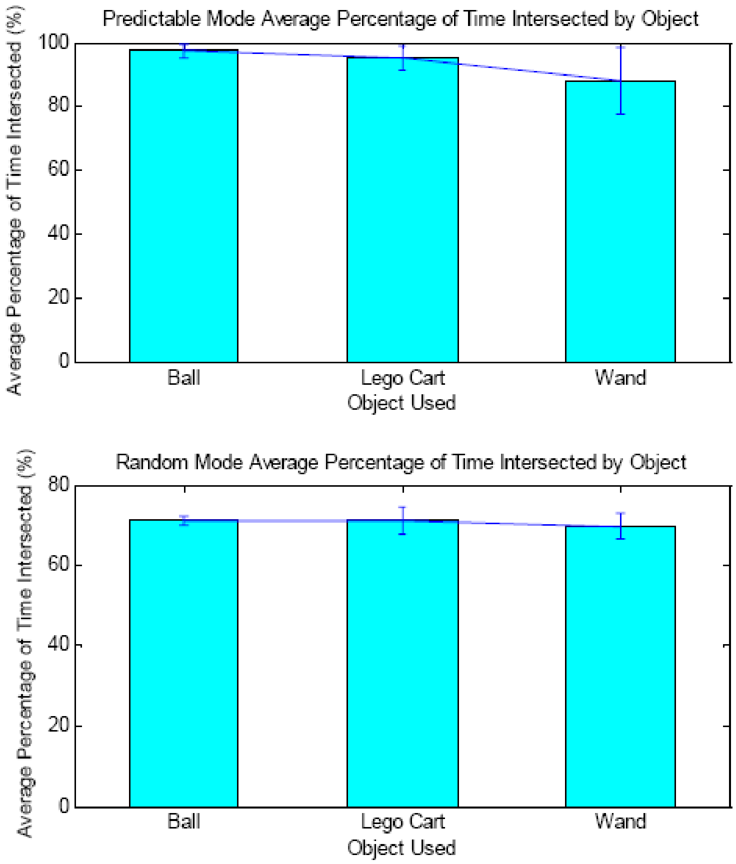


Figure 11: Average percentage of time of intersected by object showing the cursor intersection times of the leather ball, Lego cart, and wand in both predictable and random experiments.

6.2.3 Field Testing Results

All participants enjoyed the therapy program and did have fun playing a variety of commercial video games such as Lego Racers, Pac-man, Boulder Dash, and Crimson Invaders.

13 of 16 subjects strongly agreed that the games were fun, motivational and improvement to their current exercise regime. 3 of the 16 subjects agreed that the games were fun, motivational and improvement to their current exercise regime.

Subjects also commented that the games offer lots of flexibility with regards to difficulty levels and types of movements and exercises that can be used in therapy and games that could be played.

For a span of over one year the device was used in a clinical setting using a range of objects. All people received at least two one-hour sessions and four participants received ten one-hour sessions.

To study the effects on motivation and use of this device the test subjects were given a survey at the end of a treatment session and were asked to rate the performance of the interface and the effect of the motivational influence on their desire to continue their exercises on a scale of strongly disagree, disagree, agree and strongly agree. The participants were also invited to comment on the treatment.

7 Conclusion and Future Work

7.1 Discussion and Conclusions

The contribution of this thesis is ....

7.1.1 mini-Bird Sensor Evaluation

The direct data from the mini-Bird showed a best deviation of 4.8%. The results do show that this sensor has acceptable fidelity responsiveness with similar precision for purposes of gaming. It can be seen from the data that most subjects were able to retain a consistent degree of error comparing the results from the rotated and non-rotated data. Thus the readings are highly dependant upon the subject and error can be corrected for by changing the object used during a therapy session.

7.1.2 USB Mouse Comparison

Percentage of cursor intersection and cross-correlation of the generated test signal and the experimental results were used as a metric to compare the performance of a standard computer mouse and magnetically-tracked mouse via the embedded sensor.

Both predictive mode results for the magnetically-tracked mouse via the embedded sensor had a group average of over 89% of time intersecting the cursor in the X and Y-axis. The group average of time intersecting the cursor in random mode was 67.1±7.2% along the X-axis and 79.9±7.6% along the Y-axis. The difference between the group average of the predictive modes in the X and Y-axis of the standard computer mouse and instrumented mouse through the embedded system were 9.3±5.2% along the X-axis and 7.9±8.7% along the Y-axis. The difference in group average of the random modes, in both X and Y axis, were 18.3±7.6% along the X-axis and 11.8±3.0%. along the Y-axis. The differences in this score in the random modes can be attributed to a 7.4±2.3-degree phase difference (102 ms lag) and a 7.6±2.6-degree difference (105 ms lag) in phase at the peak r-value versus a maximum of a 1.6±1.3 (22 ms) phase difference found in the predictive experiments.

The cross-correlation of the waveform data are similar between both the standard computer mouse and magnetically-tracked mouse via the embedded sensor with the largest difference of 2.032±0.02% correlation with the Y-axis random mode and minimal difference of 0.462±0.001% in the predictable X-axis mode with an average of 1.13±0.02%.

The results from the cross correlations of the magnetically-tracked mouse to the generated waveform signal show that the embedded device is capable of tracking a cursor with a very high correlation to the generated signal. Given that the low overall lag, or phase difference, of the embedded system and the high correlation between the generated signal and the data show that both the magnetically-tracked mouse via the embedded system and a standard computer mouse have comparable performance.

7.1.3 Non-standard Object Center of Area

Non-standard objects, such as wands, carts, balls used in therapeutic exercise each have beneficial properties that can offset difficulties for motion and enhance motions to remain competitive in a gaming environment.

All objects faired best in the predictive mode along the Y-axis and X-axis respectively whereas in the in the randomized modes tracing performance was better when using the mouse. The minimum difference was 0.24±0.002% using the wand in following a predictable pattern with a maximum of 2.588±0.010% using the Lego cart following a random mode. The average overall difference between the cross correlation of the magnetically-tracked mouse via the embedded interface and the standard computer mouse in the random experiments was 2.37±0.02%. The average overall difference between the magnetically-tracked mouse via the embedded interface and the standard computer mouse was 0.385±0.005% with the predictable mode experiments.

The predictive modes all fared approximately equal or better than its mouse counterpart in its respective axis. The performance of the instrumented ball via the embedded system differed from the standard mouse by 1.4±2.0% along the Y-axis, while the cart differed by 3.6±3.7% along the Y-axis. The performance in the predictive modes of the cart and ball surpassed the performance of the instrumented mouse by having an average of 4.3% (cart) and 6.5% (ball) increase in time intersecting the test cursor. The wand was just under a 1% difference from the mouse instrumented with the sensor at 88.0±10.0%. The random mode results were more uniform with an average intersection of 70.7±4.8% group average intersections.

The phase differences at the peak r-value were lower for all the objects with the exception of the cart in the random test showing 9.6±1.7 degree phase difference or 133 ms lag with the lowest being the wand at a 4.8±1.6 degree or 67 ms phase difference. This contrasts the phase difference of under 1 degree at peak r-value in the predictive tests. .

Video games have a combination of predictive and random components. The results show that can be used to control a cursor compared to the magnetically-tracked mouse results from the previous experiment. The results do indicate that certain objects have better performance and advantages in different axes and modes that is up to the therapist to choose a right-fit of object, game type, and speed for the patient. Considering the high level of cross correlation with the test signals, and higher percentages of cursor intersection in predictive and some in the random modes, the system can achieve the objective to be functionally competitive in a gaming environment using instrumented objects.

7.1.4 Field Testing

The results of the field-testing shows that the instrumenting objects using the embedded system was successfully tested over a year with the sample group of patients in a clinical setting. The results support the premise that functional and motivational interactive video games will increase practice time and practice intensity and it is hypothesized that the amount of recovery should increase. Thus as future work, a Phase 1 randomized clinical trial is warranted to evaluate this hypothesis.

7.2 Future Work

7.2.1 System Upgrades

A future upgrade would be to move to a different controller like the 18F4550 would allows up to 16 endpoints [4] on one controller where the keyboard mode could be placed along side the mouse and joystick modes of operation. Using the USB 2.0 interface greater reporting speeds will be possible to increase reporting resolution.

As well, for greater functionality, custom device drivers could be used to communicate to the device from the computer directly for custom applications, but are not necessary in this configuration.

7.2.2 Inclusion of Motion Filters

A gaming environment is a motivator when it is possible to succeed and achieve the objectives set by that environment. Filters that allow for phase advancing, or rudimentary anticipation of motion would assist patients with a poor responsive ability to react to a gaming stimulus by virtually increasing reactive or predictable response time. This combined with point averaging methods, or low pass filters would be able to assist with the removal of hand tremors or occasional erratic hand or finger movement that may impede successful game play.

7.2.3 Development of Intelligent Filters

The experimental data showing the performance, or accuracy, difference between physically advantaged objects, such as the leather ball, over physically disadvantaged objects, such as moving the sensor in a “free-hand” fashion lead to developing an intelligent filtering mechanism. Phase advancing, point average, and common low or high pass filtering are effective strategies to assist poor exercise movement in a virtual environment to help the patient be successful within the gaming criteria. However creation of an adaptive system using rough sets for analysis and classification to determine and assist when there is a high enough probability that a successful move would have been accomplished with a healthy subject.

7.2.4 Development of Expert System for Functional and Motion Analysis

Development of an expert system of hand and arm function related to object manipulation and functional use would be useful. The expert system will explore the interrelationships between physical attributes (neuro-muscular system and impairments), functional attributes and psychological attributes, namely to quantify fun and motivational factors. The goal will be to develop a clinical-based and home expert system to help define level of impairment and its relationship to functional loss, guidelines and games for training, and detailed assessment and outcome measures. This includes learning in real-time software systems, and adapting to the user as the user improves or changes over time.

