ABSTRACT

AMBULATORY MEASUREMENT OF BODY POSITION

by

Swetha Vennamaneni

Ambulatory monitoring is playing an important role in the clinical and research field. In the modern era, physicians are showing much interest in measuring heart rate, blood pressure and many other physical and cardiac conditions and recording electrocardiogram (ECG, a popular technique for diagnosing heart related disease), while the patient is ambulatory. Heart rate, blood pressure and ECG waveform can change because of body position. In the case of the ECG, the changes caused by body position are can change the ST-T segment and also the QRS amplitude. The heart rate and blood pressure changes when there is a change in position from standing to sitting, sitting to standing, sitting to lying or any of the combinations. The goal of this project was to develop a device that can measure body position using an accelerometer technique and to interface the accelerometer with a handheld computer. A software program was also developed to display and store the position information into a handheld computer. The software program was developed in LabVIEW PDA module environment.

To prove the validity and accuracy of the system, a pilot experiment was conducted where the readings from the device at different positions and during normal activities were recorded from five healthy subjects and compared. Data showed that as the subjects changed their posture, the system was able to correctly identify three basic body postures, which are sitting, standing and lying.

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by
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This thesis is dedicated to my husband and my family.
Thank you for always supporting my efforts.

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CHAPTER 1

INTRODUCTION

1.1 Objective

The goal of this research was to develop an ambulatory device that can collect the body position data and store in the PDA for up to 24 hours. Physicians today are increasingly interested in ambulatory measurement of cardiac and physical disorders. Ambulatory measures are recorded to a handheld or portable recording device. This is in contrast to bench top or desktop equipment. An ambulatory system allows the patients to move freely and carry out their daily lives. There are many devices out in the market, like the LifeShirt that can measure cardiac response and physical response ambulatory.

Body position can affect the electrocardiogram (ECG), heart rate, blood pressure and other cardiac responses. There is a change in the ECG waveform, heart rate and blood pressure when there is a change in body position. The change in the ECG waveform can be seen in the ST segment or ST-T complex. These changes are not always due to ischemia but are sometimes due to body position. In the case of heart rate, the heart rate decreases throughout a posture change from upright seated to lying and standing to lying, whereas the heart rate increases in the standing and sitting position compared to the lying position [5,6,7,8,9,10]. In the case of blood pressure (BP), the BP decreases throughout a posture change from upright seated to lying and standing to lying [5, 6, 7, 8, 11].

A device that can measure body position ambulatory was designed in this study. When the physician wants to read the ECG, heart rate, blood pressure or any other response of a patient ambulatory, this device can be given to the patient to determine his/ her body position. With this information, the physician can know whether the changes in ECG, heart rate, and blood pressure were due to any disorder or due to change in body position.

In order to analyze and compare the data with the normal responses, five subjects were recruited. Accelerometers were used in this study to determine the body position. Subjects were asked to put three accelerometers on their body and the readings were taken. One accelerometer was to be worn on the lower leg, one on the thigh and other on the abdomen. The data was recorded using LabVIEW software programming and was stored in a PDA.

1.2 Background Information

1.2.1 Body Position

Body position or posture refers to the position of the limbs relative to one another. Generally body position can be classified into three different categories: sitting, standing, and lying. The body position can be described using three body sections: the trunk of the body, the upper leg (above the knee), and the lower leg (below the knee). Standing therefore can be defined as the trunk, the lower leg, and the upper leg being parallel to gravity. Sitting is when the trunk and lower leg is parallel to gravity, but the upper leg is perpendicular to gravity. Lying is when the trunk, upper leg, and lower leg are perpendicular to gravity. These definitions are general. The specific details are discussed in Section 2.3.2.

1.2.2 Cardiovascular Response to Body Position

During ambulatory monitoring, the ability to know a patient's position is important. Body position and postural changes determine a gravitational gradient acting upon the cardiovascular and pulmonary systems. Changes in body position can change the heart rate and blood pressure. Changes in body position alter the electrical axis of the heart, resulting in changes in QRS amplitude and the ST-T segment [12] and also, ischemia appears primarily as change of amplitude in the ST-T segment, and in advanced stages the QRS complex is affected as well [4]. Due to this reason, the positional changes can be misclassified as ischemia during ambulatory monitoring. The body position relationship between heart rate and blood pressure has been extensively studied and well documented in various papers [5,7,8,9,10,11,12]. Studies show that there was a significant increase in the heart rate when the posture changed from lying to standing, lying to sitting or sitting to standing and there was a decrease in heart rate from standing to the lying position, sitting to lying or standing to sitting. The heart rate was highest when standing and lowest when lying. The mean heart rate in the lying, sitting, standing, then sitting and finally lying positions was 66.1±12.1; 72.1±11.2; 79.3±10.6; 72.4±10.7 and 65.13±10.7beat/min respectively [13]. The blood pressure decreases from standing to the lying position, sitting to lying or standing to sitting and the blood pressure increases when the posture changed from lying to standing, lying to sitting or sitting to standing [5, 6, 7, 8, 11].

1.2.3 Ambulatory Monitoring

Ambulatory monitoring is playing an important role in today's life. People in the research area and in hospitals are focusing more in measuring the cardiac and physical disorders ambulatory. Ambulatory monitoring means measuring the cardiac and physical signals of a subject during his/her daily activity. There are some advantages of ambulatory monitoring over the clinical or laboratory monitoring. In laboratory monitoring, the patient is forced not to move and to stay on the bed for hours to sometimes days, which makes the patient feel uncomfortable, whereas in ambulatory monitoring the patient/ subject can move and do his/her daily activities. The laboratory environment is novel and can induce fear, so any measurements made in it may be poorly generalizable to more natural settings. The laboratory window of observation is limited in time and infrequent events like spontaneous panic attacks are easy to miss. Using ambulatory monitoring technology, physiological reactions related to anxiety or other problems can be recorded when and where they happen. Patients with a more situational bound type of anxiety (for example, specific or social phobia) would best be assessed by first reviewing the computer diary information and identifying situations that were anxiety provoking, and then by examining the physiological records for these periods. In contrast, patients with more generalized anxiety (for example, post-traumatic stress disorder, and generalized anxiety disorder) would best be assessed by looking for a generally elevated activation profile [16]. People with disorders (like epilepsy) could benefit from a device that monitor body position and called for help if needed. An advantage of ambulatory monitoring is that the readings can be measured repeatedly, away from the hospital or general practice surgery without the need for an observer. Ambulatory monitoring improves the precision of measurement by taking numerous readings; average daytime, nighttime, and 24 hour may then be calculated [16]. The disadvantage of ambulatory monitoring is that it is very expensive and inflexible.

1.2.4 LabVIEW

Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) is a graphical programming language. The data is recorded and stored in the computer using the LabVIEW software. LabVIEW software is developed by National Instruments (Austin, Texas). There are two basic components in LabVIEW: the front panel screen and the block diagram screen. On the front panel, the running of the program and its performance can be viewed. On the block diagram the actual programming using the VIs takes place. The front panel is usually regarded as the user interface through which the user can visualize the performance of the program. On the block diagram screen, different VIs are selected and connected to carry out functions like reading the data, calculating the body position with the data, storing the data etc. This programming paradigm has been widely adopted by industry, academia and research laboratories over the world as the standard for data acquisition and instrument control software. The functions in LabVIEW are called Virtual Instruments (VIs). VIs performs small tasks like mathematical functions, recording, configuration etc. There is a function palette, which lists all the functions available with categories and sub categories. These VIs have inputs and outputs, which gives the user the necessary information needed in the selection of the parameters.

