INVESTIGATION OF HUMAN ACTIVITY STATE DETECTION AND MONITORING

By

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Presented to the faculty of the Graduate School of
The University of Texas at Arlington in Partial Fulfillment
Of the requirements
For the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON
August 2003
INVESTIGATION OF HUMAN ACTIVITY STATE DETECTION AND MONITORING

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ABSTRACT

INVESTIGATION OF HUMAN ACTIVITY STATE DETECTION AND MONITORING

Publication No._______

Jeevan Francis D'Souza, M.S.

The University of Texas at Arlington, 2003

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Periodic clinical visits are merely “snapshots” of the patient’s status, giving rise to portable monitoring instruments. This thesis describes a second generation system for objective and unobtrusive physical activity monitoring. The approach recognizes that complex dynamic situations can be characterized by activity states defined by feature combinations.

A generic platform supporting research and field use was developed for a subject-worn system incorporating a MEMS-based sensor, new microcontroller technology, and a "raw data" logging mode for data-basing sensed parameters. An experiment was conducted
with 10 subjects and five test states: lying, sitting, standing, walking, and running. Data representing thigh acceleration was logged and processed to derive amount of motion and orientation. Histograms were used to develop state detection rules found to be approximately 95 percent accurate across all states. It is concluded that the system and approach will support exploration of a wide variety of activity states and detection schemes.
ACKNOWLEDGEMENTS

I am thankful to Dr. George V. Kondraske who was my supervising professor and was instrumental in the design and conceptualization of my thesis. I also thank the Committee comprising of Dr. Qilian Liang and Dr. Jung-Chih Chiao, who reviewed my work and gave me constructive feedback.

I’m grateful to Mr. John Stevens, the technical staff of the Human Performance Institute at the University of Texas at Arlington, who was instrumental in the fabrication of my research unit.

Finally I would like to thank the fore-runners of my thesis concept, namely Mr. Abhijeet Dubashi, and Mr. Gopinath Ganapathy, whose ideas and papers, helped me design my thesis.

May 8, 2003
## TABLE OF CONTENTS

ABSTRACT ...................................................................................................................... III
ACKNOWLEDGEMENTS ................................................................................................. V
LIST OF TABLES .............................................................................................................. VIII
LIST OF FIGURES ........................................................................................................... IX

### CHAPTER

1. INTRODUCTION
   - 1.1 INTRODUCTION ................................................................................................... 1
   - 1.2 LITERATURE REVIEW ....................................................................................... 2
       - 1.2.1 EXTERNAL ACTIVITY MONITORING DEVICES ........................................... 2
       - 1.2.2 SUBJECT WORN ACTIVITY MONITORING SYSTEMS ........................... 4
   - 1.3 SUMMARY ......................................................................................................... 12
   - 1.4 OBJECTIVES ..................................................................................................... 14

2. SYSTEM CONCEPT AND DESIGN ........................................................................ 16
   - 2.1 GLOBAL DESIGN ISSUES .............................................................................. 16
   - 2.2 SECOND GENERATION ACTIVITY STATE DETECTION AND MONITORING SYSTEM ... 19
   - 2.3 SLU HARDWARE DESIGN DETAILS ............................................................. 27

3. SOFTWARE DESIGN AND IMPLEMENTATION ..................................................... 29
   - 3.1 INTRODUCTION ............................................................................................... 29
   - 3.2 SOFTWARE DESIGN CONSIDERATIONS ...................................................... 29
   - 3.3 RAW-DATA LOGGING MODE .......................................................................... 32
   - 3.4 STATE DETECTION LOGGING MODE ............................................................. 35
3.5 Support Subroutines ................................................................. 37

4. Experimental System Evaluation ............................................. 38
   4.1 Overview and Objectives ...................................................... 38
   4.2 Bench Test and Calibration .................................................. 38
   4.3 Human Subject Experiments ................................................ 41
       4.3.1 Experimental Procedure .............................................. 41
       4.3.2 Data Analysis ............................................................ 47
   4.4 Results ................................................................................. 55
   4.5 Global Performance Observations ........................................ 58

5. Conclusions and Future Research ............................................. 60
   5.1 Review of Objectives ............................................................ 60
   5.2 Cost-Performance Analysis ................................................... 61
   5.3 Overall Evaluation ............................................................... 63
   5.4 Real-Time Performance ......................................................... 64
   5.5 Recommendations for Future Work ....................................... 65
   5.6 Concluding Remarks ........................................................... 66

Appendix

A. Schematic ................................................................................. 67
B. Experimental Data and Plots ..................................................... 71
C. UTA IRB Document ................................................................. 81

References .................................................................................... 85

Biographical Statement ................................................................ 89
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Summary of results after the literature review</td>
<td>13</td>
</tr>
<tr>
<td>2.1 Power consumption</td>
<td>26</td>
</tr>
<tr>
<td>4.1 Accelerometer Specifications</td>
<td>41</td>
</tr>
<tr>
<td>4.2 Scripts used to instruct the subject for static and dynamic testing</td>
<td>42</td>
</tr>
<tr>
<td>4.3 Data used to design the thigh angle concept</td>
<td>49</td>
</tr>
<tr>
<td>4.4 Ranges from the histograms</td>
<td>56</td>
</tr>
<tr>
<td>4.5 Summary of Threshold Criteria Used in State Detection Rules</td>
<td>57</td>
</tr>
<tr>
<td>4.6 Performance of state detection rules</td>
<td>58</td>
</tr>
<tr>
<td>5.1 Component Cost for the HASDMS</td>
<td>62</td>
</tr>
<tr>
<td>B.1 Calibration Data</td>
<td>72</td>
</tr>
</tbody>
</table>
# LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Video content extraction used to monitor human activity</td>
<td>4</td>
</tr>
<tr>
<td>1.2 PSG Device and Plots</td>
<td>6</td>
</tr>
<tr>
<td>1.3 ACTIWATCH Device and plots</td>
<td>8</td>
</tr>
<tr>
<td>1.4 Octagonal Basic motion logger</td>
<td>9</td>
</tr>
<tr>
<td>1.5 Micro mini motion logger</td>
<td>10</td>
</tr>
<tr>
<td>1.6 HASDMS – I mounted on the thigh</td>
<td>12</td>
</tr>
<tr>
<td>2.1 General Architecture of the HASDMS</td>
<td>16</td>
</tr>
<tr>
<td>2.2 Typical voltage outputs at the $X_{filt}$ and $Y_{filt}$ pins at various positions of the IC</td>
<td>20</td>
</tr>
<tr>
<td>2.3 Basic Connections of the ADXL202 chip</td>
<td>20</td>
</tr>
<tr>
<td>2.4 Basic Connections of the ADuC824 chip</td>
<td>22</td>
</tr>
<tr>
<td>2.5 Basic Connections of the ST Microelectronics memory chip</td>
<td>24</td>
</tr>
<tr>
<td>2.6 Connections with the TC232CPE</td>
<td>25</td>
</tr>
<tr>
<td>2.7 A functional Block diagram of the ASDMS</td>
<td>27</td>
</tr>
<tr>
<td>3.1 Flowchart for the SLU main operating system showing power saving</td>
<td>31</td>
</tr>
<tr>
<td>3.2 Flowchart of the Raw-data Logging routine</td>
<td>34</td>
</tr>
<tr>
<td>3.3 Flowchart of the Activity State Logging routine</td>
<td>36</td>
</tr>
<tr>
<td>4.1 Orientation of the Accelerometer w.r.t the case and definition of axes</td>
<td>39</td>
</tr>
<tr>
<td>4.2 Attaching the straps of the SLU</td>
<td>45</td>
</tr>
<tr>
<td>4.3 Wearing the SLU</td>
<td>46</td>
</tr>
<tr>
<td>4.4 Plot of Calibration data</td>
<td>50</td>
</tr>
</tbody>
</table>
4.5 Summary of the minimum and maximum limits of motion of the 0-deg sensor 52
4.6 Summary of the minimum and maximum limits of motion of the 90-deg sensor 52
4.7 Summary of the minimum and maximum limits of Angle 53
4.8 Summary of the min and max AOW1s limits of motion of the 0-deg sensor 53
4.9 Summary of the min and max AOW1s limits of motion of the 90-deg sensor 54
4.10 Summary of the minimum and maximum AOW1s limits of angle 54
4.11 Histogram showing number of AOW1s samples present in each angle range 55

A.1. Schematic of Accelerometer board 68
A.2. Schematic of ADuc824 & STM24512 board 69
A.3: Schematic of circuit board for interfacing SLU with the PC 70

B.1 Number of samples VS amount of motion of the 0-deg sensor for Lie state 73
B.2 Number of samples VS amount of motion of the 0-deg sensor for sit state 73
B.3 Number of samples VS amount of motion of the 0-deg sensor for stand state 74
B.4 Number of samples VS amount of motion of the 0-deg sensor for walk state 74
B.5 Number of samples VS amount of motion of the 0-deg sensor for run state 75
B.6 Number of samples VS amount of motion of the 90-deg sensor for Lie state 75
B.7 Number of samples VS amount of motion of the 90-deg sensor for sit state 76
B.8 Number of samples VS amount of motion of the 90-deg sensor for stand state 76
B.9 Number of samples VS amount of motion of the 90-deg sensor for walk state 77
B.10 Number of samples VS amount of motion of the 90-deg sensor for run state 77
B.11 Number of samples VS Angle for Lie state 78
B.12 Number of samples VS Angle for Sit state 78
B.13 Number of samples VS Angle for Stand state 79
B.14 Number of samples VS Angle for Walk state 79
B.15 Number of samples VS Angle for Run state 80
CHAPTER 1

INTRODUCTION

1.1 Introduction

Human activity monitoring is a general term applied to describe efforts to either qualitative recordings or objective quantitative measures that reflect some aspect of human activity. Generally speaking, the term usually pertains to activities that are motion related. However, other types of activities may also be included in the broadest interpretation. A good deal of research has been undertaken on this topic motivated by a variety of purposes, including medical rehabilitation and security applications resulting in a variety of different approaches and instruments. Some of these motivational applications are listed below.

Neuro-muscular-skeletal rehabilitation uses such systems for objective outcome measurement, monitoring learning associated with lower extremity prostheses, effectiveness of interventions (medication, functional electric stimulation, etc.) and compliance with outpatient exercise programs. Cardiovascular diagnosis and rehabilitation uses activity monitoring for objective outcome measurement, and objective, automatic logging for correlation of specific activities with cardiac responses (i.e. adjunct to Holter monitoring). Similarly, occupational medicine uses activity monitoring to validate severity of injury, to determine compliance with rehabilitation exercise programs, and to determine return-to-work readiness in worker’s compensation cases. In the field of gerontology, applications include use to screen individuals for suitability for different living environments, early warning of
medication sensitivities, and multiple medication incompatibilities. There are also applications in psychiatry and psychology for detecting psychomotor drug effects and hyper-hypo-activity in children and adults. In sports medicine, activity monitoring can be foreseen to be helpful in rehabilitation compliance and post-injury return-to-play readiness. New technologies have increased performance, lowered the cost, and offer the opportunity to incorporate greater sophistication. This thesis represents a follow on to one unique approach in this field conceived by Kondraske that focuses on the concepts of "activity states" (e.g. walking, standing, etc.) and revisits a first-generation Human Activity State Detection and Monitoring System that implemented this concept (Ganapathy and Kondraske, 1990) to detect a specific set of such activity states (sitting, standing, walking, and running). This approach differs conceptually from work of others that generally focus on recording simply the amount of activity. The interest now is on developing a flexible research platform and methodology that would support investigations into detection and discrimination of a wider variety of activity states. In addition, this thesis initiates a longer-term research strategy that enables meaningful investigation of competing approaches for processing sensor data to discriminate activity states.