A Testbed

The testbed makes it possible to experiment and acquire differential results from standard input devices such as a mouse to the input obtained through the embedded device created for this thesis.

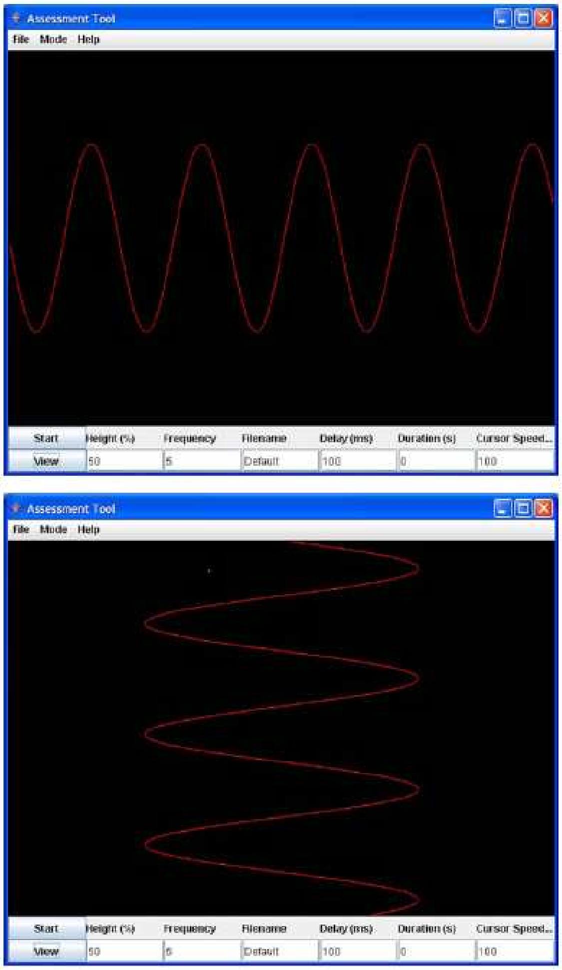
A.1 The ART Assessment Program

The secondary objective of the thesis is to demonstrate and compare the functionality and output of both the sensor and hardware interface. Thus the requirements for a software testing utility must have the ability to interface with both the sensor and embedded hardware, provide a standard or common predictable testing environment, and be able to compare the output of the thesis hardware against known devices. The ART program was developed from these requirements for this purpose.

The ART, or Assessment Rehabilitation Tool, is an objective assessment tool designed to monitor, record and quantify the ability of patients to handle and manipulate objects. The program is written in Java, using both the GNU serial libraries, and Sun Serial Port libraries to communicate via the serial port. The program's design allows it to use any set of instrumentable objects as appropriate to evaluate any geometric property (size shape weight, solid or liquid) or material quality (roughness slipper sticky or compliant). In the present thesis the ART tool provides a means to test the responsiveness and accuracy of the sensor apparatus. The software is designed to interface directly from the mini-Bird sensor or directly from the hardware component via a standardized mouse movement.

The software is able to configurable cursor motion in a simple waveform, such as a predictable sine wave, or a randomized wave. The cursor motion trajectories are configurable in amplitude and frequency. The readings are configured according to the parameters entered including delay in milliseconds and cursor speed delay in milliseconds. Through these parameters it is possible to configure a data capture rate, and speed that the test is performed.

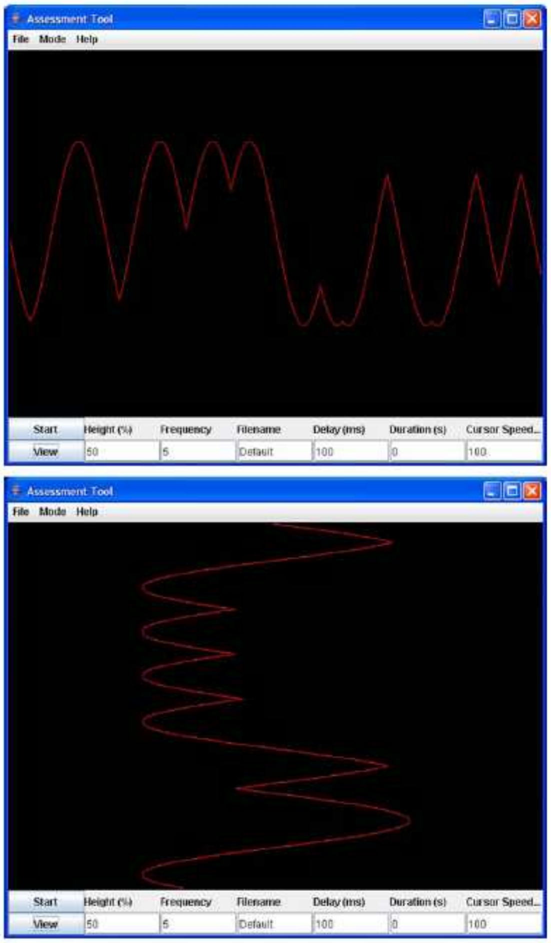
The method by which testing occurs is that a customizable sized cursor is shown on the screen that will follow the reference motion pattern requested. The subject then can perform a visual guided tracking task; follow the reference waveform by moving the computer mouse, sensor, or moving a given object with the sensor attached. Several tests were done with motion sensor directly connected to computer then through the embedded interface



Height (%)	Frequency	Filename	Delay (ms)	Duration (s)	Cursor Speed...
50	5	Default	100	0	100

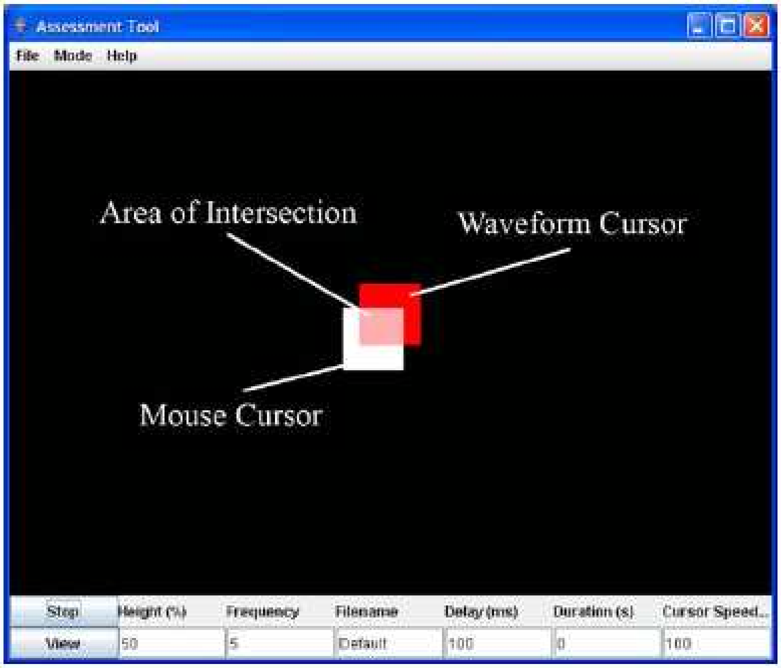
Height (%)	Frequency	Filename	Delay (ms)	Duration (s)	Cursor Speed...
50	6	Default	100	0	100

Figure 12: A.R.T. Screenshot showing predictable vertical and horizontal sine waves



Height (%)	Frequency	Filename	Delay (ms)	Duration (s)	Cursor Speed...
50	5	Default	100	0	100

Figure 13: A.R.T. Screenshot showing random vertical and horizontal sine waves



Height (%)	Frequency	Filename	Delay (ms)	Duration (s)	Cursor Speed...
50	5	Default	100	0	100

Figure 14: ART screenshot of Center of Area test showing mouse and waveform cursors

A secondary method of testing is through the embedded interface. The testing software allows mouse cursor output to be tracked along with the data from the test pattern. To determine accuracy, both the waveform cursor and the mouse cursor are visible as blocks on-screen. These blocks will change color as they intersect as a measure of biofeedback to the subject. The cursor intersection, in percent, along with waveform and cursor data is recorded for external programs to analyze the standard and logged waveforms.

Video games and virtual environments require some degree of accuracy and precision in control. Given that the intersection test is measured via mouse cursor location relative to the waveform location on the screen, the similarity to a real game that would be used for therapy is simulated. Most video games or video feedback are based on intersections of on-screen avatars or cursors of various shapes, speeds, and sizes. The area-intersection tests are designed to mimic similar movements both predictable and random that a representative video game would exhibit by allowing all aspects to be configured.

Notation

x	Horizontal Axis Position Coordinate
t	Coordinate Capture Point in Time
x_t	Current Horizontal Axis Position Coordinate as of time t
x_{t-1}	Previous Horizontal Axis Position Coordinate as of time t
s	Scale Output
y	Vertical Axis Position Coordinate
y_t	Current Vertical Axis Position Coordinate as of time t
y_{t-1}	Previous Vertical Axis Position Coordinate as of time t
$\bar{x_l}$	Axis Low Threshold
$\bar{x_u}$	Axis Upper Threshold
$direction$	Output Positional Direction State
n	User Selectable Numerical Sensitivity Setting $n \epsilon Z$
$S(n)$	Scaled output based on the Sensitivity Setting (see n)
out	see $direction$

B Software Architecture

This Appendix describes the software architecture for the embedded system. UML Flowcharts describe the program logic within the embedded system.