1.2.5 PDA and Computer

Personal digital assistant or PDA is one of the fastest selling consumer devices in history. The idea of making a small hand-held computer for storing addresses and phone numbers, taking notes and keeping track of daily appointments originated in the 1990s, although small computer organizers were available in the 1980s [18]. One of the first PDA's that was commercially available was Apple Computer's Newton Message Pad. The PDA's are designed to complement a desktop or laptop computer, not replace one. They started out as PDA's but are now called Pocket PCs or handheld computers because they are running a fuller operating system that can run similar programs to that on a desktop PC.

The PDA is a rectangular shaped device that rests easily in the palm of your hand as shown on Figure 1.1. A touch-sensitive display screen dominates the front of the device. A pen-shaped device called a stylus is used to interact with the PDA. The lower section of the PDA usually contains buttons for quickly accessing different functions.

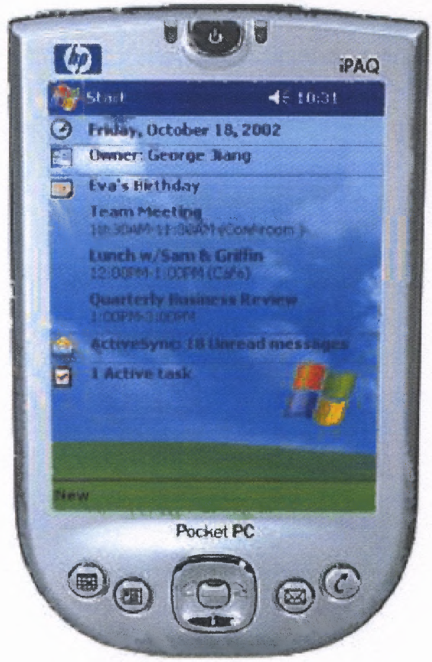

Figure 1.1 Appearance of a PDA.

The PDA is capable of handling many things. The parts that make a PDA are shown in Figure 1.2. In addition to basic calendar, address book, and task-list programs, high-end PDA's often allow for wireless connection to the Internet (for Web browsing and e-mail), have built-in MP3 players, take digital photographs, and double as mobile telephones. Some new PDA's can even double as global positioning devices, showing users exactly where they are on a map. PDA's are able to exchange information with full-sized computers. For instance, a document can be transferred from the computer to the PDA so that one can work on it while on the go. The process of exchanging information between your computer and the PDA is called, appropriately, "synchronizing" them.

Unlike a desktop computer, the PDA doesn't have a hard drive. It stores basic programs (address book, calendar, memo pad and operating system) in a read-only memory (ROM) chip, which remains intact even when the machine shuts down. The data and any programs added later are stored in the device (RAM). All PDA's use solid-state memory; some use static RAM and some use flash memory [18]. Some are even incorporating removable forms of memory. PDA's usually come with 2 MB minimum of memory. One megabyte of memory can store up to 4,000 addresses and 100 e-mail messages. However, many application programs take up memory space, so more advanced models usually have more memory (128 to 256 MB). Also, windows CE operating system takes more memory space so PDA's with this operating system usually have 16 or 32 MB. In some PDA models, the amount of memory is upgradeable to even 1GB.

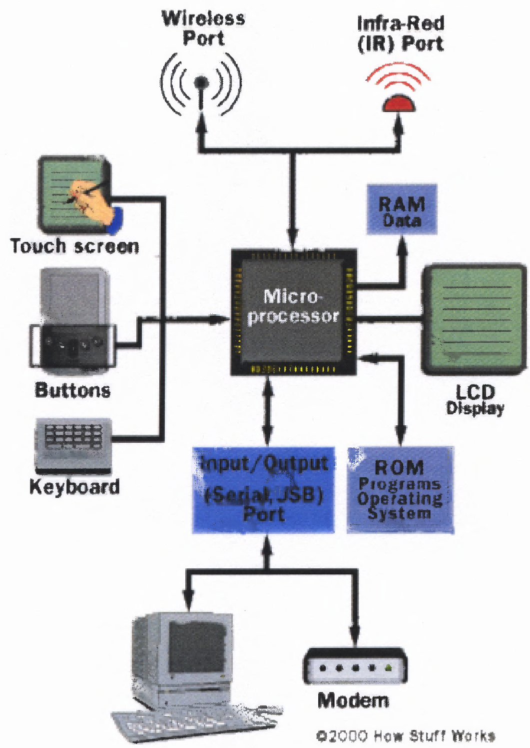

Figure 1.2 Parts that make up a PDA.

The PDA's function is similar to the computer. The PDA has memory, a screen, keyboard, etc. One can even browse through the PDA. The differences between the computer and the PDA are:

1. The PDA has less memory than the computer.

2. The PDA has an onscreen keyboard.

3. The PDA has a slow processor compared to the computer.

The model of the iPAQ (pocket PC) used in the current study is HP5555 series (manufactured by Hewlett-Packard, CA). The iPAQ pocket PC HP5555 series have 48 MB ROM and 128 MB RAM. The operating system in the pocket PC HP5555 series is windows CE 4.2.

1.2.6 Accelerometer

The accelerometer plays an important role in this thesis study. With the help of the accelerometer, the body position is measured. Accelerometers are used to convert acceleration from gravity or motion into an electrical signal. The accelerometer is an instrument that measures the rate at which the velocity of an object is changing (i.e., its acceleration). There are many different types of accelerometers.

In past years, several types of miniaturized accelerometers based on silicon micromachining techniques have been investigated. One of the commercially interesting application fields for such silicon accelerometers is the automotive industry where many low-cost sensors are needed for airbags, smart suspensions, electronic steering and position finding. Low-cost accelerometers are also of interest to the TV and computer industry for so called gesture-controlled remote controls, which convert the movement of a human hand into an electronic signal or into the position of an arrow on the screen of a monitor. Also, in the biomedical field, accelerometers are of interest for motion control [19].

All silicon accelerometers make use of a suspended mass, which moves when the device is accelerated. There are different possibilities for the detection of this movement. Most silicon accelerometers make use of the capacitive or the piezoresistive principle. In a capacitive acceleration sensor the body and the mass are insulated from each other and their capacitance, or charge storage capacity, is measured. As the distance decreases, the capacitance increases and electric current travels towards the sensor; when the distance increases, the opposite occurs. The sensor converts the acceleration of the body into an electric current, charge or voltage. The acceleration-sensing element is made of single crystal silicon and glass [20].

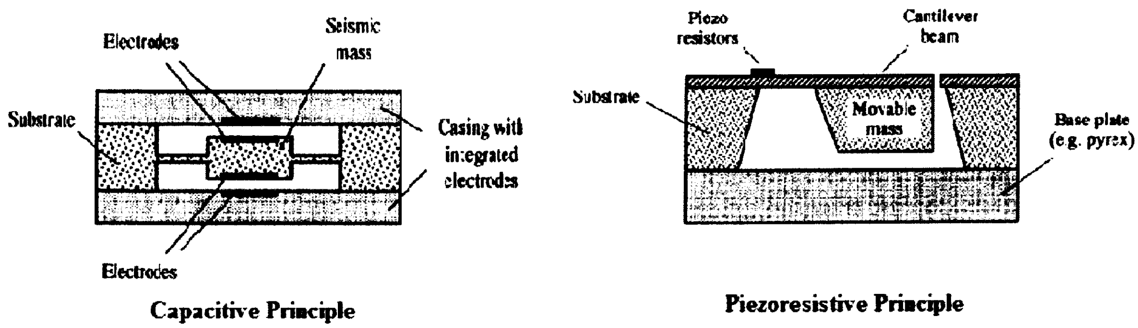

Figure 1.3 Capacitive and Piezoresistive measurement of acceleration.