1.2 Literature Review

All the approaches to activity monitoring can be organized into two main classifications viz. External and Subject Worn

1.2.1 External Activity Monitoring Devices:

External activity monitoring devices are devices that are not worn or attached to the subject. Rather they "observe" from a distance. They do not move along with the subject and hence the subject is confined to a defined space in case he/she has to be monitored. Most external monitoring devices are video-based. Examples of such devices are reviewed below.
Video Monitoring:

Human activity is frequently monitored using video cameras. Mounting video cameras is relatively inexpensive, but the process of reviewing video and videotapes requires considerable time of skilled human experts (e.g. clinicians, nurses, etc.). Furthermore, review is generally qualitative. Although surveillance cameras are already prevalent in many application domains, data from these sources is currently used only "after the fact" as a forensic tool.

This concept has been reviewed from a paper by (Collins et al, 2000). This method does not cause any discomfort to the patient. However, he subjects are confined to a given environment within the reach of the camera. Human intervention would be required to change video media at regular intervals.

Activity Detection by Video Content Extraction (ADVICE):

ADVICE (Activity Detection by Video Content Extraction) is under research in many laboratories. It is an integrated system of algorithms for detecting, tracking, recognizing, and filtering human activity in video streams. This research (Kim, 1999) addresses four core issues: 1) detection and tracking of people viewed by a passive or active camera; 2) integrated identification and tracking of people; 3) modeling, classification, and recognition of human activities; and 4) content-based filtering.

Here human activity is detected using algorithms from the video file that has already been captured. The algorithms go through the entire video and summarize the results of the human activity which is directly viewed by the medical personnel. It may be possible to adapt this approach for use in the medical, rehabilitation, and behavioral applications that are of interest in order to reduce the amount of skilled human time required for evaluations. The
disadvantages here again are: 1) the requirement of a technical expert to exchange video storage media at regular intervals and 2) the patient is confined to a fixed area.

Figure 1.1 Video content extraction used to monitor human activity

1.2.2 Subject Worn Activity Monitoring Systems

Subject worn activity monitoring devices are devices that are worn by or attached to the subject. They could be strapped or hooked on to the subject under test. They move along with the subject and hence the subject is not confined to a small area or cell in case he/she has to be monitored. They generally use portable battery cells which last for at least several hours and in some cases, many days. Examples of such devices are given below:

Electromyography:

One project (Sherrill et al, 2002) compared the performance of surface electromyography (EMG) with that of accelerometry in the detection and classification of functional motor activities (FMAs). The outcome of the project guides the development of a wearable, user-friendly system to automatically monitor an individual’s functional status in the home and relay that information to a remotely located caregiver. Accelerometers are microelectronic devices capable of sensing the accelerations of the body segment
to which they are attached, and have been widely used for ambulatory monitoring in the rehabilitation literature and in the medical device industry. Surface EMG electrodes detect the electrical activity of muscles beneath the skin surface, and are a novel approach to ambulatory monitoring.

Earlier work with EMG suggests it to be a viable alternative or complement to accelerometers. To explore the relationship between the two sensor types, simultaneous recordings of EMG and accelerometer signals were obtained while 12 subjects performed a predetermined sequence of tasks in the laboratory. Preliminary results suggested that accelerometers have higher levels of sensitivity than EMG for given levels of specificity and misclassification.

Accelerometry has also been used in longer-term gross physical activity monitoring to evaluate the effectiveness of back surgery (Bussman et al, 1998) and other mobility-related conditions (Aminiam et al, 1999), individuals with multiple sclerosis (Ng and Braun 1997), and patients undergoing regular hemodialysis (Johansen et al. 2000). In each of these cases, the amount of acceleration of a given body segment was simply integrated over a specified time window and used to reflect activity.

Polysomnography (PSG):

Polysomnography (PSG) has been the standard approach to diagnosing sleep disorders. PSG consists of recording a number of physiologic parameters on the patient while they sleep. They are, Limb activity, position, snoring, respiration, pulse rate and oxygen saturation.
Previously Compliance verification could be obtained in large measure only with the use of PSG, when a subject was monitored in a sleep lab. PSG is very costly and requires that a subject remains overnight in a sleep lab. (McKenzie, 2002) Below are the figures related to PSG:

![Example PSG device and output plots](image)

**Figure 1.2.** (Left) PSG Device (Right) Output Plots

Several commercial subject-worn devices are available that reflect the current state-of-the-art in physical activity monitoring. Three are briefly summarized below.
ACTIWATCH:

ACTIWATCH is a commercial device by Mini Mitter Co. Inc, Oregon USA. The Acti-watch is an actigraphic device which measures human activity. The two major applications of the actiwacth are to measure sleep/wake patterns and periodic limb movements in sleep (PLMS).

ACTIWATCH is a small, rugged data logger that records gross motor activity. The device is strapped onto any limb of the human subject. Each model of the Actiwatch is equipped with an accelerometer which measures acceleration and is converted to digital data before being used for analysis.

The Accelerometer within the Actiwatch is capable of sensing motion with a minimum resultant force of 0.01g and can integrate both degree and intensity of motion (McKenzie, 2002). The Actiwatch is an actigraphy device that is the size of a standard wrist watch. It allows for the recording of the smallest movements at an adjustable rate allowing logging to go on for up to 44 days. The memory size is 64 KB. Data transfer to a PC is done using wireless technology.
The graph above does not show a specific activity, but tells us the amount of activity of the wrist. This is an example of activity monitoring and not activity detection.

Octagonal BASIC Motion logger

Another commercial device is produced by Ambulatory Monitoring Inc. (www.ambulatory-monitoring.com). It is an actigraphic type device which measures human activity. It looks like a watch and its main features include event marker; audible feedback; 2MB memory; 2-3 Hz filter; sensitivity is 0.01g at mid band; Aero Crossing (ZC), Time-Above-Threshold (TAT), and Proportional Integrating Measure (PIM) modes of operation and Tri-mode (ZC, TAT, and PIM simultaneously); waterproof (shower safe); and easy coin cell battery exchange (60-day battery life) via compartment isolated from sealed interior electronics.
Another commercial device by Ambulatory Monitoring Inc. is also an actigraphic device which measures human activity. It looks like a watch and its main features include:

- 1" diameter x 0.35" height - weighs under 1/2 oz. (14g)
- Non-volatile 32K memory
- 16 Hz. sample rate - 2-3 Hz. bandwidth
- Zero Crossing or Proportional Integrating Measure (low and high sensitivity) modes of operation
- 1 minute fixed epoch length yielding up to 22 days of recording time per initialization
Figure 1.5 Micro mini motion logger

Human Activity State Detection and Monitoring System:

Activity can mean many things. It can reflect higher-level concepts, in which a global index reflecting the amount of activity is desired, such as mobility in bed. On the other hand, extreme details regarding the amount and the timing of activities, or activity patterns, may be of interest, as in monitoring activity of skeletal muscles. Many early attempts were made to measure activity level over time which was termed as human activity monitoring.

Kondraske observed that while humans engage in activities which are often quite complex dynamically and kinematically, there are distinct patterns that lead us to identify specific states such as standing, walking, etc. Information regarding the frequency, duration, and transitioning of such activity states over a period of time can be highly beneficial to the effective diagnosis, treatment, and facilitation of individuals with various pathologies (e.g., neurological, psychological, orthopedic, etc., deficits). Additional benefits can be obtained in behavioral research, pharmaceutical clinical trials, and many other investigative...
endeavors. Based on this, a prototype system dubbed the HASDMS-I was developed and evaluated (Ganapathy and Kondraske, 1990). Recent literature review indicates that this approach remains unique; it is the only effort found that ventures into activity state detection.

In the first generation system, the parameters used to discriminate activity states are the angle between long axis of the thigh and gravity and its frequency of movement in the sagittal plane. The sensing of the axis and the plane is done by electronic accelerometers. In situations where there is slight, intermittent, or no thigh movement, the angle of orientation is utilized to determine whether the activity is lying/sitting or standing, the frequency of the gait cycle, along with the orientation of the thigh, is utilized to determine whether the activity is walking or running.

This system relies solely on the orientation and motion of the thigh to determine the specific activity state. The sensing unit is worn on the thigh. Therefore, with the thigh in a (relatively) horizontal orientation, no movement (or slight intermittent motion) is interpreted as a state of lying or sitting. Larger movements of the thigh when in a relatively horizontal orientation result in an unknown state that may be due to activities such as stair-climbing or bicycle riding. When the thigh is oriented closer to vertical, the possible activity states include standing, walking, and running. These states are distinguished by zero, low, or high changes in thigh movement, respectively.

The information is passed on to a host computer which displays the activity state in various forms.
The prototype was evaluated by comparing the state detected by the device and the state observed by an observer, for a period of 1 minute. The human subject was made to wear the device on his/her and perform the activity called out by the observer. After the experiment, the readings were compared as shown below. This prototype achieved over 95% accuracy in a simple validation study (Ganapathy and Kondraske 1990).

1.3 Summary

After studying the various types of physical activity monitoring systems we can summarize that each one of them has their own advantages and disadvantages.
Table 1.1 Summary of results after the literature review

<table>
<thead>
<tr>
<th>No.</th>
<th>Device</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>1.</td>
<td>VIDEO</td>
<td>- no discomfort to the subject</td>
<td>- non-portable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Activity states can be determined</td>
<td>- subject is restricted to an area</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- change of media regularly</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Expensive due to need for human expert evaluator</td>
</tr>
<tr>
<td>2.</td>
<td>ADVICE</td>
<td>- no discomfort to the subject</td>
<td>- non-portable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- monitors human activity state</td>
<td>- subject is restricted to an area</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- change of media regularly</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- not suited for this application</td>
</tr>
<tr>
<td>3.</td>
<td>Electromyography</td>
<td>- Subject worn</td>
<td>- Electrodes cause a little discomfort</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Electrodes are not as sensitive as accelerometers</td>
</tr>
<tr>
<td>4.</td>
<td>Polysomnography</td>
<td>- Subject-worn</td>
<td>- Subject requires to stay in a lab overnight</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Expensive</td>
</tr>
<tr>
<td>5.</td>
<td>Actiwatch</td>
<td>- Portable</td>
<td>- does not detect the activity state</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- monitors human activity</td>
<td>- Used for sleep/wake patterns</td>
</tr>
<tr>
<td>6.</td>
<td>Octagonal basic</td>
<td>- Portable</td>
<td>- does not detect the activity state</td>
</tr>
<tr>
<td></td>
<td>Motion logger</td>
<td>- monitors human activity</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Micro-mini</td>
<td>- Portable</td>
<td>- does not detect the activity state</td>
</tr>
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An ideal combination for a many applications encountered would be to have a highly accurate, activity state detection system at a relatively low cost.