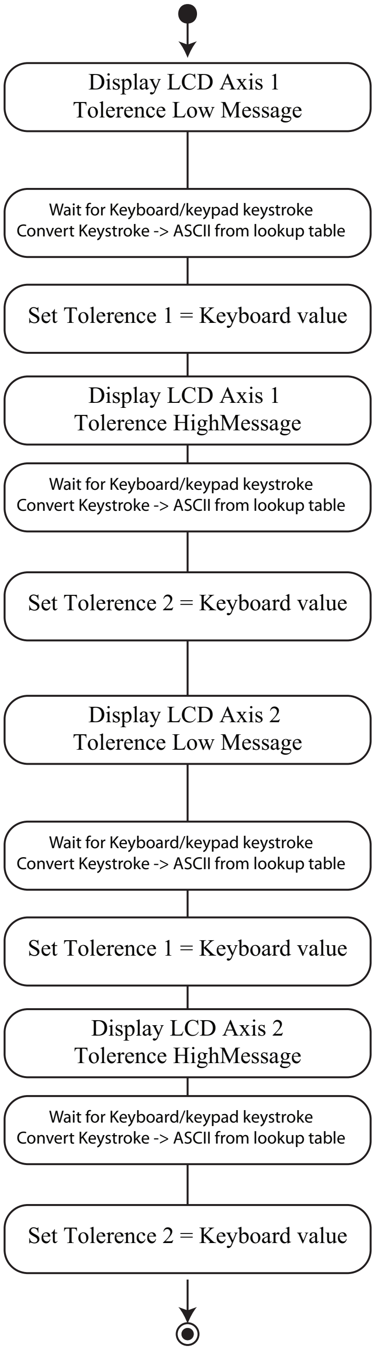
Glossary

CIM:	Constraint Induced Therapy The non-afflicted limb is constrained by a sling or cast forc
ECG:	Electrocardiography
EDR:	Electrodermal Response
EEG:	Electroencephalography
EKG:	Electrocardiography
EMG:	Electromyography
Biofeedback:	A biological signal is recorded, amplified/conditioned and presented in real-time in a si
Virtual Reality:	A computer simulation of a system that enables a user to perform operations on the sim
Virtual Immersion	see Virtual Reality

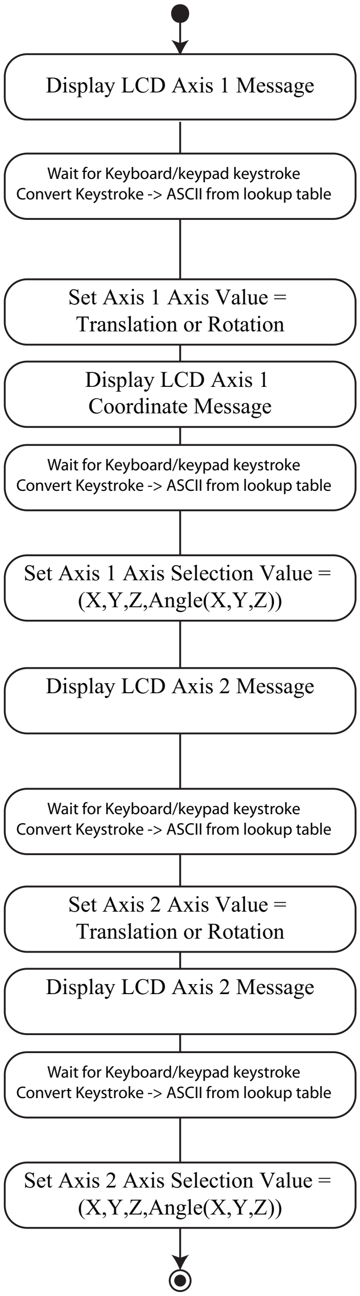
Menu F2 Tolerence Selection

Note:
The tolerence values are the distance between the lower tolerence and the upper or high tolerence forming a Tic TacToe grid in space or the same on a sphere

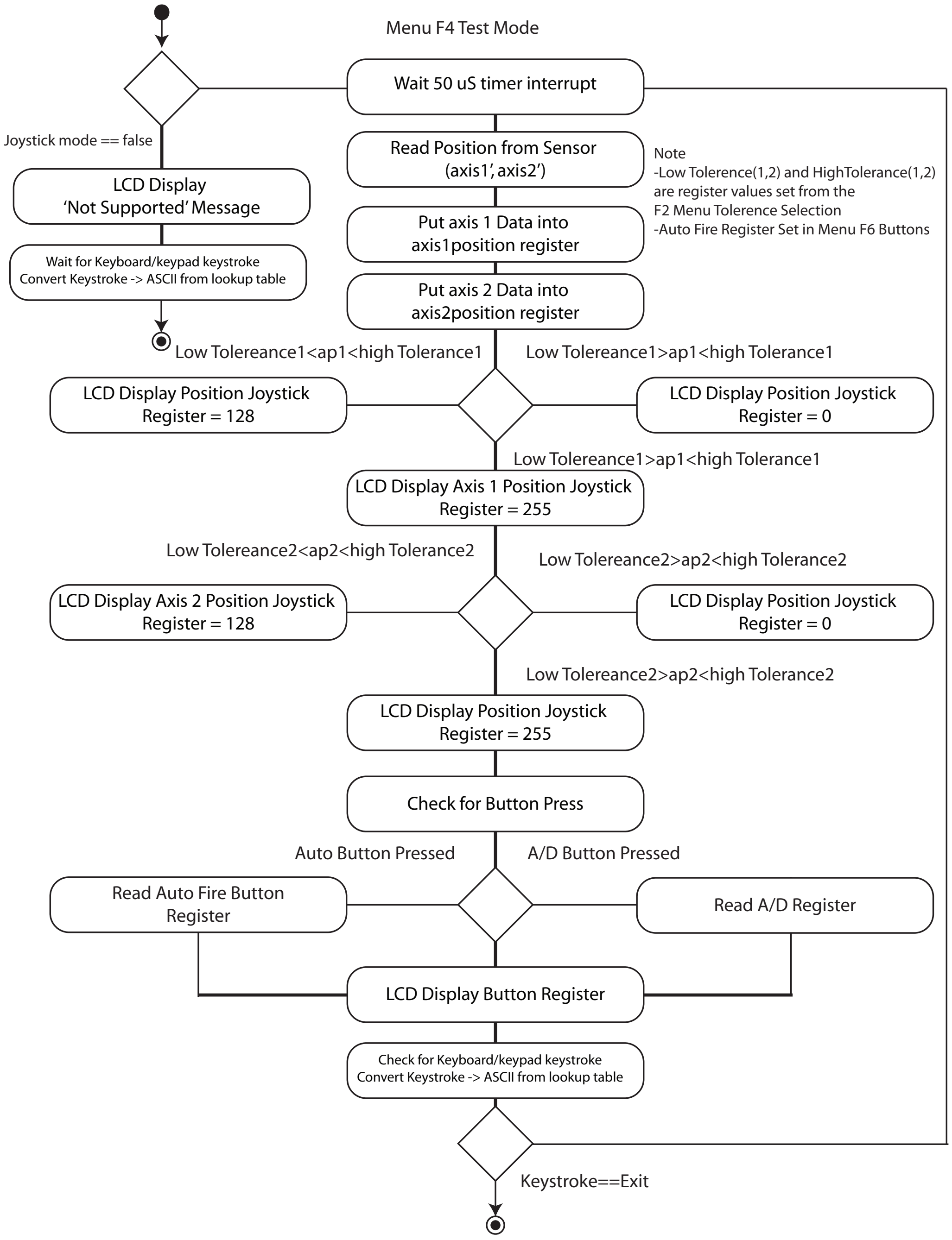
See the Diagram Page for an example of straight linear and angular grids



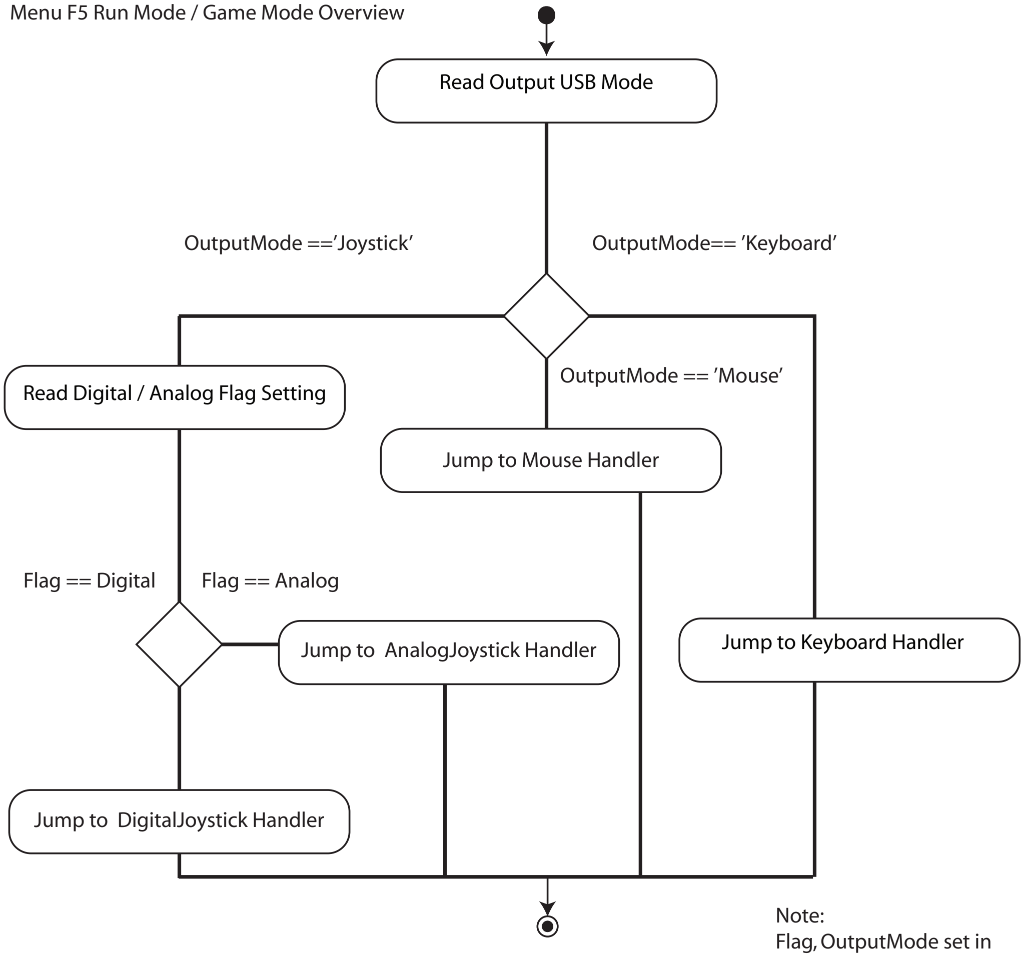
Menu F3 Axis Selection



Note:
Only Valid Values for the first is
Translation or Rotation
and the second is the result that is
either X,Y,Z (ANGLE(X,Y,Z)