To measure acceleration using the piezoresistive principle, piezoresistors are placed at points of the cantilever where the largest deformation takes place. If a mass moves due to acceleration, it deforms the piezoresistors, thereby changing their resistance. The acceleration is determined from the resistance change [20]. Figure 1.3 shows a capacitive accelerometer and a piezoresistive sensor.

Disadvantages of these types of accelerometers include the sensitivity to electromagnetic interference of the capacitive sensors and the temperature and stress sensitivity of the piezoresistive sensors. Both types require rather complex and expensive electronic circuitry for signal conditioning and for the compensation of offset and cross sensitivities. Deficiencies of present-day accelerometers justify the search for new principles.

1.2.7 The Heart

The cardiovascular system consists of the heart, which is a muscular pumping device, and a closed system of blood vessels called arteries, veins and capillaries. The heart pumps blood around a closed circuit of vessels contained in the circulatory system as it repeatedly passes through various "circulations" of the body [1]. In actuality, there are two circuits, both originating and terminating in the heart. Therefore, the heart, illustrated in Figure 1.4 is divided into two function halves, each half containing two chambers: an atrium and a ventricle. The atrium on each side empties into the ventricle on that side. There is no direct flow between the two atria or the two ventricles in a healthy individual.

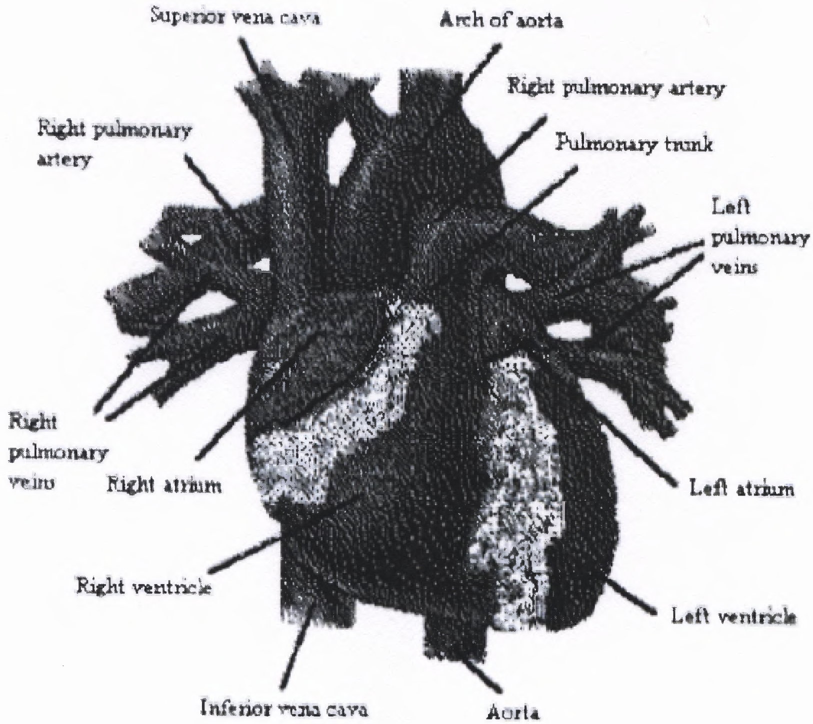

Figure 1.4 The parts of a heart.

Blood is pumped by the pulmonary circuit from the right ventricle through the lungs and then into the left atrium. The blood is then pumped by the systemic circuit, from the left ventricle, through all the tissues of the body except the lungs, and then to the right atrium. In both circuits, the vessels carrying blood away from the heart are called arteries, and those carrying blood from either the lung or all other parts of the body back to the heart are called veins. Figure 1.5 illustrates the heart with the systemic and pulmonary circulations.

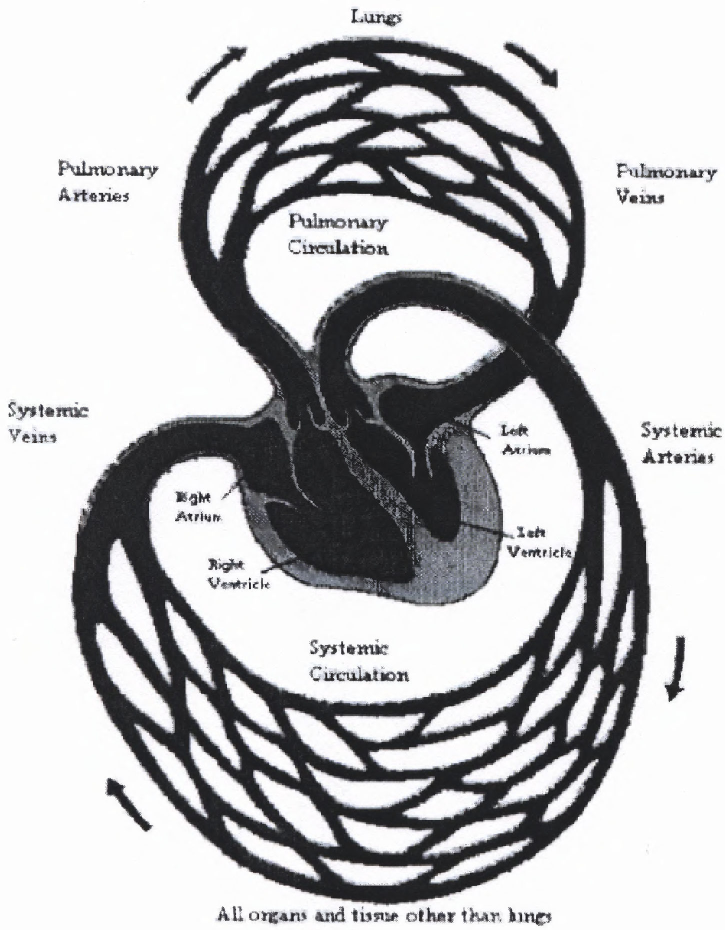

Figure 1.5 The systemic and pulmonary circulations.

The electrical conducting system of the heart is illustrated in Figure 1.6. The heart's conducting system consists of the sinoatrial (SA) node, atrioventricular (AV) node, the bundle of His, the bundle branches and the Purkinje fibers.

The electrical impulse that causes rhythmic contraction of heart muscles arises in the SA node, which is the intrinsic pacemaker of the heart. From the SA node, the impulse spreads over the atrial muscles causing atrial contraction. The impulse is also conducted to the AV node. From the AV node, the electrical impulse is conducted to ventricular muscles via the bundle of His, the bundle branches and the Purkinje fibers.

The bundle branches and the Purkinje fibers are collectively called the ventricular conduction system.