From the above discussion, it is clear that the method of activity state detection using accelerometers and an interface with a host PC is most user-friendly, economical, portable, accurate and simple. The Actiwatch, Octagonal basic mini logger, micro mini motion logger, and HASDMS incorporate these attributes, but HASDMS is the only device that monitors human activity and measures the activity state. The remaining devices in the table can achieve any one of the two characteristics.

1.4 Objectives

Given the above background, the objectives of this thesis are to:

1. Develop and test a hardware platform for a second-generation, subject-worn Activity State Detection and Monitoring System, incorporating new MEMS-based sensing technology and new microcontroller technology.

2. Define and incorporate a "raw data" logging operational mode to support research and building of time-series databases of various sensed parameters that can be used to
explore alternate state detection algorithms and application to detection of a wide variety of activity states.

3. Conduct experiments with human subjects to evaluate the basic hardware platform and demonstrate a rigorous experimental approach to defining criteria for activity state detection.

4. Evaluate results obtained and provide recommendations for the next phase of research.

This effort will build on the basic architecture of the first generation HASDMS. The emphasis now is not on a new device, but rather on a tool and approach to facilitate research aimed at improving state detection performance and applicability to a wider range of activity states.
CHAPTER 2

SYSTEM CONCEPT AND DESIGN

2.1 Global Design Issues

The general architecture of HASDMS as established with the first generation system is shown in figure 2.1 (Ganapathy and Kondraske, 1990). The Sensor and Logging Unit (SLU) is initially connected to a Host PC via an RS-232 serial interface for initialization. The battery -powered SLU is then disconnected and attached to the human subject. It senses some attribute of human activity periodically, processes this data to determine the activity state, and stores the results in memory. This repeats at some specified interval (e.g., every 5 seconds) until the SLU is reconnected to the host for uploading of the logged information (e.g., time series of activity states. The Host PC then displays or saves the results of logging.

![Diagram of General Architecture of the HASDMS](image)

The signal conditioning and processing involves use of a multi-channel ADC to convert the output voltages of one or more sensors to digitized values. The processor has a program
loaded into memory to control the mode of operation of the SLU. The Host PC is only connected during initialization and data uploading. During initialization, it loads a program into the SLU that determines the SLU’s operation mode and commands the SLU (e.g. start, stop logging, etc.).

As outlined in previous work (Ganapathy and Kondraske, 1990), the design of an activity state detection scheme for any given set of activity states involves identifying the type, minimal number, placement (on the human body), and orientation of sensors in order to provide sufficient information to reliably discriminate the desired states. In addition, the strategy for pre-processing sensor outputs (e.g. parameterization schemes) and determining "most likely" states are important.

For most practical, long-term monitoring applications, requiring sensors to be located at more than one or two sites on the body results in an unacceptable system configuration. Even if just two body sites are sensed, if they are not on adjacent body segments, the interconnecting cable would make utilization cumbersome.

The type of sensor utilized depends on the type of activities to be detected. For example, it is possible to consider detection and logging of cognitive activity states, such as thinking, sleeping, etc. For such states, using scalp electrodes as sensors and then digitizing and processing electroencephalography signals would be appropriate. For states such as sitting, standing, and walking, some type of motion, orientation, and/or position sensors would be appropriate. At present, interest is greater with regard to detecting the latter class of states. Recent advances in micro-machined electromechanical sensor (MEMS) technology provide new opportunities for use as the motion sensors needed in such HASDMS applications. Low cost, compact, and low power multi-axis accelerometers with
appropriate measurement ranges (e.g., Analog Devices ADXL210 and 202e) are the most common type of MEMS devices in this category. In addition, angular rate gyros have recently become available (e.g., Analog Devices ADXRS300). Due to the fact that the MEMS accelerometers exhibit D.C. response and knowledge that they would be used in the presence of the acceleration of gravity, an additional attractive aspect of these sensors is that they offer the potential to sense angular orientation. This can be extremely valuable in state detection.

To determine the minimal number of sensors required, careful optimization must be performed across the set of activity states to be detected and discriminated. Clearly, if one senses position and motion of many body segments, it is easy to have sufficient information to discriminate the desired states. However, the key to design of a practical system is to define the least complex sensor configuration; i.e., to eliminate redundancy and maximize use of all relevant information contained within a sensor's output. With the aid of systematic analyses, the power of this approach has been demonstrated (Ganapathy and Kondraske, 1990). For physical activities, the posture of body segments with respect to gravity (and each other) as well as variables resulting from the parameterization of dynamic information (e.g. absolute value of the average acceleration of the thigh over the last "t" seconds) can be used to define a multi-dimensional feature space. Along each dimension, levels (e.g. low, medium, high) can be established with specific threshold criteria for each. Cells within this multi-dimensional space are addressed by values of multi-dimensional sensory data; each cell corresponds to a unique activity state.
2.2 Second Generation Activity State Detection and Monitoring System

It is emphasized that a major aspect of this research is being pursued not simply to detect and log a specific set of activity states, but rather from the broader perspective of establishing and demonstrating systematic methodology that could be applied to detect and log any set of activity states. Similarly, the second-generation system is viewed as a more general purpose "platform" that can be configured to support a number of different issues. The design issues outlined above are taken into account in order to arrive at a second-generation HASDMS. In order to produce a flexible system to support the objectives described in Chapter 1, the current design will focus on a system housed in a single case to be placed at a single body site. In this general purpose system, capability will be provided for interfacing one optional external sensor unit (SU) providing up to two additional channels of information to the primary SLU for processing in combination with the sensor contained within the primary SLU

Hardware components selected for use in this general architecture are addressed below.

1) Sensor and Signal Conditioner

A dual-axis accelerometer (ADXL202) was selected as the sensor to be used in the SLU. Based on cost, packaging, and performance, this is considered to be an optimal choice across the range of commercially available accelerometers. The unit is contained within a single IC package which measures acceleration along two orthogonal axes of sensitivity simultaneously. The sensor consists of a micro-machined beam which has a small mass attached to it on one end, which causes the beam to bend when exposed to acceleration due to motion or gravity. Considering just gravity, Depending on the position of the chip, a deviation is caused on the beam, which causes the output voltages to vary.
The ADXL202 has a range of ±2 g's and a sensitivity of 312 mV/g. The output of each sensor is at one-half the supply voltage with no acceleration applied. Thus, with a +5V supply, the output for 0 g's is 2.5V. Bandwidth is adjustable from 0.01 - 5 KHz by selection of an external capacitor. Using gravity as the sole acceleration input, the typical voltage outputs at the $X_{filt}$ and $Y_{filt}$ pins at various angular orientations of the IC package are shown in Figure 2.2.

$Y_{filt} = 2.5V$  $Y_{filt} = 2.5V$  $Y_{filt} = 2.81V$  $Y_{filt} = 2.18V$

$X_{filt} = 2.18V$  $X_{filt} = 2.81V$  $X_{filt} = 2.5V$  $X_{filt} = 2.5V$

Fig 2.2 Typical voltage outputs at the $X_{filt}$ and $Y_{filt}$ pins at various positions of the IC

Fig 2.3 Basic Connections of the ADXL202 chip
2) Processor:

The first-generation system was specifically designed to only "detect and log" a specific set of activity states. The second-generation system adds a new "raw data logging" mode to the "state detection and logging" mode. In the raw data logging mode, the SLU needs to simply acquire sensor data at a specified sample rate and store it in memory. After a monitoring period, this raw data can be uploaded for analysis to help determine and evaluate state detection algorithms. In the activity state logging mode, the self-contained SLU must acquire sensor data, process it to determine activity states and save the activity state code for subsequent uploading to the Host PC and reporting. This mode represents the mode in which the system would be used in the field.

In order to support operation in different modes at different points in time, and also to have different algorithms in place for detecting and logging different sets of activity states, the ability to easily download a new program into the SLU is required. In addition, a single chip processor with integrated additional functions (such as A/D conversion, program memory, data memory, etc.) is desired. Lastly, power consumption is critical. Thus, intrinsically efficient operation as well as support for power conserved modes are important issues in selecting a processor. Given these criteria, an Analog Devices AduC824 "micro-converter" was selected for use as the processor in the second-generation system. The main features of this IC are enlisted below:
8051 Based Core implements the 8051-based instruction set. It operates at various clock frequencies with a maximum operating frequency of 12.58 Mhz. It consists of three 16-bit Timer/Counters, 26 Programmable I/O lines, 11 interrupt sources with 2 priority levels and a 32 kHz External Crystal.

The Chip consists of two independent Analog to Digital Converters (16 and 24 bit resolution ADCs). The 24-bit resolution ADC is called the Primary ADC and the 16-bit resolution ADC is the auxiliary ADC. The Memory of the IC consists of 8 KB on-chip Flash/EE Program Memory, 640 Bytes Data Memory and 256 Byte Data RAM.

The ADuC824 IC works at 3V and 5V supply. It has power down/idle modes. Other On-chip peripherals include a 12 bit Digital to Analog Converter (DAC), a watch dog Timer, (UART) serial input/output, Time interval Counter (TIC), $I^2C$ compatible and SPI serial I/O. All this is packaged in a single 52-Lead Plastic Quad Flat Pack MQFP with dimensions of 13mm x 10mm.
3) External Memory for Logged Data Storage

While the AduC824 contains much functionality in one-chip, it does not contain sufficient memory for logging raw data or activity states over extended periods of time. In the raw-data mode, assume a typical sampling and logging rate of 5 samples per second. Each of the two ADCs provides two bytes for each sample requiring four bytes of storage for each sample. Thus, 20 bytes of storage are required each second. \[ (2 \text{ A/d channels}) \times (2 \text{ bytes/channel}) \times (5 \text{ samples/second}) = 20 \text{ bytes/second} \]. In this mode, storage is required to support logging over a time period of at least 10 minutes is required. This would require at least 12 Kbytes of storage \((20 \text{ bytes/sec} \times 60 \text{ sec/min} \times 5 \text{ min})\).

In the Activity State Detection Mode, assume a typical rate of computed activity states of one state per second. Efficient coding can be employed so that one memory location (1 byte) can hold 2 activity states (one in each nibble). Thus 4 bits (0.5 bytes) of storage per second are required in this mode. In this mode, storage to support continuous logging over at least one day is desired. Thus, at least 43.2 Kbytes of storage would be required \((0.5 \text{ bytes/sec} \times 60 \text{ sec/min} \times 60 \text{ min/hr.} \times 24 \text{ hrs./day})\).

The Program memory of the ADuC824 is used by the code. The Internal RAM is used for calculations. We are left with the 640 data memory. This memory will suffice for 32 seconds in the raw-data logging mode and for 21 minutes in the state detection mode. These short time spans do not support our requirement and thus there is a need for external data memory.