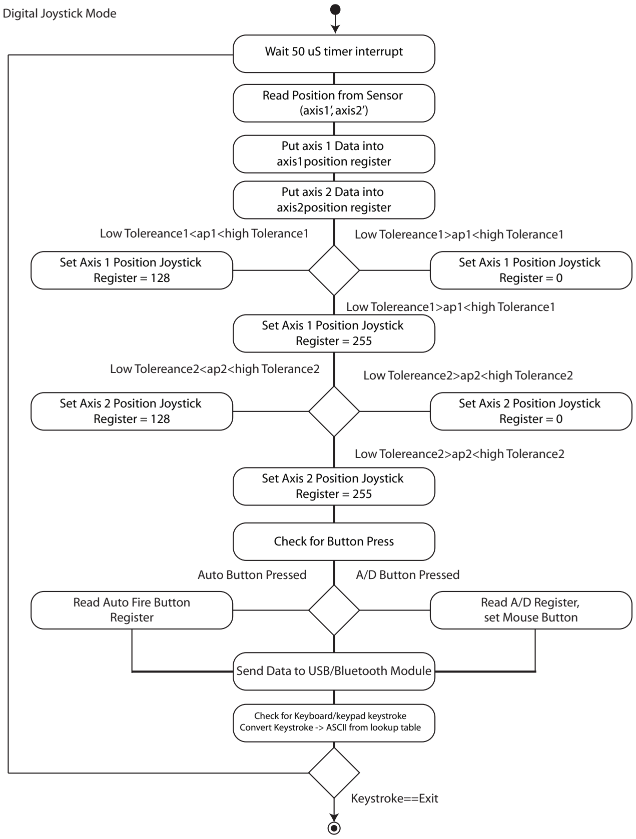

Menu F4 Test Mode
Wait 50 uS timer interrupt
Joystick mode == false
LCD Display
'Not Supported' Message
Wait for Keyboard/keypad keystroke
Convert Keystroke -> ASCII from lookup table
Read Position from Sensor
(axis1', axis2')
Note
-Low Tolerence(1,2) and HighTolerance(1,2)
are register values set from the
F2 Menu Tolerence Selection
-Auto Fire Register Set in Menu F6 Buttons
Put axis 1 Data into
axis1position register
Put axis 2 Data into
axis2position register
Low Tolereance1<ap1<high Tolerance1
Low Tolereance1>ap1<high Tolerance1
LCD Display Position Joystick
Register = 128
LCD Display Position Joystick
Register = 0
Low Tolereance1>ap1<high Tolerance1
LCD Display Axis 1 Position Joystick
Register = 255
Low Tolereance2<ap2<high Tolerance2
Low Tolereance2>ap2<high Tolerance2
LCD Display Axis 2 Position Joystick
Register = 128
LCD Display Position Joystick
Register = 0
Low Tolereance2>ap2<high Tolerance2
LCD Display Position Joystick
Register = 255
Check for Button Press
Auto Button Pressed
A/D Button Pressed
Read Auto Fire Button
Register
Read A/D Register
LCD Display Button Register
Check for Keyboard/keypad keystroke
Convert Keystroke -> ASCII from lookup table
Keystroke==Exit

Menu F5 Run Mode / Game Mode Overview



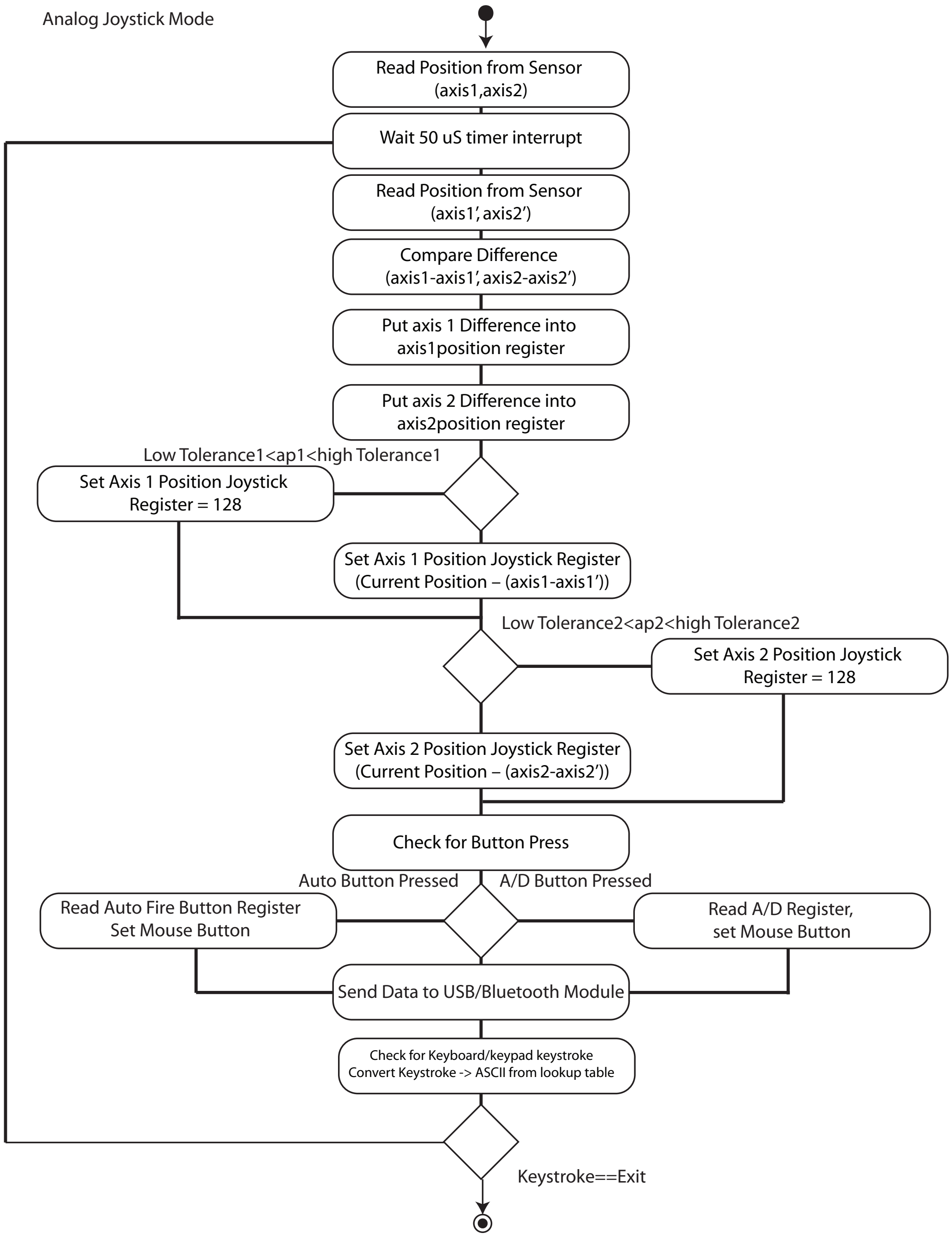
Note:
Flag, OutputMode set in
Menu F12 Output Selection