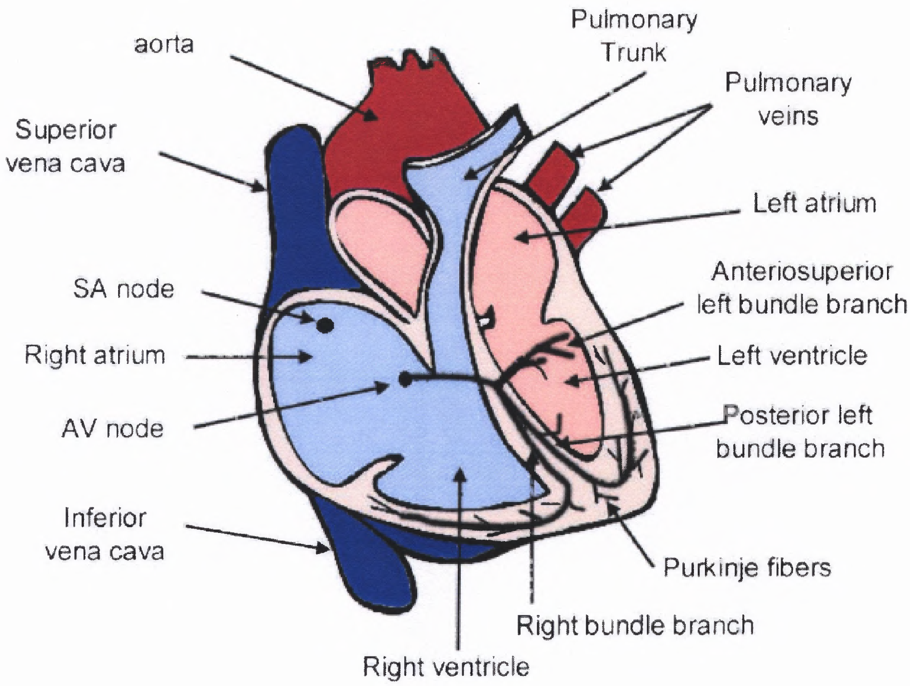

Figure 1.6 The conducting system of the heart.

1.2.8 Electrocardiogram, Heart Rate and Blood Pressure

Electrocardiogram

An electrocardiogram (ECG) is a graphical representation of the electrical activity of the heart plotted along a time axis [2]. It is a measurement that is recorded at the surface of the skin and is generated by electrical currents from the cardiac muscle action potentials that causes the contraction of the heart. A typical electrocardiogram as shown in Figure 1.7 consists of a regular sequence of waves, the P, QRS, and T waves. Each of these waves is generated by specific events in the cardiac cycle. The P wave is generated by the contraction of the atria. The QRS complex is the contraction of the ventricles and the T wave is generated by the relaxation of the ventricles. The amplitude of each of these components depends on the orientation of the heart within the individual and the position of the leads (electrodes) used to record the ECG.

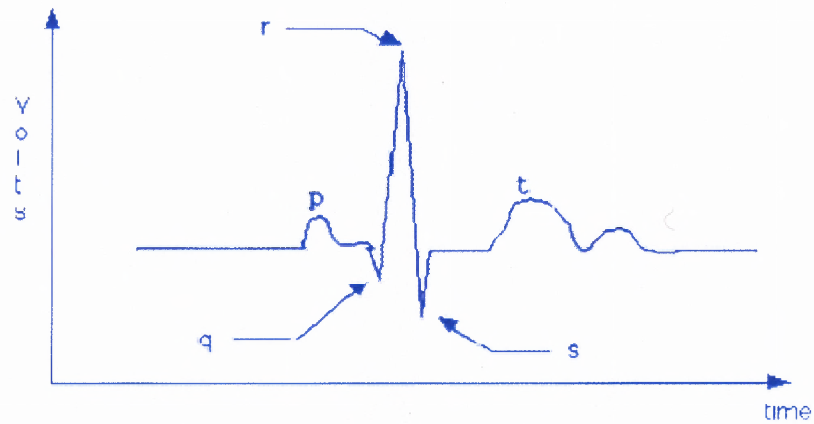

Figure 1.7 Typical ECG waveform.

Using a pair of surface electrodes and a ground electrode, the measurements of the ECG signal are obtained. The differential voltage signal can be measured on the surface of the skin. The locations of the two electrodes differ depending on the desired emphasis on the signal. Since the QRS complex is the easiest component of the ECG wave to detect, it is used as the calculation point for the determination of the heart rate.

Heart Rate

Heart rate is the number of heartbeats per unit time, usually expressed in beats per minute. The heart rate is based on the number of contractions of the ventricles (the lower chambers of the heart).

Because the ECG is plotted along the time axis, the linear distance between neighboring peaks of simultaneous heartbeats on an ECG corresponds to the time necessary for a single cardiac cycle (heartbeat). The heart rate can be calculated from the time interval between the R peaks of the ECG.

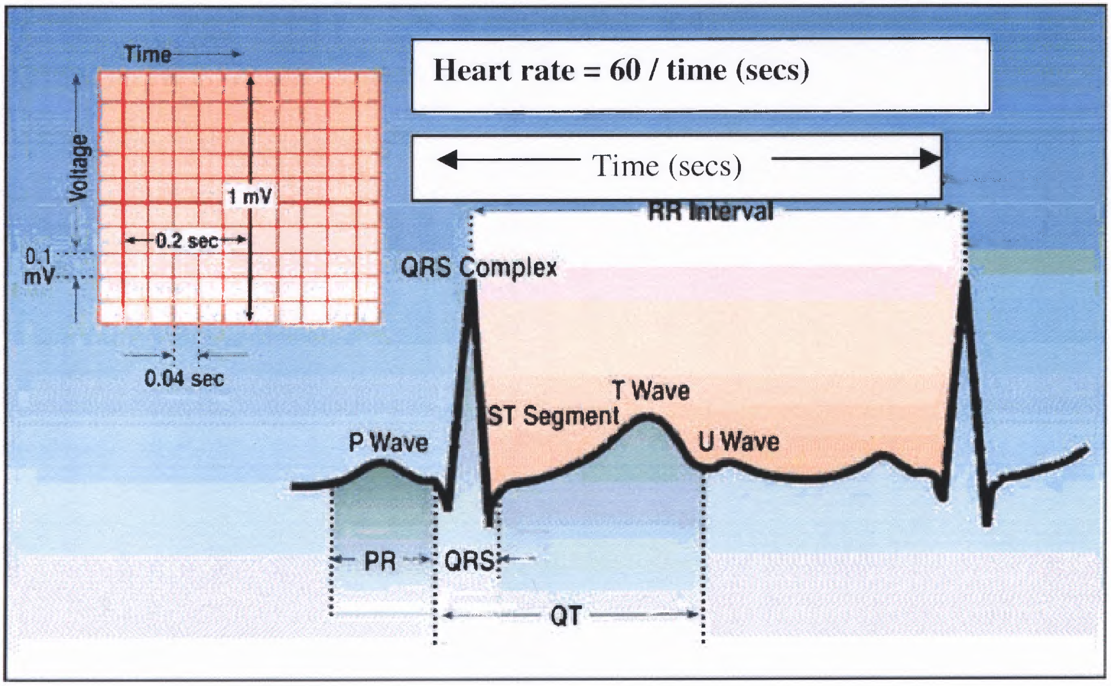

Figure 1.8 Calculation of heart rate.

Heart Rate = 60 / (R to R interval in seconds)

R-to-R interval is the time between the R peaks. It is shown in Figure 1.8.