Compact nonvolatile flash type RAMs are available with high capacities and simple serial data interfaces, which are sufficient for the low data rates required in the present application. An ST Microelectronics M24512 was selected and incorporated into the design.
Its features are a 64 KB memory capacity, two-wire Inter-Integrated Circuit (I\textsuperscript{2}C) Protocol, Hardware Write Control, Byte and Page Write, and Random and Sequential read modes. The IC is available in 8 lead Plastic Small Outline Package (SO8).

Using this chip, sufficient storage is available for about 54 minutes of continuous logging in the raw data mode and a little over 36 hours in the data logging mode using the storage rates specified. Basic connections of the memory IC are shown in the figure below:

![Basic Connections of the ST Microelectronics memory chip](image)

**Fig 2.5 Basic Connections of the ST Microelectronics memory chip**

4) Serial Communication

There is a need for a means to support communication between the host PC and the SLU. The AduC824 contains a Universal Asynchronous Receiver/Transmitter (UART), but this provides only TTL compatible signals. Level translation is required to conform to RS-232 standards, which is accomplished with a Telecom Semiconductor TC232CPE IC. The appropriate connections are shown below.
5) SLU Power Supply

The SLU needs to be powered up to be functional. A 9-volt alkaline battery can be used. Lithium batteries, while more expensive, can last up to three times that long, providing over one week continuous use given estimates of SLU current requirements and typical battery capacities. Analysis of power consumption considerations is given below.

Current drawn by each unit is as follows:
Table 2.1 Power consumption

<table>
<thead>
<tr>
<th>Component</th>
<th>Current Drawn</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADuC824 (operating at 1.57 MHz)</td>
<td></td>
</tr>
<tr>
<td>Digital Subsystems Supply</td>
<td>4000 uA</td>
</tr>
<tr>
<td>Analog Subsystems Supply</td>
<td>170 uA</td>
</tr>
<tr>
<td>Primary ADC</td>
<td>1000 uA</td>
</tr>
<tr>
<td>Auxiliary ADC</td>
<td>500 uA</td>
</tr>
<tr>
<td>ST24128</td>
<td>2000 uA</td>
</tr>
<tr>
<td>ADXL202</td>
<td>1000 uA</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>8670 uA</strong></td>
</tr>
</tbody>
</table>

During raw-data logging operation, total current drawn = 8.67 mA since all the components are powered on. In the state detection mode, total current drawn = 7.17 mA during state detection since the external memory is powered down during this phase, and 8.67 during memory dumping. A 5V linear regulator is used at present to provide regulated voltages. This is not the most efficient option. Using a worst-case assumption, it is assumed that 9V battery current will be the same as 5V current. Typical and heavy duty 9-Volt alkaline battery capacities are 160 mAH and 560 maH, respectively. Thus, these batteries should last for approximately 18 and 64 hours respectively. It is noted that these are worst case estimates that assume the processor is always in its operational mode. As described in Chapter 3, the power down mode will be utilized to gain additional efficiencies. This is estimated to quadruple battery life in the activity state logging mode.
A summary block diagram of the second-generation system is shown below:

![Block Diagram]

Fig. 2.7 A functional Block diagram of the ASDMS
(Dotted line shows disconnecting point)

Due to the small parts count and high cost performance of the VLSI chips used, the system is very low cost, especially compared to the cost of the previously used ASDM systems. A cost analysis of this HASDMS is given in section 5.2 in chapter 5.

2.3 SLU Hardware Design Details

The ADUC824 is a very powerful chip with many user options that are very relevant to the adaptable signal conditioning problem. Different configurations can be argued to be superior for one generic design over another. The absolute optimal use of the ADUC824s capabilities is beyond the scope of this thesis. Rather, it is desired to make a reasonable initial configuration choice that will: (1) permit further investigation of the adaptive signal
conditioner concepts and (2) provide an implementation that should be useful for a wide range of applications (although perhaps not the widest possible if one were to truly optimize the utilization of the ADUC824’s resources).

The ADUC824 microcontroller chip has two input pins for the primary ADC, namely AIN1 and AIN2. AIN3 is the input pin for the auxiliary ADC. The output of the unconditioned sensor is connected to the primary ADC via pin AIN1, which is the positive input pin. The negative input pin AIN2 is grounded. The primary ADC digitizes the signal from the unconditioned sensor. The signal from the reference sensor, which is connected to pin AIN3 is digitized by the auxiliary ADC. The output from the digital to analog converter is configured to appear at pin AIN4. An external reference of +5V is used. This provides an input range of 0–5.12V with the programmable gain set to "x1" and a 0–5.12V/128 or 0V to 40mV (approximately) input range with the programmable gain set to "x128".

The ADUC824 is interfaced with the M24128 memory chip through two Port 1 pins. Port 1.0 is connected to the Serial Data/ Address Input/output of the memory and the Port 1.1 is connected to the Serial Clock pin of the memory chip. This enables the microcontroller to write to and read from the EEPROM. In addition to the main components mentioned above a few discrete components such as a watch crystal, light emitting diode, resistors and capacitors also form a part of the system. A complete Circuit diagram is provided in Appendix A.
CHAPTER 3

SOFTWARE DESIGN AND IMPLEMENTATION

3.1 Introduction

A second-generation, general purpose human activity state detection and monitoring system hardware platform has been developed and fabricated as described in chapter 2 to support the objectives listed in chapter 1. This chapter discusses aspects of the design that are software dependent and an initial implementation of software for the second-generation system.

3.2 Software Design Considerations

This section outlines the design problem with specific focus on design goals and constraints imposed on the design of the micro-converter IC. The essential factors that were considered while designing the system are as follows:

- The “Human activity state detection and monitoring system” is to be designed for generic use (research to support investigation to detect different sets of activity states as well as for field use to detect and log specific states).
- The SLU should be in-circuit programmable and should be able to retain the program unless it is to be erased or changed.
• The user should be able to control the device at any point by sending commands to the SLU from the host PC.

• The system should be designed so that it requires only a one time initialization.

Since the AduC824 (and therefore, the SLU system) can be readily and repeatedly programmed through the serial interface port, the software design approach selected is to require separate programs for the raw data logging mode and for each set of activity states that are to be logged when used in the activity state detection and logging mode. It is also apparent that both raw data logging and activity state detection modes require certain common basic support functions (e.g., A/D conversion, Host PC command checking, etc.). Thus, software is structured modularly so as these support routines can be incorporated into any of the programs.

A common operational approach has also been identified that is suitable for all modes that will allow for minimal power consumption. The ADuC824 incorporates a special Time Interval Counter (TIC) that can be programmed to overflow at intervals ranging from milliseconds to days. This counter operates even when the AduC824 is placed in its energy efficient "power down mode" via a special software instruction. Additionally, the micro-converter can be programmed to allow a TIC overflow to "wake-up" the processor. The flowchart below illustrates the architecture used by all programs loaded into the SLU in order to take advantage of this feature.
Fig. 3.1 Flowchart for the SLU main operating system showing power saving use of the TIC.
As discussed, the HASDMS has two types of operating modes, raw data logging and activity state detection and logging. Thus, the HASDMS has separate algorithms for each mode of operation.

The microcontroller is 8051 instruction set compatible. The system software was written using 8051 assembly language and was compiled using the 8051 cross assembler, version 1.2h. (MetaLink Corporation. [34]). During setup, the program is downloaded from a host computer into the ADUC824 chip from the serial port using a special cable and interface adapter. In order to convert the RS232 signals into TTL/CMOS logic there is a need of a transceiver chip, which is located on the interface adapter. The industry standard TC232CPE (TelCom Semiconductor Inc, [35]) is used as the transceiver chip. The software was downloaded onto the ADUC824 using a software tool known as the Windows Serial Downloader (Analog Devices).

The algorithms control data flow between the chip and 3 main devices, namely, the host PC, the external memory and the ADXL202 accelerometer IC. The algorithms consist of a main program and several sub-routines. Let’s first look at the raw-data logging program.

3.3 Raw Data Logging Mode

The Accelerometer gives output voltages in the approximate range of 1.8V and 3.2V depending on the position and motion of the X and Y sensors. These voltages are converted by the ADCs to a two 16-bit hex numbers and dumped into memory. A conversion routine is written to convert the binary values to decimal values that can be mathematically analyzed.
In this mode, the final decimal values given to the host are in decimal form and in the range from approximately 20000d to 40000d.

The main handler for raw data logging executes after the TIC overflows, wakes up the processor, and serial communication checks are done. Thus, it is similar to an interrupt service routine. Once it gets the command, it waits for 3 minutes. Then it sends an acknowledgement (Using the sub-routine Send_Character), by lighting up the LED five times, and starts logging till the memory is full or a stop command (“4”) is given by the user. When the logging is over the device waits for the Get_SLU_Data command (“2”). Once the data is dumped on to the PC, it sends the word “DONE” indicating completion of data recovery and the program goes back to the serial input handler, ready for the next logging session. It continues in this cycle until the power supply is stopped. The flowchart of this logging mode is shown below:
Fig. 3.2 Flowchart of the Raw-data Logging routine
3.4 State Detection Logging Mode

The State detection program uses state detection rules for calculation of activity states. The algorithm is almost similar to the raw data logging program in most aspects and is described below:

The main handler for raw data logging executes after the TIC overflows, wakes up the processor, and serial communication checks are done. Thus, it is similar to an interrupt service routine. Once it gets the command, it waits for 3 minutes. Then it sends an acknowledgement (Using the sub-routine Send_Character), by lighting up the LED five times, and starts logging for 1 second. It then calculates the activity state and stores it in the 640 byte data RAM. It continues this process till a stop command (“4”) is given by the user. When 512 bytes of the RAM is filled the data is transferred to the external memory and the external memory is checked to see if it is full. If not logging continues else it stops. When the logging is over the device waits for the Get_SLU_Data command (“2”). Once the data is dumped on to the PC, it sends the word “DONE” indicating completion of data recovery and the program goes back to the serial input handler, ready for the next logging session. It continues in this cycle until the power supply is stopped. The flowchart of this logging mode is shown below:
Fig. 3.3 Flowchart of the Activity State Logging routine
3.5 Support Routines

Both modes of operation draw upon sub-routines that were written to support specific functions. The Sub-routines of the raw-data-logging mode are described below:

Start_ADC: Initializes the ADCs and sets the resolution, operation mode and conversion rate. Read_Primary_ADC: Reads the data from the primary ADC and puts it into registers. Read_Auxiliary_ADC: Reads the data from the auxiliary ADC and puts it into registers.

Write_In_EEPROM: This routine transfer data from the ADuC824 to the External memory.

Read_From_EEPROM: This routine transfer data from the External memory to the processor.

Bin_To_Asc: This routine converts the hex values coming from the ADCs to decimal numbers and further to ASCII values before the data is given to the PC.