Digital Joystick Mode

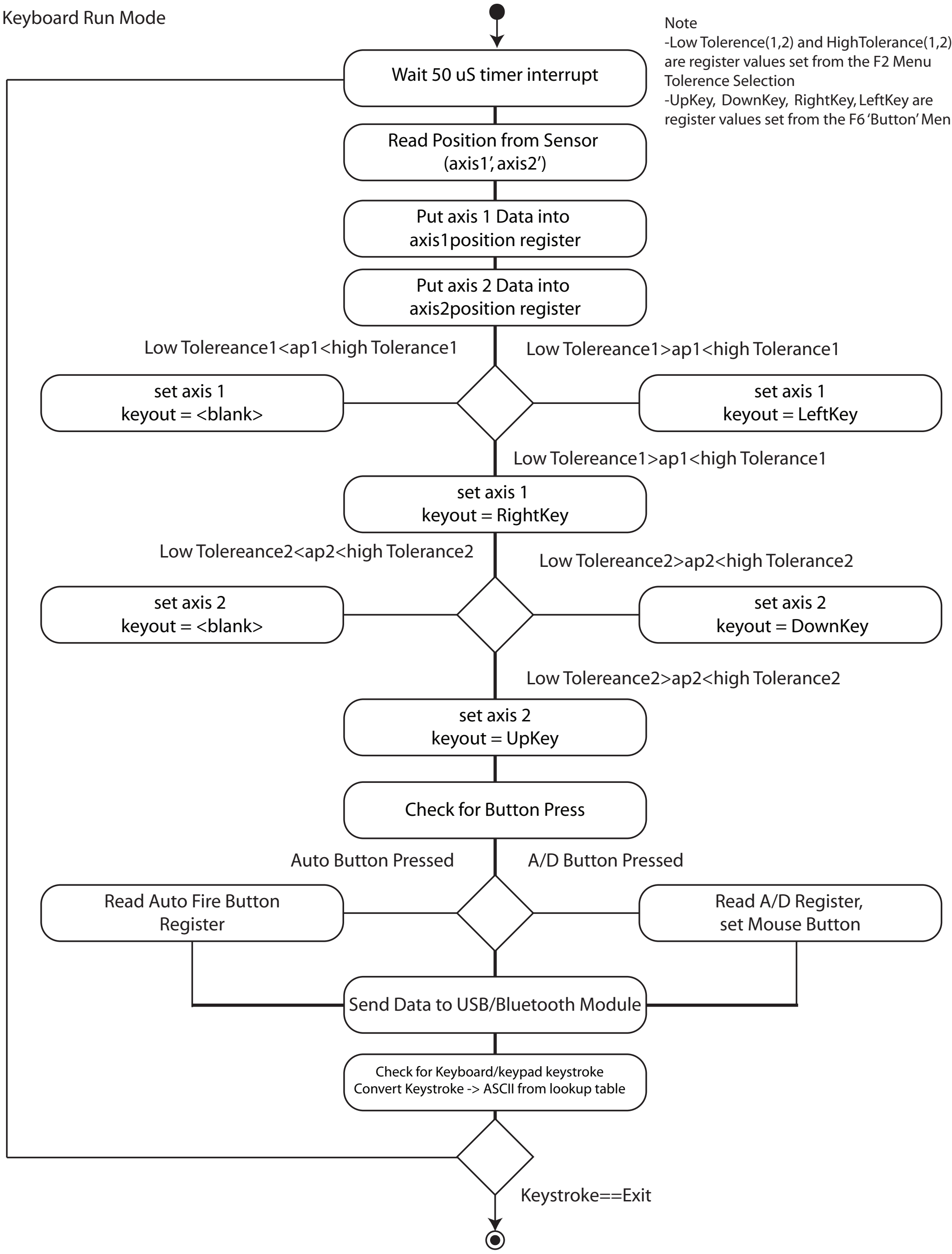


Note
Low Tolerence(1,2) and HighTolerance(1,2)
are register values set from the F2 Menu Tolerence Selection