Blood Pressure

Blood pressure (BP) is the pressure of the blood flowing through blood vessels against the vessel walls. It depends on blood flow (how much blood is pumped by the heart) and the resistance of the blood vessels to the blood flow [3]. If the pressure is high, the heart must work much harder to maintain adequate blood flow to the body. Blood pressure is continually changing depending on activity, temperature, diet, emotional state, posture, physical state and medication use. Blood pressure readings are usually given as two numbers: for example, 110 over 70 (written as 110/70). The first number is the systolic blood pressure reading and the second is the diastolic blood pressure. Systolic BP represents the maximum pressure exerted when the heart contracts. It begins with the opening of the aortic valve and the rapid ejection of blood into the aorta. This is followed by "run-off" of blood from the proximal aorta to the peripheral arteries. On the arterial pressure waveform, this appears as a sharp rise in pressure followed by a decline in pressure. The diastolic pressure represents the pressure in the arteries when the heart is at rest. Mean arterial pressure (MAP) represents the average pressure within the arterial system. Since diastole typically lasts approximately two thirds of the entire cardiac cycle, the mean arterial pressure value is closer to the diastolic value than to the systolic value.

Mean arterial pressure is defined as the sum of diastolic pressure plus one third of the pulse pressure. It can also be mathematically calculated as

$$\text{MAP} = 1/3\ (\text{systolic}+2*\text{diastolic}) \tag{1.1}$$

CHAPTER 2

INSTRUMENTATION METHODOLOGY

2.1 System Overview

This pilot system was set up to measure, display and store the body position data in real time in human test subjects. The body position was measured using accelerometers. A pocket PC was used for processing the data collected from the accelerometer.

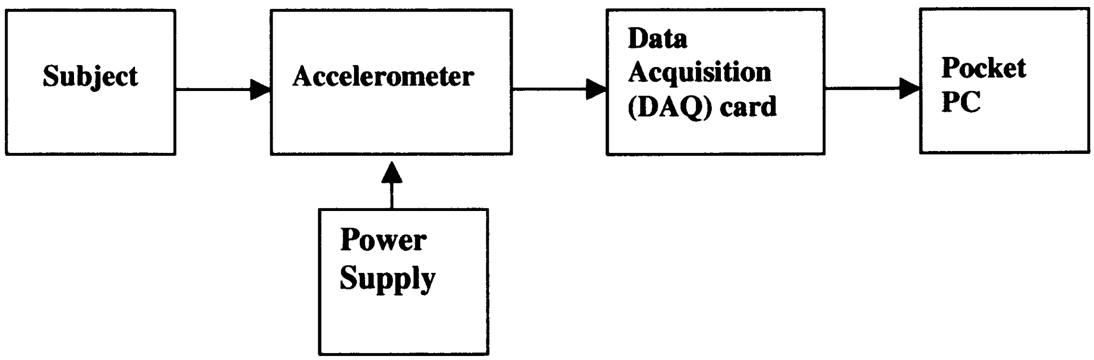

Figure 2.1 Block diagram of the body position measurement system.

Figure 2.1 shows the block diagram of the body position measurement system. The detailed description of each component is described later in this section. The accelerometers were placed at three different locations on the subject's body. One accelerometer was placed on the abdomen, one on the thigh and the other on the lower part of the leg (between the knee and the ankle). The output of the accelerometer is an analog signal. The output was fed into the data acquisition card (DAQ card). The output of the card was connected to the pocket PC. Using software, the data from the accelerometers was represented as an angle and that data was displayed and stored in the pocket PC. Depending on this angle the body position of the subject can be known.

2.2 Hardware Parameters

The primary hardware for measuring body position is the accelerometer.

2.2.1 Accelerometer

The novel thermal accelerometer MXR2999GL manufactured by MEMSIC (Andover, Massachusetts) used in this research, is based on the heat transfer principle. This accelerometer has only one moving element—a tiny bubble of heated air hermetically sealed inside the sensor package cavity. When an external force like motion, inclination, or vibration is applied, the bubble moves in a manner analogous to the bubble in a spirit level. The change of state develops a signal that is amplified, conditioned, and output as either a ratiometric or an absolute voltage.

2.2.1.1 Operating Principle of Accelerometer. The basic principle of the thermal accelerometer is based on heat transfer by natural convection [17]. The heat transfer principle is that the cooler air is denser than the warm air and any change in the accelerometer motion or orientation will cause the cooler air to force the warm air in the direction of the acceleration [22]. The accelerometer measures internal changes in heat transfer caused by acceleration. The accelerometer has a static component. The stationary component (i.e., static element or 'proof mass') in the accelerometer is a gas (air). The gaseous proof-mass provides great advantages over the use of the traditional solid proof mass. The effect of acceleration on the accelerometer is described below.

A single heat source, centered in the silicon chip is suspended across a cavity. Equally spaced aluminum/polysilicon thermopiles (group of thermocouples) are located equidistantly on all four sides of the heat source. Figure 2.2 shows the components of the accelerometer.

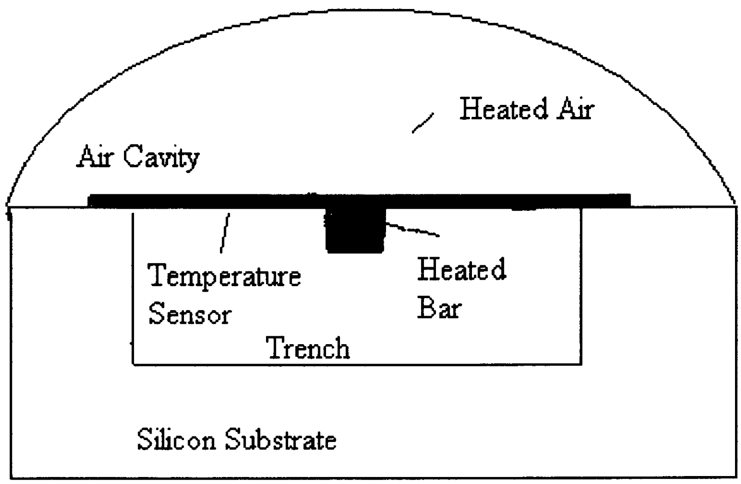

Figure 2.2 Components of accelerometer.

Under Zero Acceleration

Under zero acceleration, the temperature gradient is symmetrical about the heat source (i.e. the heated air is in the middle) as in Figure 2.3, so that the temperature is the same at all four thermopiles, causing them to output the same voltage. The cool air in the air cavity is denser than the warm air over the heater bar; any change in the sensor's motion and/or orientation causes the cooler air to force the heated air towards the end of the package cavity in the direction of acceleration (this is free convection heat transfer).

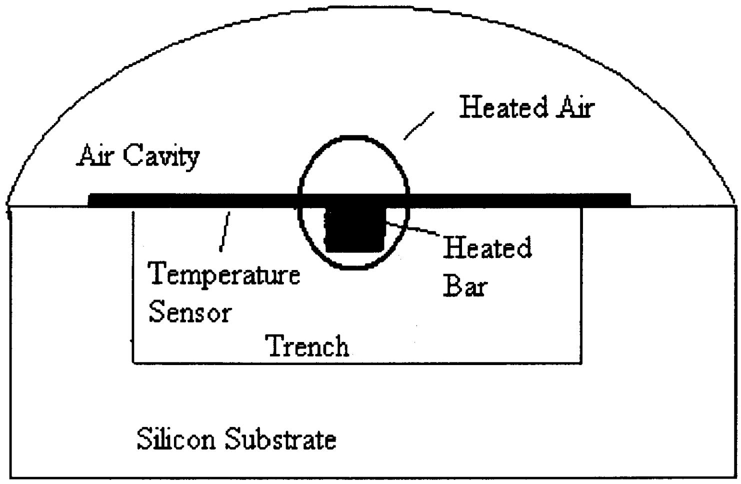

Figure 2.3 When there is zero acceleration /zero tilt.