Send_Character: This routine sends a character to the Host PC

Get_Host_Command: This routine receives a character from the host PC

Serial Port Initialization: This subroutine sets up the Serial port at a baud rate of 9600 for communication with the PC

Delay: This is a multipurpose delay routine which is used at various instances in the program.
CHAPTER 4

EXPERIMENTAL SYSTEM EVALUATION

4.1 Overview and Objectives

A prototype of the activity state detection and monitoring system was built and tested. Data was collected from bench tests (for static calibration of the accelerometers) as well as human subject experiments, and analyzed in order to validate the basic performance of the prototype and to develop new techniques of state detection. The latter demonstrates a means for optimizing state detection algorithms based on various analyses of experimental data sets. For this purpose, it was decided to re-address the same activity states as those detected and monitored with the first generation HASDMS; specifically, lying, sitting, standing, walking, and running. A central objective of this thesis is the lay the foundation for a series of such experimental studies. Sections 4.2 and 4.3 explain the experimental set up, procedures and results in detail. Some issues related to the performance of the system are discussed in section 4.4.

4.2 Bench Test and Calibration

Calibration experiments were carried out to determine the exact offsets and static sensitivities for each accelerometer channel, and to verify proper system performance in basic functionality.

The orientation of the accelerometer (with sensitive axes denoted as X and Y as described in Chapter 2) relative to the case, and then the orientation of the case relative to the body segment to which it is mounted are important. While the basic SLU has been designed
to be a general purpose device with features such as sensitive axes labeled in generic form as "x" and "y" until now, it is convenient to maps these labels to new labels as the general purpose device now becomes special purpose. To facilitate this, an orientation mark (arrow) was added to the SLU case. The two orthogonal accelerometer axes of sensitivity are denoted on its datasheet as X and Y and are oriented with respect to the IC package as shown in the figure below. This IC is oriented inside the SLU so that the top of the IC would be seen if looking into the case from the front face (i.e., the face with the orientation arrow). Thus, the axis of the package passing through the IC's orientation "notch" (denoted as the X axis in Chapter 2) is aligned with the orientation arrow shown on the SLU case. For this experiment, the SLU is to be mounted on the thigh with the SLU alignment arrow aligned with the long axis of the thigh (e.g., zero degrees difference ideally). Thus, the X-axis sensor was renamed to "0-degree sensor" and the Y sensor was renamed to "90-degree sensor". Positive accelerations are in the direction of the arrows. With the SLU mounted to the left thigh, positive accelerations are thus recorded when the thigh moves more anteriorly.

![Diagram of accelerometer orientation](image)

ADXL202 Sensors SLU case with Orientation Arrow

Fig. 4.1 Orientation of the Accelerometer with respect to the case and definition of axes
Before we understand the calibration and human subject data analysis it is important to understand the conventions used. Important definitions and conventions used in calibration and analysis are summarized below:

**Thigh Angle:**

Thigh angle is the measurement of the angular orientation of the left thigh with respect to gravity. The convention is defined such that "0 degrees" represents a perfectly vertical orientation of the left thigh. Positive angles represent clockwise rotations from the zero degree reference (eg. sitting) and negative angles represent counterclockwise rotations from the 0 degree reference (eg. sleeping face down). Thigh Angle is obtained by processing and combining Thigh_Sensor_0deg and Thigh_Sensor_90deg data which is explained below.

**Thigh Sensor 0deg:**

The accelerometer channel with its axis of sensitivity parallel to the long axis of the thigh, which should be the ADXL202's "X axis"

**Thigh Sensor 90deg:**

The accelerometer channel with its axis of sensitivity oriented 90 degrees to the long axis of the thigh, which should be the ADXL202's "Y axis"

The accelerometer provides various voltage outputs at various positions depending upon the gravitational acceleration. This information can be used for calibration. These voltages (0-5V) are converted to hex numbers (0000H – FFFFH) by the A/D converter of the ADuC824 Chip.
Table 4.1 Accelerometer Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Thigh_Sensor_0deg</th>
<th>Thigh_Sensor_90deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>312 mV/g</td>
<td>312 mV/g</td>
</tr>
</tbody>
</table>

Repeated experiments of logging gathered the same results. This showed that the prototype was working fine.

4.3 Human Subject Experiments

In order to check basic system functions and to obtain data to support state detection algorithm development, real time evaluation was carried out using human subjects. Special approval was sought and obtained from the University of Texas at Arlington Institutional Review Board for the protection of human subjects (Protocol #03-168, see Appendix C).

4.3.1 Experimental Procedure

Main Procedure:

Ten healthy subjects (7 females and 3 males) volunteered to participate in an evaluation. They were used in two data collection modes: operationally defined here as "static" and "dynamic".

Static tests involve maintaining a given activity state for a fixed time interval. No concern is given to activity state transition. This data set is used to verify the basic accuracy and validity of the device, contribute to state detection algorithm design and establish stability of the state detection algorithm evaluated. The occurrence of spurious state detections can be evaluated under conditions where the discriminating variables are likely to be perturbed slightly from ideal values.
Dynamic tests were used to verify accuracy of the monitor in detecting states and their transitions under conditions that mimic realistic activity patterns.

The charts below are scripts used to instruct the subject to perform various activity states. There are 2 charts each of 5 minutes, described below. One is for static testing and the other is for dynamic testing. Care is taken that these command assignments are logical and do not involve switching through activities which are not physically possible, like lying to running, etc. The script chart with a list of commands at known time intervals was recorded on an audio tape for use in the experiments.

All activities are mostly for 10 seconds. Rest periods (sitting) are given at intervals of about 1 minute, especially after running. In static charts all transitions are monitored by gradually going from one state to another. In dynamic charts, activities are randomly monitored as in real-life situations.

Table 4.2 Scripts used to instruct the subject for static and dynamic testing

<table>
<thead>
<tr>
<th>Activity State (Command)</th>
<th>Duration (min:sec)</th>
<th>Total Elapsed time (min:sec)</th>
<th>Activity State (Command)</th>
<th>Duration (min:sec)</th>
<th>Total Elapsed time (min:sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lie</td>
<td>0:12</td>
<td>0:00</td>
<td>Sit</td>
<td>0:19</td>
<td>0:00</td>
</tr>
<tr>
<td>Sit</td>
<td>0:09</td>
<td>0:12</td>
<td>Lie</td>
<td>0:10</td>
<td>0:19</td>
</tr>
<tr>
<td>Lie</td>
<td>0:10</td>
<td>0:21</td>
<td>Sit</td>
<td>0:09</td>
<td>0:29</td>
</tr>
<tr>
<td>Sit</td>
<td>0:09</td>
<td>0:31</td>
<td>Stand</td>
<td>0:10</td>
<td>0:38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Lie</td>
<td>0:10</td>
<td>0:40</td>
<td>Walk</td>
<td>0:09</td>
<td>0:48</td>
</tr>
<tr>
<td>Sit</td>
<td>0:09</td>
<td>0:50</td>
<td>Run</td>
<td>0:10</td>
<td>0:57</td>
</tr>
<tr>
<td>Stand</td>
<td>0:10</td>
<td>0:59</td>
<td>Stand</td>
<td>0:10</td>
<td>1:07</td>
</tr>
<tr>
<td>Sit</td>
<td>0:29</td>
<td>1:09</td>
<td>Lie</td>
<td>0:18</td>
<td>1:17</td>
</tr>
<tr>
<td>Stand</td>
<td>0:10</td>
<td>1:38</td>
<td>Sit</td>
<td>0:10</td>
<td>1:35</td>
</tr>
<tr>
<td>Sit</td>
<td>0:09</td>
<td>1:48</td>
<td>Stand</td>
<td>0:11</td>
<td>1:45</td>
</tr>
<tr>
<td>Stand</td>
<td>0:10</td>
<td>1:57</td>
<td>Run</td>
<td>0:10</td>
<td>1:56</td>
</tr>
<tr>
<td>Walk</td>
<td>0:09</td>
<td>2:07</td>
<td>Walk</td>
<td>0:08</td>
<td>2:06</td>
</tr>
<tr>
<td>Stand</td>
<td>0:09</td>
<td>2:16</td>
<td>Sit</td>
<td>0:20</td>
<td>2:14</td>
</tr>
<tr>
<td>Walk</td>
<td>0:10</td>
<td>2:25</td>
<td>Lie</td>
<td>0:09</td>
<td>2:34</td>
</tr>
<tr>
<td>Stand</td>
<td>0:19</td>
<td>2:35</td>
<td>Sit</td>
<td>0:10</td>
<td>2:43</td>
</tr>
<tr>
<td>Walk</td>
<td>0:09</td>
<td>2:54</td>
<td>Stand</td>
<td>0:09</td>
<td>2:53</td>
</tr>
<tr>
<td>Run</td>
<td>0:10</td>
<td>3:03</td>
<td>Walk</td>
<td>0:10</td>
<td>3:02</td>
</tr>
<tr>
<td>Walk</td>
<td>0:10</td>
<td>3:13</td>
<td>Run</td>
<td>0:09</td>
<td>3:12</td>
</tr>
<tr>
<td>Run</td>
<td>0:10</td>
<td>3:23</td>
<td>Stand</td>
<td>0:10</td>
<td>3:21</td>
</tr>
<tr>
<td>Walk</td>
<td>0:09</td>
<td>3:33</td>
<td>Lie</td>
<td>0:10</td>
<td>3:31</td>
</tr>
<tr>
<td>Stand</td>
<td>0:19</td>
<td>3:42</td>
<td>Sit</td>
<td>0:29</td>
<td>3:41</td>
</tr>
<tr>
<td>Walk</td>
<td>0:10</td>
<td>4:01</td>
<td>Stand</td>
<td>0:09</td>
<td>4:10</td>
</tr>
<tr>
<td>Stand</td>
<td>0:10</td>
<td>4:11</td>
<td>Run</td>
<td>0:10</td>
<td>4:19</td>
</tr>
<tr>
<td>Sit</td>
<td>0:09</td>
<td>4:21</td>
<td>Walk</td>
<td>0:09</td>
<td>4:29</td>
</tr>
<tr>
<td>Stand</td>
<td>0:10</td>
<td>4:30</td>
<td>Sit</td>
<td>0:10</td>
<td>4:38</td>
</tr>
<tr>
<td>Sit</td>
<td>0:10</td>
<td>4:40</td>
<td></td>
<td>0:10</td>
<td>4:48</td>
</tr>
</tbody>
</table>

Table 4.2 - Continued
The general procedures employed during static and dynamic tests are similar. The cassette player calls out each activity state. The subject enters that state until he/she is asked to stop or change state. The cassette player gives only single-word commands, without qualifying them. The activities being performed were visually verified by an observer. At the end of the tests, results are recorded and compared.

SLU Initialization:
The battery is placed in the device, the research device is connected to the PC interface and the program for raw-data logging is downloaded into the SLU. A Run command is given from the host PC. Once the program is running, it waits for 3 minutes for the setup procedure below to be completed, and then the LED blinks 5 times, (once per second) immediately after which the logging starts.

Attaching the Unit to the Thigh:
Elastic straps with Velcro® were used to attach the SLU to the lateral aspect of the subject's thigh. The straps were such so that the unit could be put on and adjusted by the user (e.g., in field use), however in this research study consistency was important so the investigator carried out this task to assure proper alignment (see below)
Care was taken to make sure that the wearer was standing at first and that the SLU was worn over shorts or pants, as high on the thigh as possible. Care was also taken to make sure that the unit was attached and positioned as best as is possible to match the figure below. With the SLU secured to the thigh using the straps provided, the vertical axis of the X-sensor (0-degree sensor) was aligned with the long axis of the thigh. The end of the SLU that had the LED was faced upward (i.e., toward the subject’s hip). The face of the SLU was aligned so that it lied in the sagittal plane. Once properly positioned, the straps were adjusted so that they were tight enough to prevent the SLU from moving out of alignment but not so tight to restrict blood flow or cause the wearer discomfort.