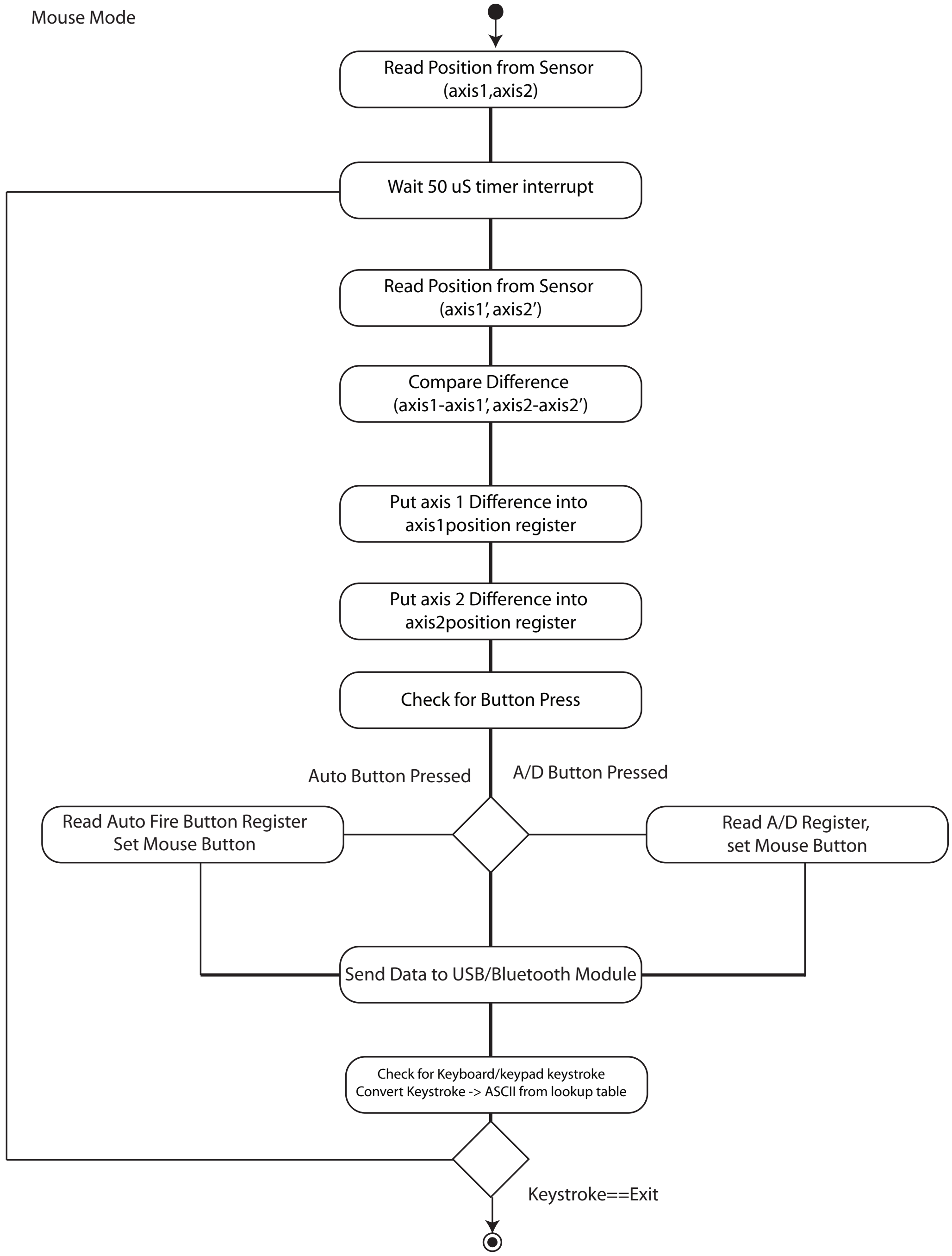
Analog Joystick Mode



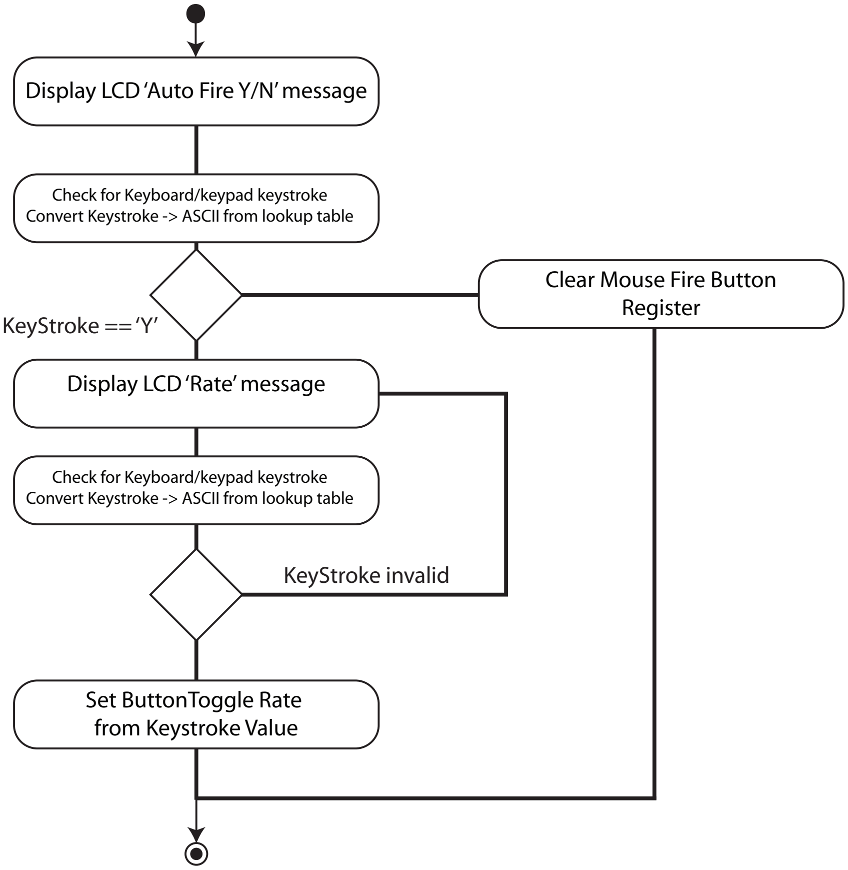
Keyboard Run Mode



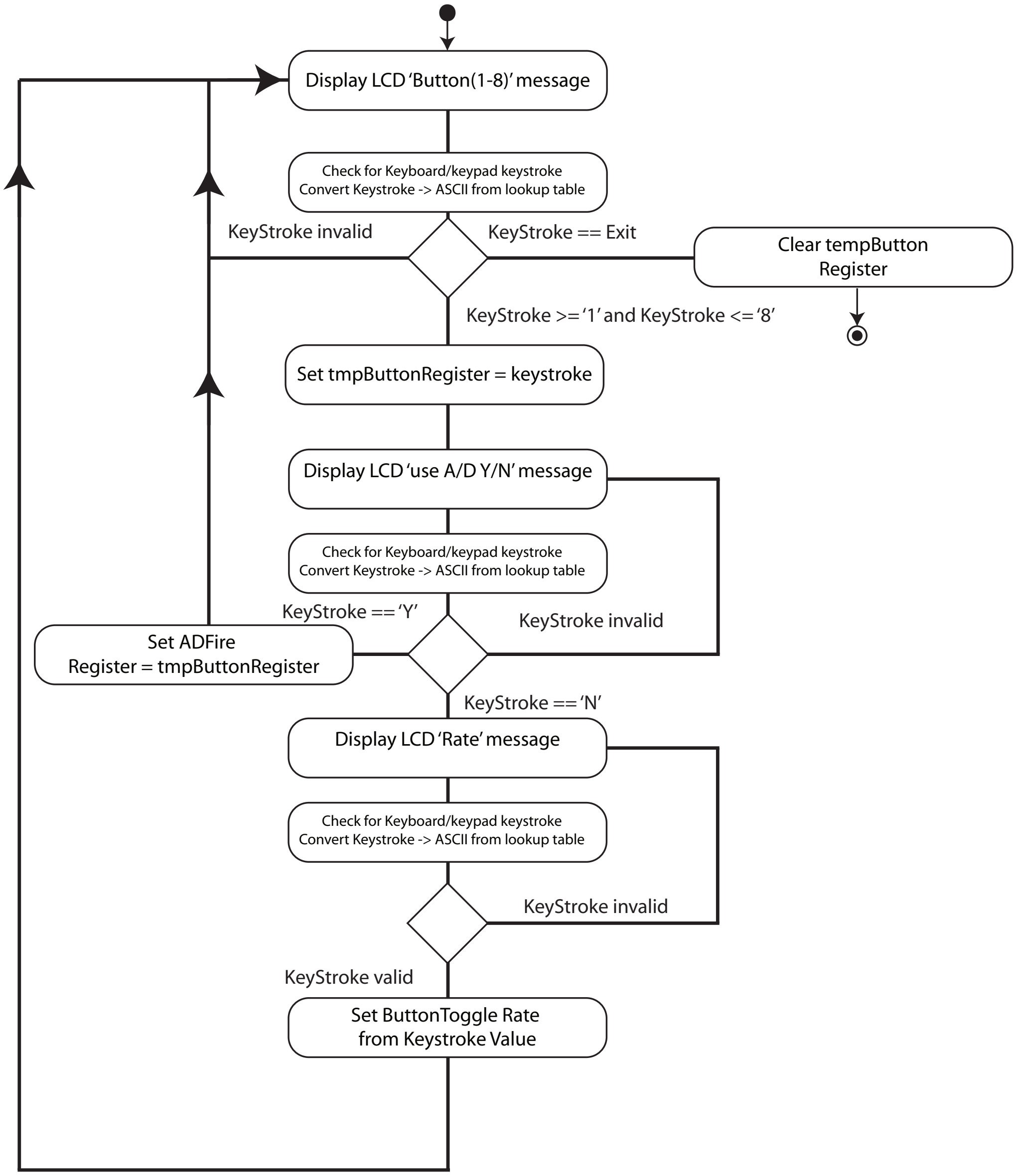
Note
-Low Tolerence(1,2) and HighTolerance(1,2) are register values set from the F2 Menu Tolerence Selection
-UpKey, DownKey, RightKey, LeftKey are register values set from the F6 'Button' Menu


Mouse Mode
Read Position from Sensor (axis1,axis2)
Wait 50 uS timer interrupt
Read Position from Sensor (axis1', axis2')
Compare Difference (axis1-axis1', axis2-axis2')
Put axis 1 Difference into axis1position register
Put axis 2 Difference into axis2position register
Check for Button Press
Auto Button Pressed
A/D Button Pressed
Read Auto Fire Button Register Set Mouse Button
Read A/D Register, set Mouse Button
Send Data to USB/Bluetooth Module
Check for Keyboard/keypad keystroke Convert Keystroke -> ASCII from lookup table
Keystroke==Exit