Under Acceleration

Under acceleration the asymmetrical temperature profile occurs as the cooler air forces the heated air in a left-to-right direction, as shown in Figure 2.4. The higher density cooler air in the cavity shifts the heated air and develops a temperature differential that affects the thermopiles and this imbalance produces different voltages at the thermopiles. The differential voltage at the thermopile outputs is directly proportional to the acceleration.

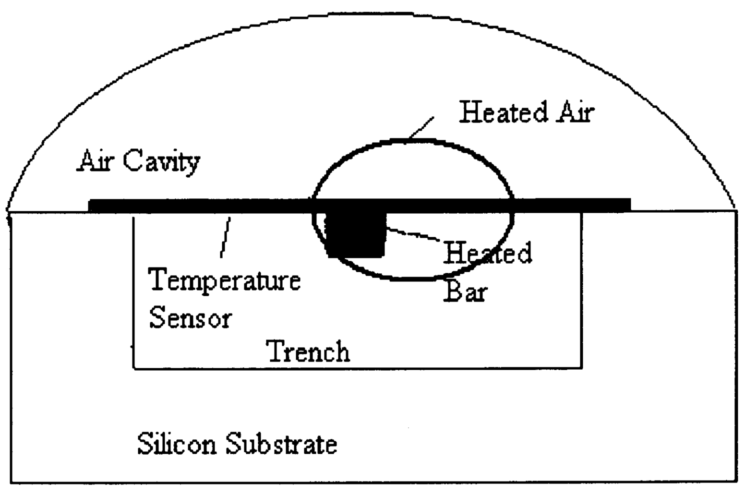

Figure 2.4 When there is acceleration / tilt.

The accelerometer used is MXR2999GL (manufactured by MEMSIC). The MXR2999GL provides a ratiometric analog output that is proportional to 50% of the supply voltage at zero g acceleration. That is, if a supply voltage of 5 Volts is provided, the output of the accelerometer at zero g acceleration is 2.5 Volts. This accelerometer is a dual axis accelerometer. The accelerometer is packaged in a hermetically sealed LCC surface mount package. The picture of the accelerometer is shown in Figure 2.5.

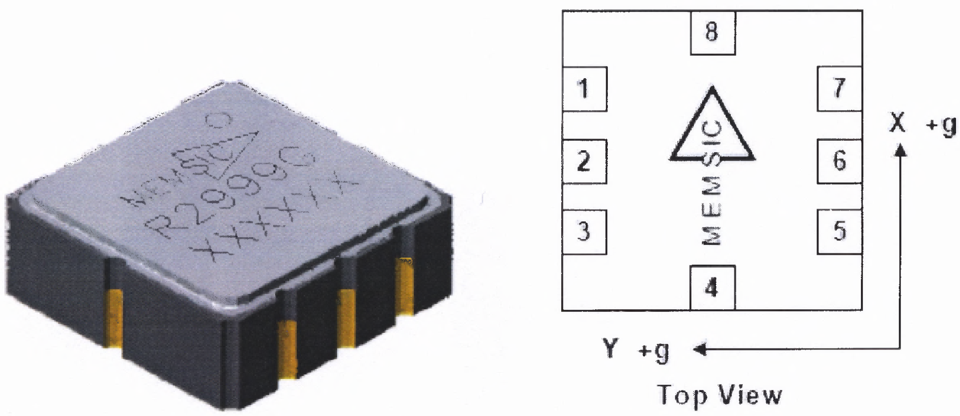

Figure 2.5 MEMSIC Accelerometer MXR2999GL.

There are two identical acceleration signal paths on the accelerometer, one to measure acceleration on the X-axis and one to measure acceleration on the Y-axis. The accelerometer has eight pins. Pin three (ground); four (voltage supply) and five (X-axis acceleration signal) are used for this experiment. The pin description of the accelerometer is shown in Table 2.1.

Table 2.1 Pin Configuration of Accelerometer

Pin	Name	Description
1	T_{OUT}	Temperature (Analog Voltage)
2	A_{OUTY}	Y-Axis Acceleration Signal
3	Gnd	Ground
4	V_{DA}	Analog Supply Voltage
5	A_{OUTX}	X-Axis Acceleration Signal
6	V_{Ref}	2.5 V Reference
7	Sck	Optional External Clock
8	V_{DD}	Digital Supply Voltage

The supply voltage range for the accelerometer is 3.6V to 5.2V. In this design, the supply voltage was 5 Volts. The output voltage of the accelerometer changes as the supply voltage drops. Therefore to maintain a constant voltage, a 5V voltage regulator was used with a 9V battery. The regulator will allow the system to work even as the battery begins to die. The regulator can maintain 5V even as the battery voltage drops to 6V. This accelerometer is most sensitive to changes in position or tilt, when the accelerometer's sensitive axis is perpendicular to the force of gravity, or parallel to the earth's surface. Similarly, when the accelerometer's axis is parallel to the force of gravity, or perpendicular to the earth's surface, it is least sensitive to changes in tilt. In this design only one axis was used.

2.2.1.2 Measuring the Accelerometer Output. The output of the accelerometer, which is a voltage, was measured by rotating the accelerometer at every 10-degree angle. The angles were considered by hanging a weight on a string and suspending it in the direction of gravity, the angle in the direction of gravity was considered as 90 degrees and the direction perpendicular to gravity was considered as 0 degrees. A protractor was placed in such as way that the 90 degrees on the protractor coincides with the string, which is in the direction of gravity. When there is a change in the orientation of the accelerometer, the output voltage of the accelerometer changes. The output of the accelerometer is a voltage, which is proportional to angle. Using LabVIEW, a software program was written that accepts the voltage at the accelerometer through an analog to digital converter (the DAQ card) and then converts the voltage back into an angle.

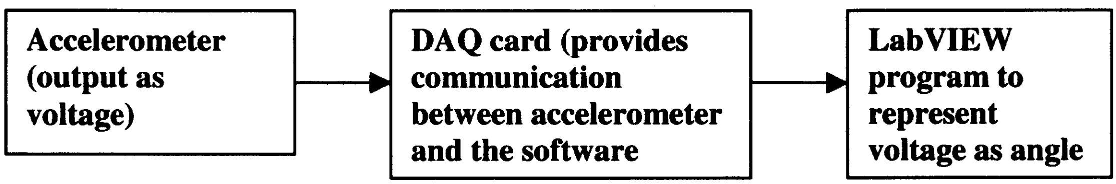

Figure 2.6 Block diagram that shows the conversion of the sensor output voltage to angle.

The accelerometer rotation was made in both the X-axis and the Y-axis. When rotating the accelerometer along the X-axis, the acceleration at the X-axis output (i.e. at A_{outx}) was zero and the Y-axis output (i.e. at A_{outy}) was changing. Similarly when rotating the accelerometer along the Y-axis, the acceleration at the X-axis output was changing and the Y-axis output was zero. The output of the accelerometer at every 10 degrees rotation in the Y-axis direction is shown in Table 2.2.

It is seen that the voltage is the same at 10 degrees and 170 degrees, 20 and 160, 30 and 150 and so on. It is also the same at 190 and 350 degrees, 200 and 340 degrees and so on. The output voltage numbers are the same in the 0 to 180 degrees and 180 to

360 degrees ranges except the voltage is negative in the 180 to 360 degrees range. The values in Table 2.2 were taken and a graph was plotted using Microsoft excel to see the graphical response of the accelerometer output versus angle. Using excel a formula that fits the transfer function was generated. This formula was used in the LabVIEW programming to calculate the angle in real time. The graphical response of the accelerometer output versus angle is shown in Figure 2.7. In this experiment the values from 0 to 90 degrees and from 180 to 270 degrees were taken since the others values are the same. The graphical response taking the accelerometer output values in 0 to 90 degrees range and 180 to 270 degrees range and the formula obtained are shown in Figure 2.8.