The SLU was properly mounted to produce results consistent with the above conventions. The SLU has an arrow on its face that provides a means to obtain proper orientation (see figure to right). The SLU was attached so that the back of the unit (i.e., the side opposite the face with the orientation arrow) was against the left thigh of the subject and the orientation arrow is facing "up" with the subject standing. The Box was tied onto the left thigh of the
subject with the LED facing away from the knee. The accelerometer notch is placed in the same direction as the LED which is also in the same direction as the arrow head.

Fig. 4.3 Wearing the SLU: Align the SLU with the long axis of the thigh and in the subject’s sagittal plane.

Raw Data Logging:
This audio cassette player with the script commands was started on the fifth "blink" of the SLU’s LED to provide a basic synchronization of the tape and logged data. Raw acceleration data logging continues until the memory is exceeded or a stop command is given from the PC after reconnecting the device. The stop command was given after approximately five minutes. The SLU was then re-connected to the PC and logged data was uploaded and saved in an ASCII text file.
4.3.2 Data Analysis

The data saved in text (.txt) files on the PC was imported into Microsoft © Excel for the analysis aimed at determining state detection criteria.

Once logging was done, the next step in the thesis was to discover new techniques of state detection. State detection analysis was carried out using the raw data collected for each of the 10 subjects. The analysis was carried out in different phases. All analyses were carried out for the static and dynamic tests. First we started out with the preliminary analysis where a new concept of separating angle and motion from acceleration was discovered. This concept was not used in the previous systems and is unique to this thesis. The analysis was done on a spread sheet in which the following variables were calculated:

0-degree calibration in g’s:

This is the value of raw data from the 0-degree sensor in g’s. The formula used here was:

\[ K_0 \text{ (in g’s)} = \frac{\text{raw data value} - 32058}{4281} \]

0-degree moving averages:

The moving average of all the 0-degree calibrated readings calculated over a period of 1 second (5 samples)

0 degree motion:

This is the amount of motion sensed by the 0-degree sensor of the ADXL202. Moving averages resemble the dc and low frequency response of the readings, thus leaving high frequency components which we could categorize as motion components. Motion was determined by subtracting the moving averages from the calibrated raw data values.
**Absolute 0 degree motion:**

This is the absolute value of the 0-degree motion values.

**AOW1s for 0-deg motion:**

This is the average taken over a 1 second window (5 samples of absolute 0-degree motion). This technique is used for noise reduction since the data of some patients may have high frequency components.

**90-degree calibration in g’s:**

This is the value of raw data from the 90-degree sensor in g’s. The formula used here was:

\[
K_{90} \text{(in g’s)} = \frac{\text{raw-data value} - 31759}{4331}
\]

**90-degree moving averages:**

The moving average of all the 90-degree calibrated readings calculated over a period of 1 second (5 samples)

**90 degree motion:**

This is the amount of motion sensed by the 90-degree sensor of the ADXL202. Moving averages resemble the dc and low frequency response of the readings, thus leaving high frequency components which we could categorize as motion components. Motion was determined by subtracting the moving averages from the calibrated raw data values.

**Absolute 90 degree motion:**

This is the absolute value of the 90-degree motion values.

**AOW1s for 90-deg motion:**

This is the average taken over a 1 second window (5 samples of absolute 90-degree motion). This technique is used for noise reduction since the data of some patients may have high frequency components.
Sum of moving averages:

- This is the summation of the values of the moving averages for both the sensors

Difference of moving averages:

- This column had the differences of the values of the moving averages for both the sensors

Angle:

- This column had the thigh angle in degrees. A table was made of angles from -120 to 120 degrees and the negative cosine and negative sine values were calculated, which ranged from -1 to 1. These values corresponded to the values of the raw-data in g’s. The negative cosine values corresponded with the 0-degree sensor and the negative sine values corresponded with the 90-degree sensor. These values were further analyzed and their summation and differences were calculated as show in the table below.

Table 4.3 Data used to design the “Thigh Angle” concept

<table>
<thead>
<tr>
<th>Theta (Angle)</th>
<th>0 deg Sensor</th>
<th>90 deg Sensor</th>
<th>Summation</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-cosine</td>
<td>-sin</td>
<td>0deg + 90deg</td>
<td>0deg - 90deg</td>
</tr>
<tr>
<td>-120</td>
<td>0.5000000000</td>
<td>0.866025404</td>
<td>1.366025404</td>
<td>-0.366025404</td>
</tr>
<tr>
<td>-110</td>
<td>0.342020143</td>
<td>0.939692621</td>
<td>1.281712764</td>
<td>-0.597672477</td>
</tr>
<tr>
<td>-100</td>
<td>0.173648178</td>
<td>0.984807753</td>
<td>1.158455931</td>
<td>-0.811159575</td>
</tr>
<tr>
<td>-90</td>
<td>0.000000000</td>
<td>1.000000000</td>
<td>1.000000000</td>
<td>0.000000000</td>
</tr>
<tr>
<td>-80</td>
<td>-0.173648178</td>
<td>0.984807753</td>
<td>0.811159575</td>
<td>-1.158455931</td>
</tr>
<tr>
<td>-70</td>
<td>-0.342020143</td>
<td>0.939692621</td>
<td>0.597672477</td>
<td>-1.281712764</td>
</tr>
<tr>
<td>-60</td>
<td>-0.500000000</td>
<td>0.866025404</td>
<td>0.366025404</td>
<td>-1.366025404</td>
</tr>
<tr>
<td>-50</td>
<td>-0.642787610</td>
<td>0.766044443</td>
<td>0.123256833</td>
<td>-1.408832053</td>
</tr>
<tr>
<td>-40</td>
<td>-0.766044443</td>
<td>0.642787610</td>
<td>-0.123256833</td>
<td>-1.408832053</td>
</tr>
<tr>
<td>-30</td>
<td>-0.866025404</td>
<td>0.500000000</td>
<td>-0.366025404</td>
<td>-1.366025404</td>
</tr>
<tr>
<td>-20</td>
<td>-0.939692621</td>
<td>0.342020143</td>
<td>-0.597672477</td>
<td>-1.281712764</td>
</tr>
<tr>
<td>-10</td>
<td>-0.984807753</td>
<td>0.173648178</td>
<td>-0.811159575</td>
<td>-1.158455931</td>
</tr>
<tr>
<td>0</td>
<td>-1.000000000</td>
<td>0.000000000</td>
<td>-1.000000000</td>
<td>-1.000000000</td>
</tr>
<tr>
<td>10</td>
<td>-0.984807753</td>
<td>-0.173648178</td>
<td>-1.158455931</td>
<td>-0.811159575</td>
</tr>
<tr>
<td>20</td>
<td>-0.939692621</td>
<td>-0.342020143</td>
<td>-1.281712764</td>
<td>-0.597672477</td>
</tr>
<tr>
<td>30</td>
<td>-0.866025404</td>
<td>-0.500000000</td>
<td>-1.366025404</td>
<td>-0.366025404</td>
</tr>
</tbody>
</table>
Table 4.3 - Continued

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>-0.766044443</td>
<td>-0.642787610</td>
<td>-1.408832053</td>
<td>-0.123256833</td>
</tr>
<tr>
<td>50</td>
<td>-0.642787610</td>
<td>-0.766044443</td>
<td>-1.408832053</td>
<td>0.123256833</td>
</tr>
<tr>
<td>60</td>
<td>-0.5000000000</td>
<td>-0.866025404</td>
<td>-1.366025404</td>
<td>0.366025404</td>
</tr>
<tr>
<td>70</td>
<td>-0.342020143</td>
<td>-0.939692621</td>
<td>-1.281712764</td>
<td>0.597672477</td>
</tr>
<tr>
<td>80</td>
<td>-0.173648178</td>
<td>-0.984807753</td>
<td>-1.158455931</td>
<td>0.811159575</td>
</tr>
<tr>
<td>90</td>
<td>0.0000000000</td>
<td>-1.000000000</td>
<td>-1.000000000</td>
<td>1.000000000</td>
</tr>
<tr>
<td>100</td>
<td>0.173648178</td>
<td>-0.984807753</td>
<td>-0.811159575</td>
<td>1.158455931</td>
</tr>
<tr>
<td>110</td>
<td>0.342020143</td>
<td>-0.939692621</td>
<td>-0.597672477</td>
<td>1.281712764</td>
</tr>
<tr>
<td>120</td>
<td>0.5000000000</td>
<td>-0.866025404</td>
<td>-0.366025404</td>
<td>1.366025404</td>
</tr>
</tbody>
</table>

A plot of the above values was drawn and is shown below.

![Figure 4.4 Plot of the data from the above](image-url)
By observing the behavior of the moving averages of both sensors individually and in combination, it was observed that a piecewise approach could be used to obtain a simple-to-calculate, linear relationship between digitized sensor values and thigh_angle. The final formula used was:

If Sum of the 0 and 90 deg moving averages < 0,

\[
\text{Thigh Angle} = ((0 \text{ deg moving average} - 90 \text{ deg moving average} \times 45) + 45),
\]

else

\[
\text{Angle} = -1 \times ((0 \text{ deg moving average} + 90 \text{ deg moving average}) \times 45) + 45]
\]

Once the preliminary analysis was completed, two approaches were carried out to discover new state detection techniques. First, analyses were done over continuous readings for each state. Thus for each subject, separate columns were made for each state which was further divided into 3 sub-columns viz., 0-deg motion, 90-deg motion and Angle, ending up with 15 columns per subject. Data was taken from the last half of each state activity and put under the appropriate column to avoid error. Minimum, average and maximum values were calculated for each subject for angle and motions. Finally all the data for all 10 subjects was summarized in a single spread sheet and minimum, average and maximum values were calculated. Plots were made based on the min, average and max values of the max values. These plots are shown below:
Fig 4.5 Summary of the minimum and maximum limits of motion of the 0-deg sensor for each state

Fig 4.6 Summary of the minimum and maximum limits of motion of the 90-deg sensor for each state
Similar analysis were carried out using the values of motion and angle averages over a period of 1 second (5 samples) and the following figures were obtained.

Fig 4.7 Summary of the minimum and maximum limits of Angle for each state

Fig 4.8 Summary of the minimum and maximum limits of motion of the 0-deg sensor for each state averaged over a time period of 1 second
Fig 4.9 Summary of the minimum and maximum limits of motion of the 90-deg sensor for each state, averaged over a time period of 1 second.

Fig 4.10 Summary of the minimum and maximum limits of angle for each state averaged over a time period of 1 second.

Finally static and dynamic data were combined for the AOW analysis and 15 histograms were drawn for each state and each parameter (2 types of motion and, angle). The
histograms showed frequency of samples in a particular range along with the cumulative distribution. One such Histogram is shown below.