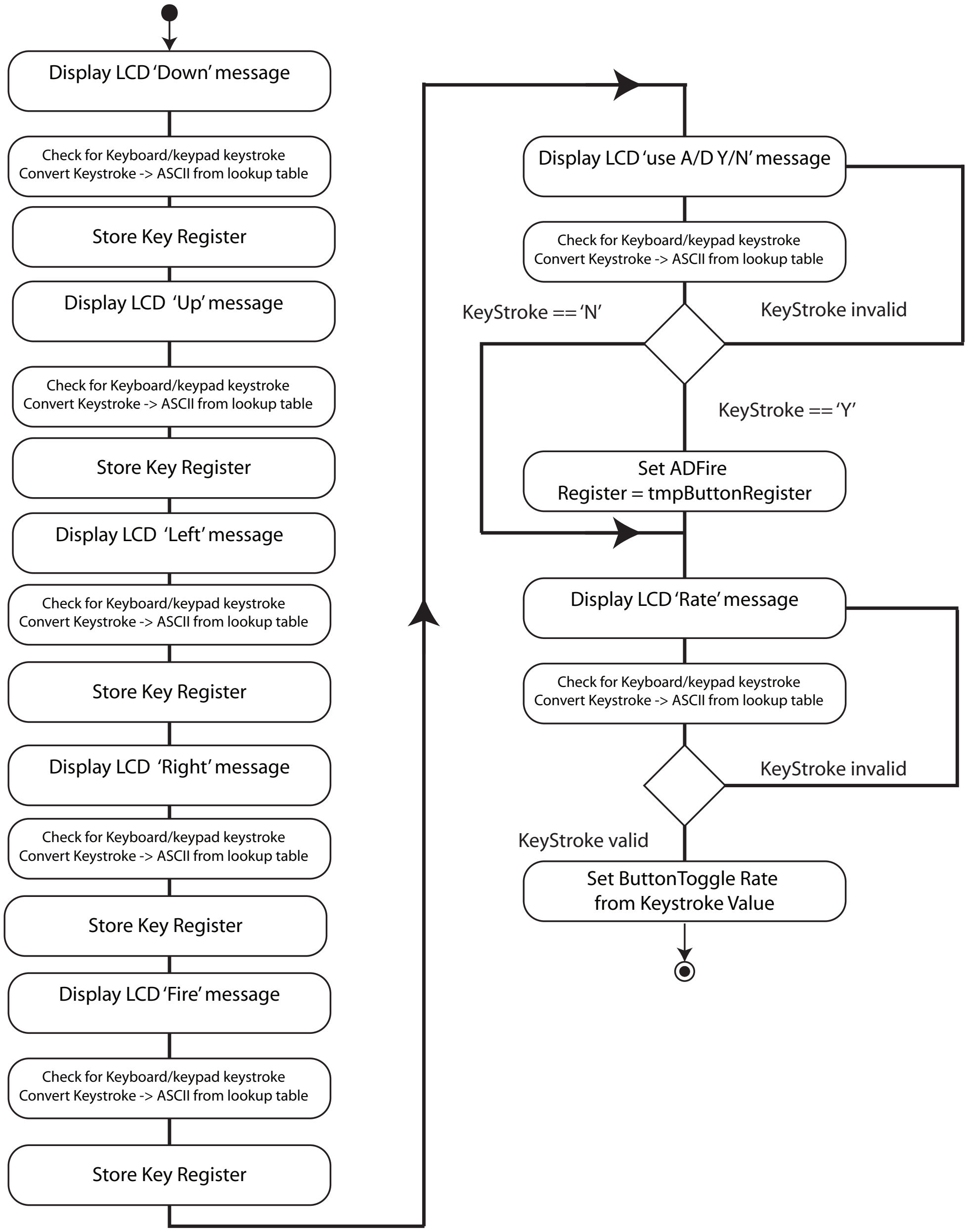
Menu F6 Button Fire / Toggle Selection



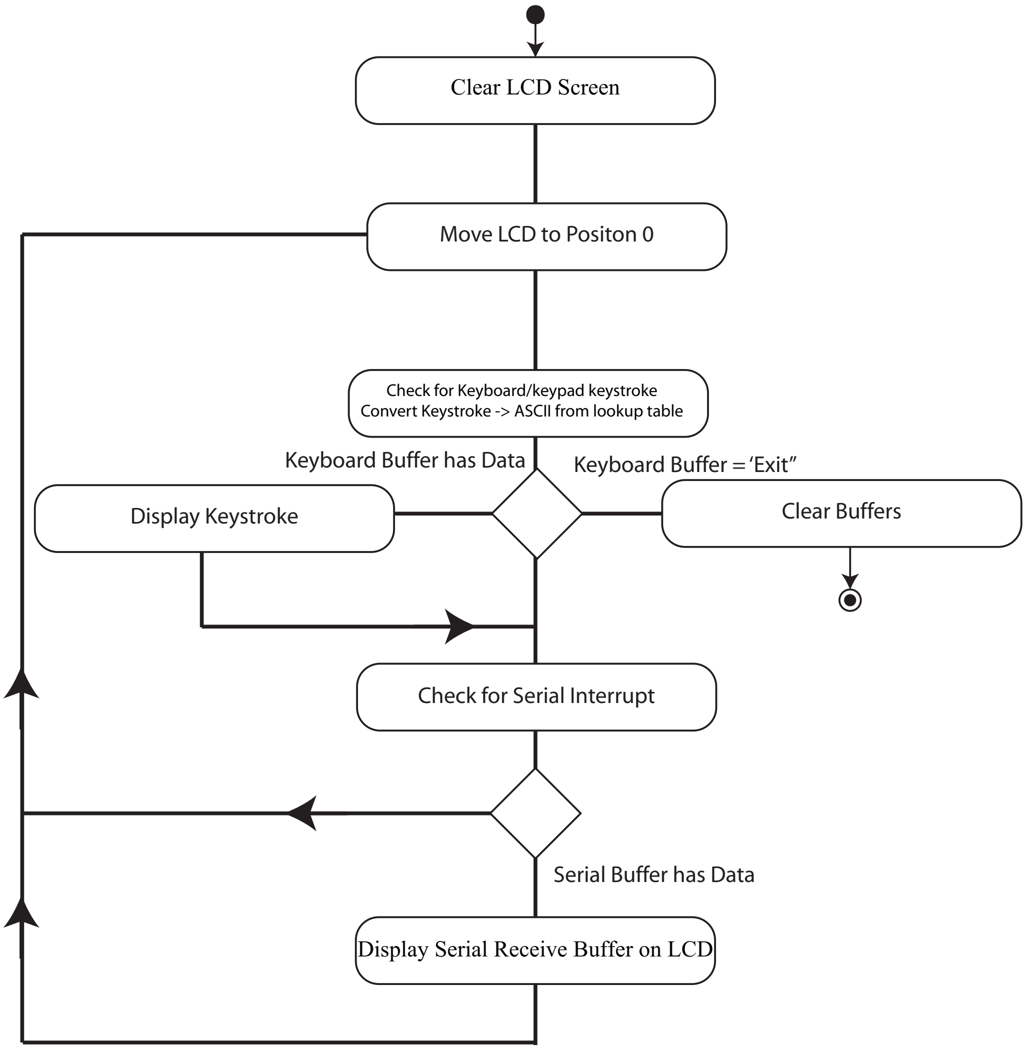
Menu F6 Joystick Button Fire / Toggle Selection



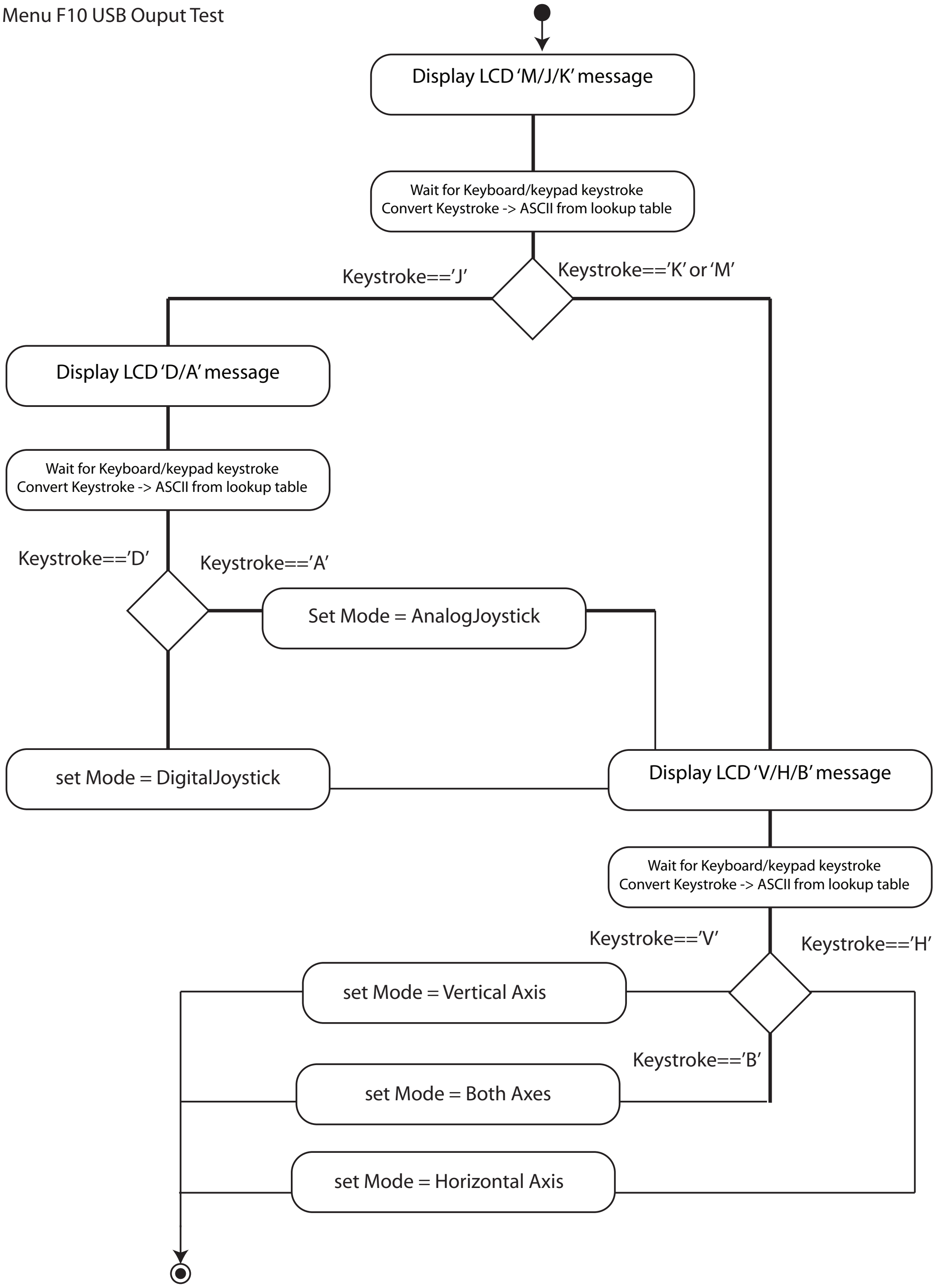
Menu F6 Keyboard Button Fire / Toggle Selection