Table 2.2 Accelerometer Response

Xout (in volts)	Angle	Xout (in volts)	Angle
2.5	0	2.5	180
2.6736	10	2.3263	190
2.842	20	2.1579	200
3	30	2	210
3.1427	40	1.8572	220
3.266	50	1.7339	230
3.366	60	1.6339	240
3.4396	70	1.5603	250
3.4848	80	1.5159	260
3.5	90	1.5	270
3.4848	100	1.5159	280
3.4396	110	1.5603	290
3.366	120	1.6339	300
3.266	130	1.7339	310
3.1427	140	1.8572	320
3	150	2	330
2.842	160	2.1579	340
2.6736	170	2.3263	350
2.5	180	2.5	360

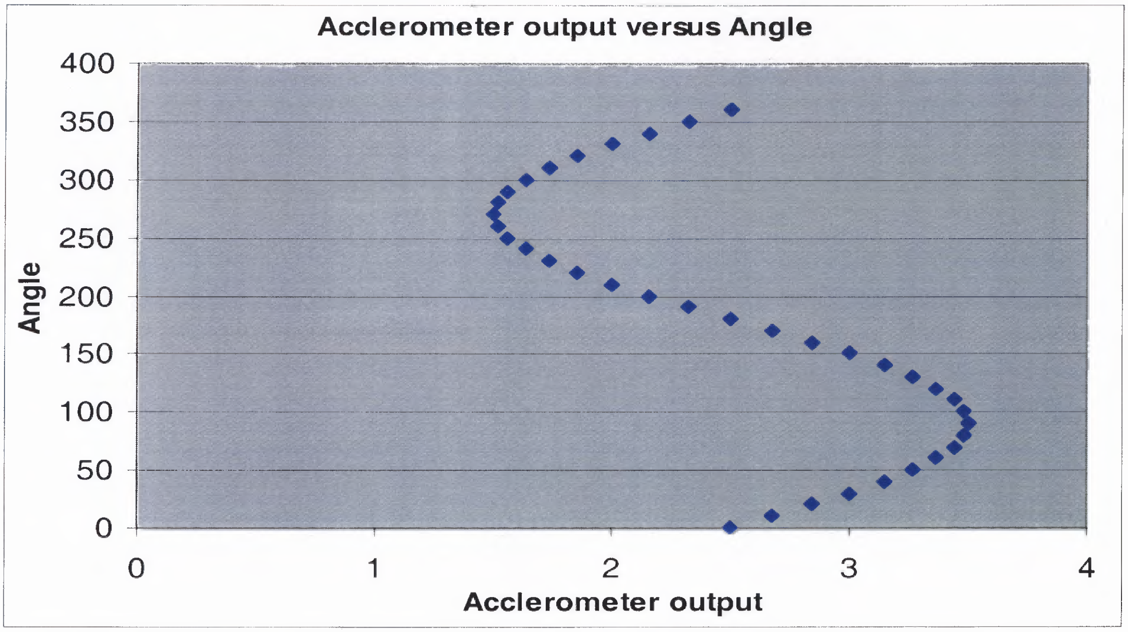

Figure 2.7 Accelerometer output versus angle for 360 degrees.

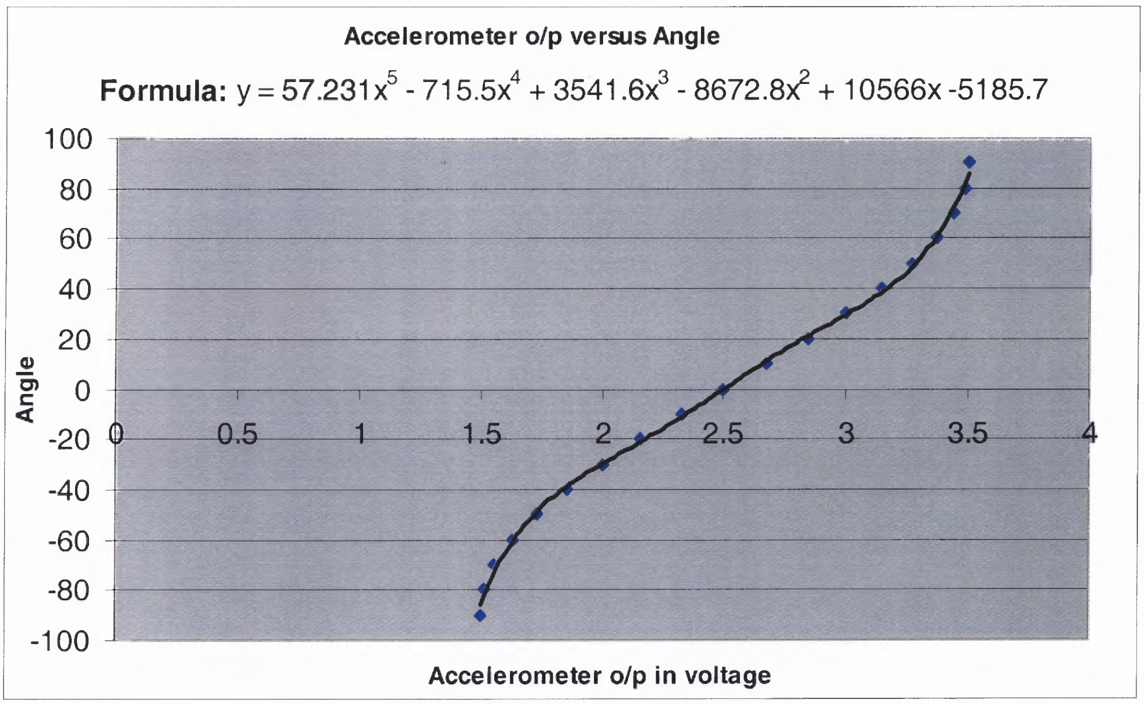

Figure 2.8 Accelerometer output versus angle (from 0-90 and 180-270 degrees).

2.3 Software Development

2.3.1 LabVIEW PDA

The major part of the project was concerned with creating a program with the software parameters that were ideal for measuring the body position and displaying it. The program was written using the LabVIEW PDA version for data acquisition and to store and display the data in the pocket PC. The reason for using the LabVIEW PDA version was because a pocket PC (also known as PDA) was used. The pocket PC stores the recorded data in a file. LabVIEW provides the tools optimized for PDA-based measurement applications and optimized for memory usage. There is difference between the VIs used in LabVIEW and the VIs used in the LabVIEW PDA version. One VI in the LabVIEW PDA does the work done by three or more VIs in regular LabVIEW. The reason for this is due to the pocket PC memory. National Instruments is still trying to decrease the VIs so that less memory can be used for the program. The National Instruments LabVIEW PDA Module extends LabVIEW development to applications for handheld devices. With the LabVIEW PDA module, one can develop a program in LabVIEW and easily download applications to small, portable pocket PC targets. The National Instruments (NI) LabVIEW PDA Module automatically compiles VIs to run on selected pocket PC targets and downloads the completed application to the pocket PC. The LabVIEW PDA Module modifies the LabVIEW environment to make it easier to build flexible and powerful applications on the pocket PC, and adds new technology to LabVIEW to optimize applications to run on the smaller memory space and unique processors that are common to pocket PC's [21].