Fig 4.11 Histogram showing the number of AOW1s samples present in each angle range for the RUN state

4.4 Results

The data collected during these experiments and the histograms drawn showing number of AOW1s samples present in different ranges for all three parameters, for all states are given in appendix B. Just by systematically comparing the histograms, ranges for each state were determined for each derived variable. They are shown in the table below:
Table 4.4 Ranges from the histograms

<table>
<thead>
<tr>
<th>State</th>
<th>0-degree motion range (g’s)</th>
<th>Angle Range (Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lie</td>
<td>0.0025 – 0.0125</td>
<td>82.5 - 100</td>
</tr>
<tr>
<td>Sit</td>
<td>0.0025 – 0.0150</td>
<td>65 – 87.5</td>
</tr>
<tr>
<td>Stand</td>
<td>0.0025 – 0.0175</td>
<td>-12.5 – 7.5</td>
</tr>
<tr>
<td>Walk</td>
<td>0.0500 – 0.3500</td>
<td>-12.5 – 15</td>
</tr>
<tr>
<td>Run</td>
<td>0.4000 – 2.0000</td>
<td>-35 – 35</td>
</tr>
</tbody>
</table>

From the histogram ranges, it is clearly seen that for the lie, sit and stand states the amount of motion is very less and thus a common number (0.02) in g’s is used for all three states. What separates the states clearly is the angle. For the lie state, the angle observed was generally above 82.5 degrees and thus 87.5 degrees was selected as a threshold for a confident “LIE” state. The subject could also be lying on the stomach, in which case the angle would be below -75 degrees. The angle range between 82.5 and 87.5 was seen for the “LIE” and “SIT” state and thus has been termed as the “LIE/SIT” state. If the angle is in the range 65 – 82.5 it is a confident “SIT” state. There is a gap in the histogram thresholds for motion between the “STAND” and “WALK” state. Thus the split difference between 0.0175 and 0.05, using the formula 0.0175 + (0.05-0.0175)/2 was calculated. The rules for the “STAND” state hence had a motion threshold up to 0.034 g’s and the angle was decided to be from -12.5 to 10 degrees. Walking was split into two states, namely, “WALK” and “FAST WALK”. The angle thresholds were the same (-15 – 15 degrees), but the motion threshold was made at 0.3 g’s. Finally the “RUN” state was given the same rules as seen in the histogram. Any state
that did not obey these rules was entitled to an “UNKNOWN” state. Thus this thesis gave rise to new states (FAST WALK) and clearly distinguished between the LIE and SIT state.

While there are a number of different strategies that can be explored, a straightforward rule-based approach was selected because the histograms revealed that it should be possible to discriminate state by applying the combination of range for two of the three derived variables: AOW_0-degree motion and AOW_Angle (thigh angle). The basic state detection rule takes the form:

\[
\text{IF} \quad 0\text{-deg\_LT} < 0\text{-deg\_Motion} < 0\text{-deg\_UT} \quad \text{AND} \quad AOW\text\_Angle\_LT < AOW\text\_Angle < AOW\text\_Angle\_UT \quad \text{THEN} \quad \text{State} = \text{State I}
\]

<table>
<thead>
<tr>
<th>State</th>
<th>0-degree motion range (g’s)</th>
<th>Angle Range (Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lie</td>
<td>&lt; 0.02</td>
<td>&gt; 87.5 or &lt; - 75</td>
</tr>
<tr>
<td>Lie/Sit</td>
<td>&lt; 0.02</td>
<td>82.5 – 87.5</td>
</tr>
<tr>
<td>Sit</td>
<td>&lt; 0.02</td>
<td>65 – 82.5</td>
</tr>
</tbody>
</table>

Table 4.5 Summary of Threshold Criteria Used in State Detection Rules
<table>
<thead>
<tr>
<th>Activity</th>
<th>Detected</th>
<th>Lie (%)</th>
<th>Sit (%)</th>
<th>Stand (%)</th>
<th>Walk (%)</th>
<th>Run (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lie</td>
<td>58.46</td>
<td>4.70</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Lie / Sit</td>
<td>28.71</td>
<td>17.15</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Sit</td>
<td>8.20</td>
<td>69.80</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Stand</td>
<td>0.00</td>
<td>0.00</td>
<td>94.22</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Walk</td>
<td>0.00</td>
<td>0.00</td>
<td>3.50</td>
<td>83.20</td>
<td>3.33</td>
<td></td>
</tr>
<tr>
<td>Fast Walk</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>9.05</td>
<td>4.44</td>
<td></td>
</tr>
</tbody>
</table>

Results obtained through statistical analysis were also compared to the observer’s records and a summary is shown in the table below:

Table 4.6 Performance of state detection rules (detected) from the analysis as compared to the observer (actual) using data across all 10 subjects.
Finally these rules were implemented in a state detection algorithm which was written in assembly code and downloaded into the research unit. An experiment for state detection was carried out on one subject. The results were compared to that of the observer and were seen to match in almost all cases.

4.5 Global Performance Observations

The calibration experiment showed that the prototype functioned well for raw-data logging. The data and plots from the experiments were analyzed. The graphs reflect averages across all ten subjects. The new techniques of state detection was discovered and found to be quite stable. New activity states were discovered. The device was reprogrammed using the new rules, and the results obtained were comparable to those of the human observer with regard to detection and measurement of the duration of the activity states selected.
5.1 Review of Objectives

This thesis is an investigation of human activity state detection and monitoring, with emphasis on bringing forth special attention to a convenient method for gathering raw data to support research and simultaneously supporting field use via programming to detect and log a specific set of activity states, using a newer micro controller, mixed signal hardware and more integrated LSI.

The main objectives of this thesis were:

1. Develop and test a hardware platform for a second-generation, subject-worn Activity State Detection and Monitoring System, incorporating new MEMS-based sensing technology and new microcontroller technology.

2. Define and incorporate a "raw data" logging operational mode to support research and building of time-series databases of various sensed parameters that can be used to explore alternate state detection algorithms and application to detection of a wide variety of activity states.

3. Conduct experiments with human subjects to evaluate the basic hardware platform and demonstrate a rigorous experimental approach to defining criteria for activity state detection.

4. Evaluate results obtained and provide recommendations for the next phase of research.
In addition to the emphasis on research methodology, this thesis investigated a second generation HASDMS platform and improves on the first generation model in terms of data acquisition, hardware design and software design. Improvements realized are summarized below:

- A newer, more powerful and more integrated micro controller was used, with mixed signal hardware and more integrated LSI
- New MEMS-based sensors were used for better performance and to have more information which permitted better estimation of key parameters such as thigh angle.
- New software modes were identified, to allow for better power efficiency and longer battery life with smaller packaging.
- New algorithms for detecting of lying, sitting, standing, walking, and running activity states were developed.
- An initial database of raw dual-axis accelerometer data was established as a basis to further study detection of one set of activity states.

5.2 Cost-Performance Analysis

Cost analysis of the system was done by calculating the per unit price of each component with the assumption that a 1,000 units were built. This is shown in table 5.1.
Table 5.1. Component Cost for the HASDMS

<table>
<thead>
<tr>
<th>Description</th>
<th>Part#</th>
<th>Manufacturer/Distributor</th>
<th>Quantity</th>
<th>Unit Price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Printed Circuit Board</td>
<td></td>
<td>Express PCB</td>
<td>1,000</td>
<td>0.50</td>
</tr>
<tr>
<td>Microcontroller</td>
<td>ADUC824</td>
<td>Analog Devices</td>
<td>1,000</td>
<td>12.85</td>
</tr>
<tr>
<td>EEPROM</td>
<td>M24512</td>
<td>ST Microelectronics</td>
<td>1,000</td>
<td>3.00</td>
</tr>
<tr>
<td>Accelerometer</td>
<td>ADXL202</td>
<td>Analog Devices</td>
<td>1,000</td>
<td>13.60</td>
</tr>
<tr>
<td>Trans-receiver</td>
<td>TC232CPE</td>
<td>Telecom Semiconductor</td>
<td>1,000</td>
<td>5.00</td>
</tr>
<tr>
<td>Watch crystal</td>
<td>EC38T</td>
<td>Allied Electronics</td>
<td>1,000</td>
<td>0.30</td>
</tr>
<tr>
<td>5% Carbon film, 1/4 watt resistors</td>
<td>QBK-ND</td>
<td>Digikey</td>
<td>1,000</td>
<td>0.08</td>
</tr>
<tr>
<td>0.1uF, 25V Ceramic Disk Capacitors</td>
<td>ECK-F1E104ZV</td>
<td>Digikey</td>
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<td>Digikey</td>
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Grand Total = $35.66
Labor costs, assuming mass production, are estimated to be $15 per unit, providing a total cost of approximately $50 per unit. This does not include the case and straps of the system. However, the major concept of the approach presented is that the performance of the system allows one to utilize very inexpensive components and sensors, with mass production costs of the order of a few dollars. Thus, a total manufacturing cost of $45–$55 dollars in order to obtain a relatively high performance system is considered to be quite reasonable. Actually, selling prices of $100–$150 should be obtainable.

### 5.3 Overall Evaluation

The activity state detection system is designed to detect and monitor human activity. In order to test and evaluate the current prototype, the physical quantities under observation were human subjects. The results and data obtained from the experimental evaluation for one set of activity states accomplished two things: 1) they show that the prototype detected and monitored human activity states very satisfactorily, and 2) they demonstrated the experimental approach recommended for development including recording of raw data to establish databases, processing of raw data to obtain strategically designed derived variables, and statistical analyses of derived variables to provide a basis for state detection/classification rules. Table 5.1 shows that it is a cost effective system. It has been shown that new technology now allows a highly integrated approach that results in few, relatively low cost components and a very small package. In general the system can be evaluated in terms of the following criteria:

- **Performance:** It was observed that the software algorithms were effective in data collection and state detection. The performance depends on the precision of the ADCs and the bandwidth of the sensors in the 0–5V range. The experimental evaluation
showed that the prototype was able to detect and monitor human activity with very little error.

- **Implementation:** The prototype showed that it is easy to fabricate and operate the system. It uses an algorithm written in 8052 assembly code that is adaptable to the changes required in future systems of its kind. It is relatively easy to build such a system, as there are no stringent manufacturing constraints.

- **External factors:** The tests carried out on the prototype reveal that the performance of the system is independent of the type of sensor used. It also showed that the system performance is independent of time.

- **Size:** The system is compact. Due to the small number of components involved, the system is light and easy to incorporate into other systems or subjects such as robots, and so on and so forth. The size of the HASDMS prototype is 3” x 2” x 0.75”.

- **Cost Analysis:** The cost of the research device is explained in Table 5.1.

### 5.4 Real Time Performance

The testing of the current generation prototype evaluated the real time performance of the system. The manner in which this was done was explained in section 4.2 in chapter 4. In this section we draw conclusions from the analysis of the results obtained during the tests. The limitations of the current generation prototype are as follows:

- The ADUC824 has 8 Kbyte ROM (program memory) and 256 bytes of volatile memory, so there is a need for external nonvolatile memory for data storage. This makes it necessary to incorporate another chip in the system, which is used to store data.