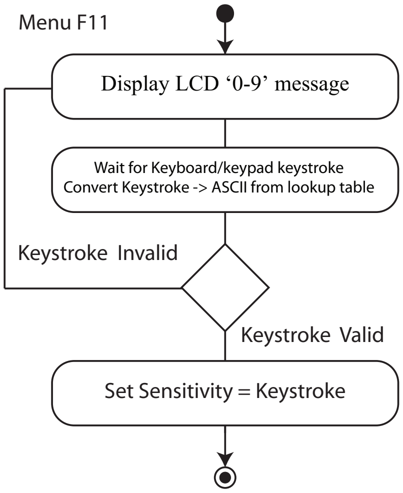
Menu F7 - Test Terminal



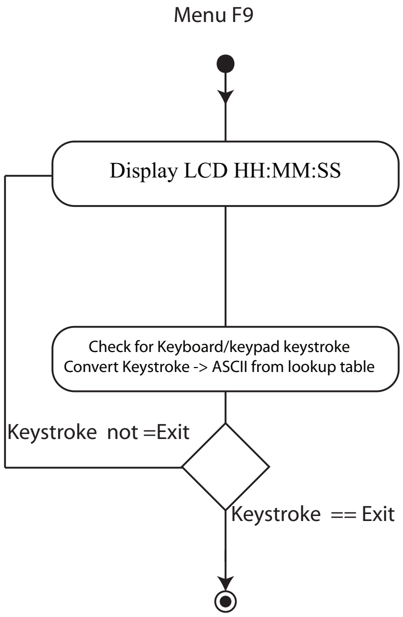
Menu F10 USB Ouput Test



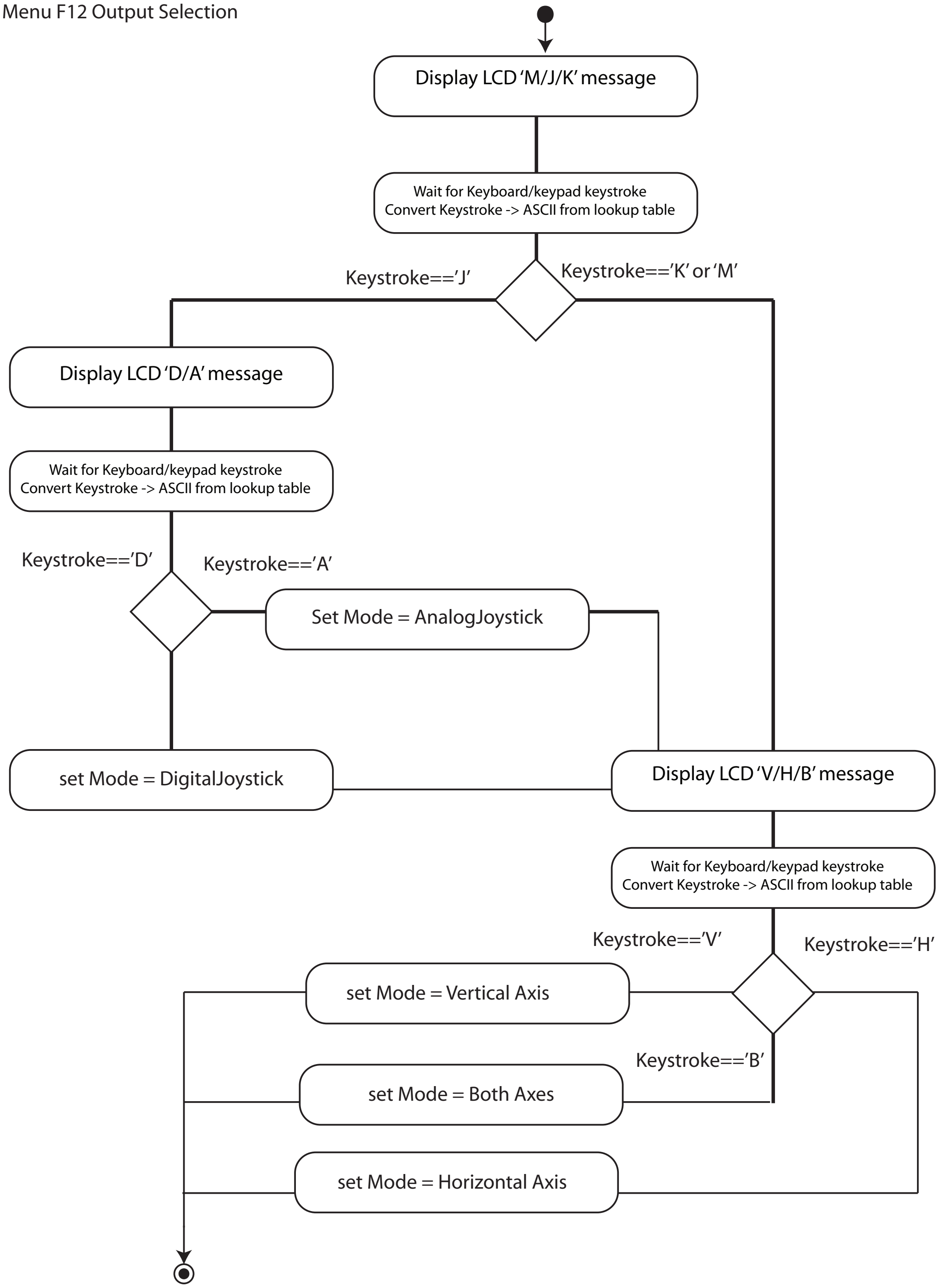
Menu F11 Sensitivity Selection



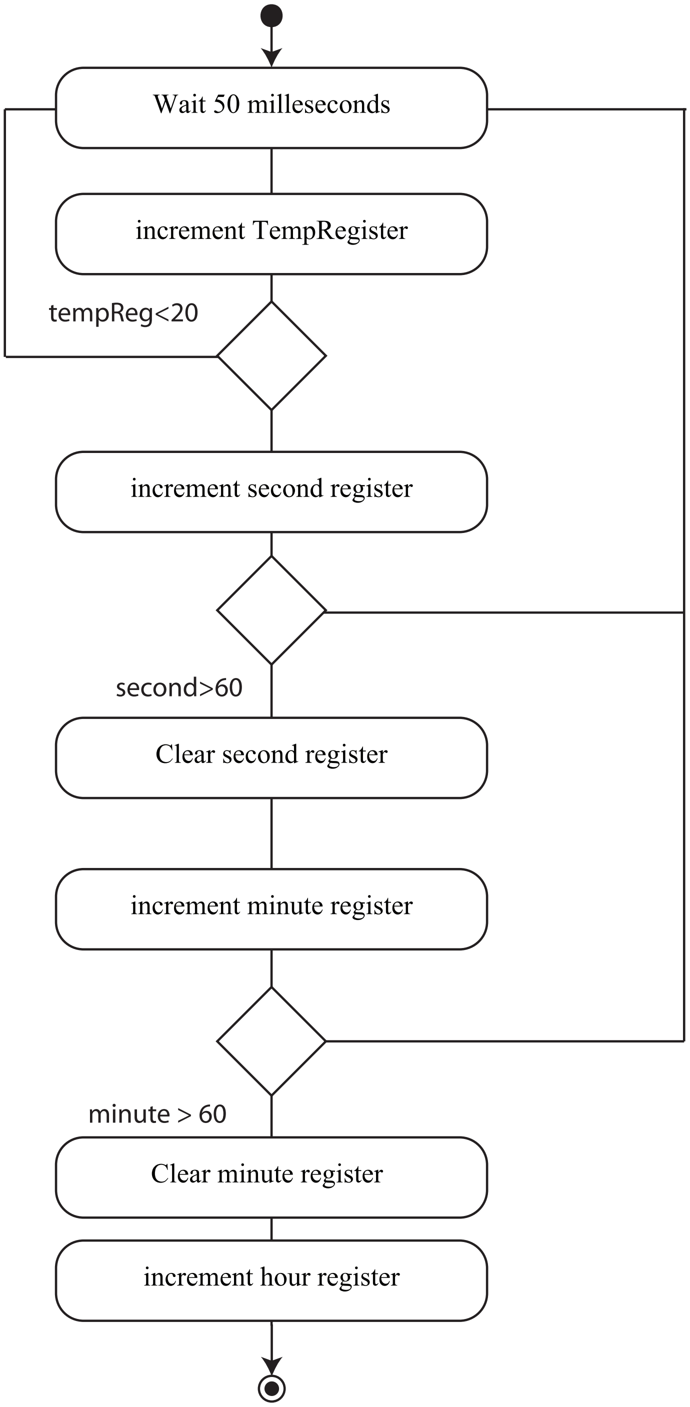
Menu F9 Real Time Clock Display



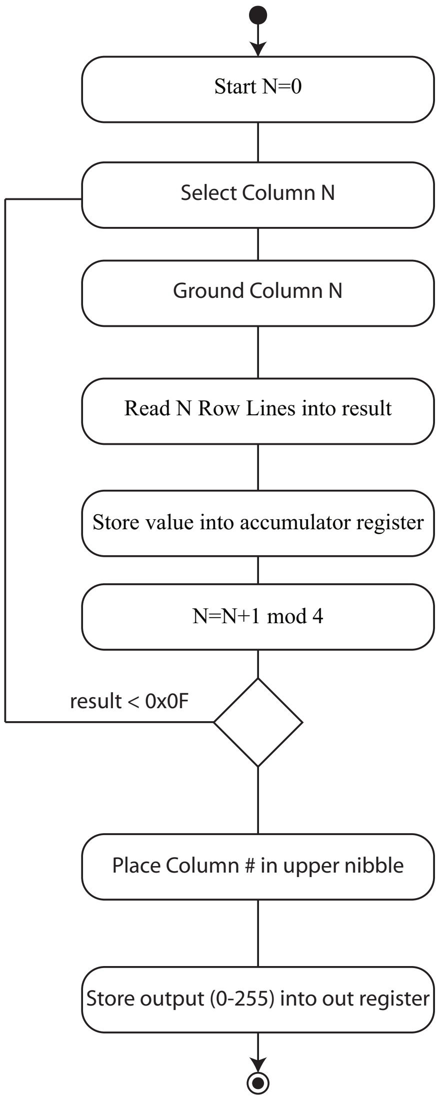
Menu F12 Output Selection

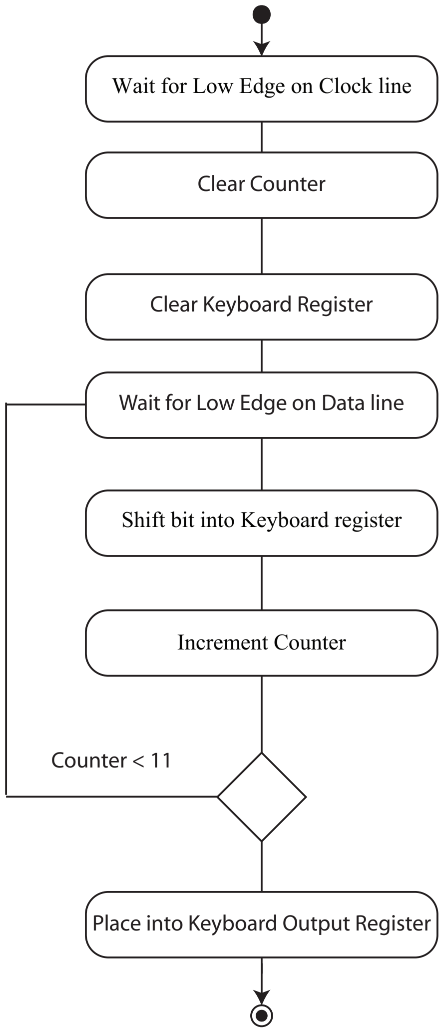


Real time Clock

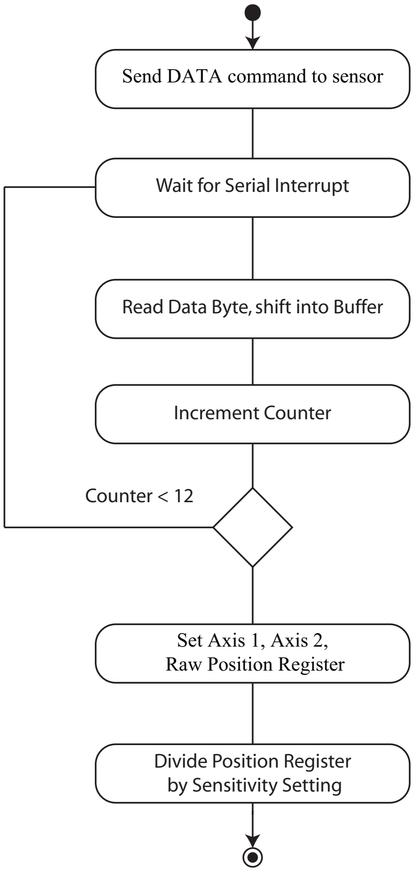


Sensor Unit


Start N=0
Select Column N
Ground Column N
Read N Row Lines into result
Store value into accumulator register
N=N+1 mod 4
result < 0x0F
Place Column # in upper nibble
Store output (0-255) into out register


Wait for Low Edge on Clock line
Clear Counter
Clear Keyboard Register
Wait for Low Edge on Data line
Shift bit into Keyboard register
Increment Counter
Counter < 11
Place into Keyboard Output Register

Sensor Communication Unit



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