- The raw-data logging mode requires significant memory since it stores direct ADC digitized data and so it can log for only around 54 minutes with the present 64Kbytes
of external memory. This can be overcome by increasing the size of the memory chip. This thesis is more of a research model and thus a small memory chip serves the purpose.

5.5 Recommendations for Future Work

Although the current generation prototype was successful in achieving the desired objectives there are a few suggestions that can be implemented in future generation devices. These are:

- Hardware plays an important role in making the system more cost effective and efficient. The number of components in the system, determines the size and the cost of the system. The external memory used in the current system could be eliminated if on-chip memory is increased. With the advances in VLSI technology and the availability of more on chip memory, the need of an external memory device may be eliminated, thereby further reducing the size and cost of the system.

- In the current prototype, the ADUC 824 was interfaced to the external memory using two Port 1 pins, namely Port 1.0 connected to the serial data line and Port 1.1 to the serial clock pin of the EEPROM. The ADUC 824 supports a two wire serial interface mode that is Inter Integrated Circuit (I\(^2\)C) compatible. The design may be improved by connecting the SDATA (Pin #27 of ADUC 824) to the serial data line of EEPROM (M24128) and SCLOCK (Pin #26 of ADUC 824) to the serial clock pin of the M24128. This will enable faster data transfer operations (read and write) between the microcontroller and the EEPROM.

- The state detection rules could be modified by slightly changing the thresholds to get more accuracy in some states and exploring other methods as database sizes increase, such as neural network approaches.
• Additional states should be investigated. This should focus on discriminating new states with the thigh mounted devices (e.g., stair climbing, stair descending), as well as looking at states that can be detected for upper extremity tasks (with the SLU mounted to an upper extremity limb segment).

5.6 Concluding Remarks

The originally stated objectives have been achieved. The system is considered to be a worthwhile research and development platform for use in exploring a wide variety of physical activity states, including those that involve the whole body or primarily the upper or lower extremity. When evaluated in a typical state detection scenario, results comparable to those of a human observer with regard to detection and measurement of the duration of the activity states selected can be achieved. The approach described here provides a systematic methodology for obtaining hard data directly related to quality of life. This technology and methodology has promise for use in a variety of medical, non-medical, and sports applications.
APPENDIX A

CIRCUIT DIAGRAMS
Figure A.1: Schematic of accelerometer board

Rset = 1M  C1 = 0.1μF  C2 = 22pF  C3 = 22pF
R2 = 3.9k, C1 = 10μF, C2 = 1μF, C3 = 0.1μF, C5 = 0.1μF, C6 = 1μF, C7 = C8 = 10pF. J1 is a SIP connector.

Figure A.2. Schematic of ADuC824 & ST24512 Circuit Board
Figure A.3. Schematic of circuit board for interfacing SLU with PC

C6 = C7 = C8 = C9 = C10 = 0.1μF;
J3 is a SIP connector; J2 is a DB 9 connector.
APPENDIX B

HISTOGRAMS OF HUMAN ACTIVITY STATE MONITORING
Table B.1 Calibration Data

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<th>90 deg</th>
<th>0 deg</th>
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Figure B.1 Number of samples VS amount of motion of the 0-deg sensor for the Lie state

Figure B.2 Number of samples VS amount of motion of the 0-deg sensor for the Sit state
Figure B.3 Number of samples VS amount of motion of the 0-deg sensor for Stand state

Figure B.4 Number of samples VS amount of motion of the 0-deg sensor for Walk state
Figure B.5 Number of samples VS amount of motion of the 0-deg sensor for Run state

Figure B.6 No. of samples VS amount of motion of the 90-deg sensor for the Lie state
Figure B.7 No. of samples VS amount of motion of the 90-deg sensor for the Sit state

Figure B.8 No. of samples VS amount of motion of the 90-deg sensor for the Stand state
Figure B.9 No. of samples VS amount of motion of the 90-deg sensor for the Walk state

Figure B.10 No. of samples VS amount of motion of the 90-deg sensor for the Run state
Figure B.11 Number of samples VS angle for the Lie state

Figure B.12 Number of samples VS angle for the Sit state
Figure B.13 Number of samples VS angle for the Stand state

Figure B.14 Number of samples VS angle for the Walk state
Figure B.14 Number of samples VS angle for the Walk state

Figure B.15 Number of samples VS angle for the Run state
APPENDIX C

IRB APPROVAL DOCUMENT
PARTICIPATION EXPLANATION AND CONSENT FORM

PROJECT TITLE: Investigation of Human Activity State Detection and Monitoring

INVESTIGATORS: George V. Kondraske, Ph.D., Professor, Electrical and Biomedical Eng.
Jeevan D’Souza (Graduate Student, EE Department)

TELEPHONE NUMBERS: (817) 272-3454 (lab), (817)-272-2335 (office)

BACKGROUND INFORMATION:
I have been asked to participate in a research study that will investigate the ability to detect basic human activities like sitting, lying, walking using simple motion sensors and special data processing techniques. At present, we are attempting to build a database of sensor signals that correspond to different activities so that we can produce a computer program that can process sensor data to determine which of the listed activities a person is engaged in at a given point in time. This investigation has the potential to lead to devices that will allow medical practitioners (e.g., neurologists) and others to monitor behavior and performance of patients and their disease progression and/or recovery.

PROCEDURES:
If I agree to participate in this study, I will be involved in one experimental session that will be performed at the Human Performance Institute at the University of Texas at Arlington. In this experiment, a small box will be loosely attached to my outer thigh with a Velcro strap. I will be asked to follow a simple script that will require me to stand-up, sit down, walk, jog for a short distance, and lie down at different points in time over a 10 minute period. The total session will last approximately 30 minutes. The commands that require me to move from one activity to the next will be presented by an audio tape.

RISKS THAT MAY OCCUR DURING THE STUDY:
There are few potential risks involved in this study and the risk level is similar to that I would encounter in carrying out daily activities. I may experience some fatigue.

BENEFITS FOR YOUR PARTICIPATION:
By participating, I will be assisting in the evaluation of new methods that may benefit many others in the future. I will also learn about some new technology and aspects of activity state detection. This research will serve as groundwork for future research that may prove to be valuable for diagnosis and evaluation of the effectiveness of new drugs and therapies.

AVAILABILITY OF COMPENSATION AND MEDICAL TREATMENT FOR INJURY:
The investigators will make every effort to prevent physical injury that could result from this research. If I am injured, the research protocol does not require the payment of financial compensation to me from the investigator or the University of Texas at Arlington. Medical treatment for physical injuries is not available from the researchers as part of the research protocol. The
University of Texas at Arlington Heath Services will provide medical treatment, should an acute condition arise from my participation in this study. I will be financially responsible for any emergency medical care I receive.

CONFIDENTIALITY:
I have the right to privacy, and all information that is obtained in connection with this study and that can be identified with me will remain confidential as far as possible within state and federal law. Everything the investigators learn about me in the study will be confidential. The results of this study may be published in the medical literature or for teaching purposes, but no names or other information that can be used to identify me will be used. No photographs or videotapes will be used. Records will be kept regarding my participation in the study and will be made available for review only as required by the Food and Drug Administration.

REQUEST FOR MORE INFORMATION:
If I have any questions about the study, I should contact:

Dr. George Kondraske
(817) 272-3454

If I need to report any adverse event or problems concerning my participation, I should contact:

Dr. George Kondraske
(817) 272-3454

If I have any questions about my rights as a research subject I should contact:

Dr. Marianne R. Woods, Assistant Vice President for Research / Director of the Office of Research, at (817) 272-2105.

REFUSAL OR WITHDRAWL OF PARTICIPATION:
My participation is voluntary and I may refuse to participate, or may withdraw consent and discontinue participation in the study at any time without prejudice to my present enrolment or employment at the University of Texas at Arlington (if applicable). Either George Kondraske or Jeevan D'Souza may terminate my participation in this study after they have explained the reasons for doing so. I will be given a copy of this form to keep.

CONSENT TO PARTICIPATE:
I am making a decision whether or not to participate in this study. I should not sign this consent form until I have read (or have been read) and understand the information presented in the previous pages, and until all my questions about the experimental project and the study procedures I will undergo have been answered to my satisfaction. My signature indicates that I have made an informed decision to participate.

I have explained to __________________________________________ the purpose of the experimental project, the procedures required, and the possible risks and benefits to the best of my ability.

____________________________________  ______________________
Signature of investigator                     Date
Signature of person obtaining consent ____________________________ Date

_________________________________________________________ - has explained to me the purpose of the experimental project. I have read (or been read) and understand this consent form. I have been given an opportunity to ask questions regarding the experimental project and the study procedures I will undergo, and I believe that I have sufficient information to give this informed consent. Alternatives to my participation in the study have been discussed. To the best of my knowledge, I am not participating in any other medical research. Therefore, I agree to give my consent to participate as a subject in this research project.

Signature of subject ____________________________ Date
REFERENCES


30. Delsey Sherrill, Carlo DeLuca, Paolo Bonato, Serge Roy, “*Comparison of Surface Electromyography and Accelerometry in Function Motor Activity Monitoring*” (Neuromuscular Research Center, Department of Biomedical Engineering, Boston University, 2002)


35. http://www.minimiter.com

BIOGRAPHICAL STATEMENT

JEEVAN D'SOUZA

Jeevan D’Souza received his Bachelor of Engineering in Electronics from Shivaji University, Kolhapur, India in May 2000. He then served as an adjunct lecturer in the D.Y. Patil College of Engineering and Technology for a year. As a lecturer he has taught the subjects computer organization and architecture, Information systems and analysis, Operating systems, and Computer practice. His earned his Master’s Degree in Electrical engineering from the University of Texas at Arlington, where he did a thesis based on microprocessor-based instrumentation under the supervision of Dr. George Kondraske. His research interests include digital design, logic circuits, assembly language programming, microprocessors, computer architecture, interfacing techniques and Boolean mathematics. He plans to do a Ph.D. in Computer Engineering and spend his life as a professor of Engineering.

GEORGE KONDRASKE

George V. Kondraske Ph.D. is Professor of Electrical and Biomedical Engineering at the University of Texas at Arlington and founding director of the Human Performance Institute. He received a B.S. in electrical engineering from the University of Rochester in 1978 and M.S. and Ph.D. in biomedical engineering from the University of Texas at Arlington and
University of Texas Southwestern Medical Center at Dallas (joint program) in 1980 and 1982, respectively. Since then, he has conducted human and systems performance research sponsored by NIDRR, NSF, NASA, DOE, USAF, NIH, the Veterans Administration, the Texas Higher Education Coordinating Board, as well as a number of industrial firms. He is widely recognized for his work in human performance modeling and measurement. Key contributions include the development of a Human Performance Capacity Measurement System (now commercially available and in use in nine countries), General Systems Performance Theory, and the Elemental Resource Model for human performance. He has applied these tools to problems in medical rehabilitation, ergonomics, sports, music, and other areas. He has authored over 200 publications on these topics. In 1986, he was awarded the IEEE Engineering in Medicine and Biology Society Early Career Award and received the Association for the Advancement of Medical Instrumentation Career Achievement Award in 1989.