2.3.2 Software Development/Design

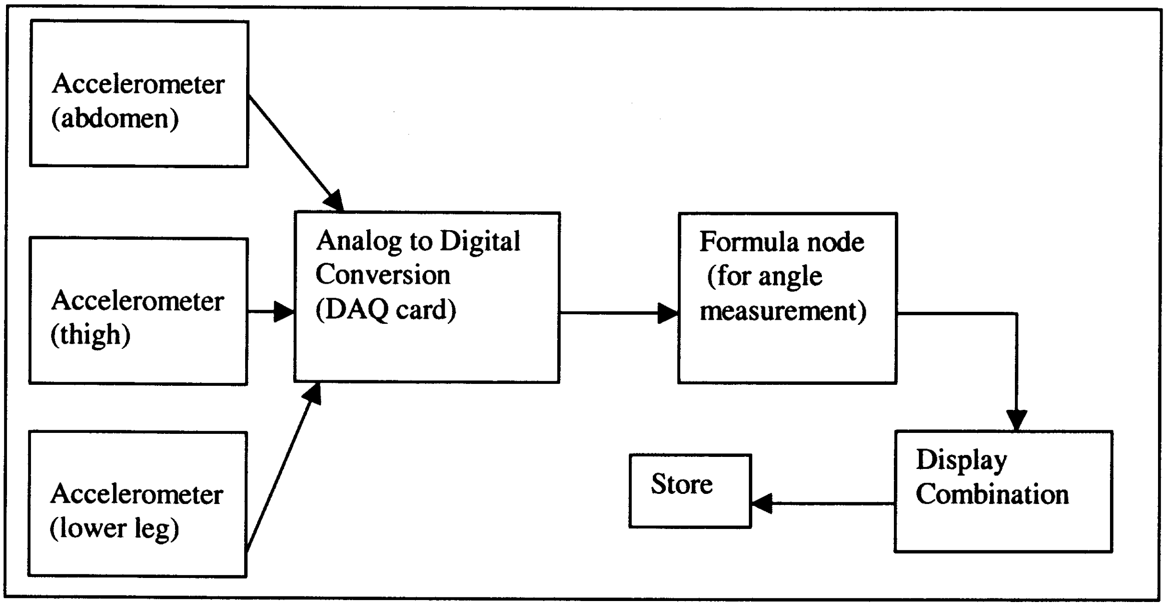

Figure 2.9 Block Diagram of the Software Design.

Figure 2.9 shows a synopsis of the software design. The output of the three accelerometers was fed to an analog to digital converter, which is the DAQ 6024E card in this study. NI DAQ 6024E PCMCIA card was used to interface the accelerometers and the PDA. The DAQ 6024E features 16 channels of analog input, two channels of analog output, a 68-pin connector and eight lines of digital I/O. The 6024E series DAQ card is placed in the expansion pack of the pocket PC.

The output data collected from the accelerometers was sent to the formula node to calculate the angle. The output of the accelerometer is voltage; this voltage was converted into angle for easy calculations. The data was then displayed. The displayed data was a text representing standing, sitting or lying positions. This representation was done by performing more calculations and with the help of the VIs. The data collected was stored in the pocket PC along with the data and time it was recorded.

The software program starts by initializing communication to the hardware. “DAQmx base start” VI was used in the beginning of the program. In this VI the task to be performed was indicated. A task that is suitable for one’s own application can be selected from the tasks listed in the “DAQmx base start” VI. In the “DAQmx base start” VI the channels to be read, the number of samples per channel and the scan rate was set. Three channels were used for this system. The first channel reads the output from the accelerometer placed on the trunk of the body (abdomen), the second channel reads the output from the accelerometer placed on the upper leg (thigh) and the third channel reads the output from the accelerometer placed on the lower leg. The scan rate was given as five. The reason for selecting five as scan rate is because if we increase the scan rate to 10, the program was collecting four samples per second. Since one sample per second is enough for this pilot and storing one sample per second does not take much space, the scan rate was given as five. The output of the “DAQmx base start” VI was given to the “DAQmx base Read” VI. The “DAQmx base Read” VI reads the analog data. It reads one or more floating-point samples from a task that contains one or more analog input channels. This VI can also read the digital data. The instances of this polymorphic VI specify what format of samples to return, whether to read a single sample or multiple samples at once, and whether to read from one or multiple channels. The program for data acquisition is shown in Figure 2.10.

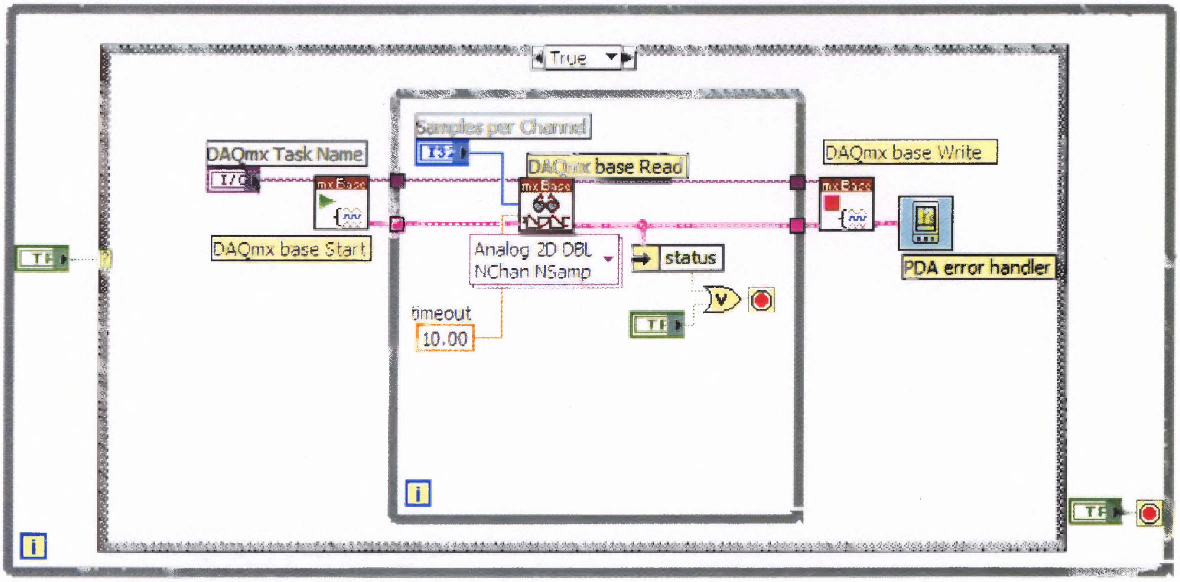

Figure 2.10 The block diagram of the data acquisition process in LabVIEW.

The second step of the program was to represent the output voltage of the accelerometer as an angle, which was done using a formula node. The output voltage of the accelerometer was measured for each 10-degree angle. Graph that represents the relation between the voltage and the angle was obtained using Microsoft excel. This formula was written in the formula node. The next step of the program was to round up the angle values for easy representation. For example, if the output from the formula node is 83.2, it was rounded off to 80 degrees. This step was used to save the memory of the pocket PC. Then the output was given to another formula loop for representing the body position. The body position obtained was stored and displayed. In this program only three cases of posture were assumed. They are: sitting, standing and lying. In the sitting posture the output at the abdomen (trunk of the body) was 90-degrees, the output at the thigh (upper part of the leg) was 0-degrees and the output at the lower leg was 90-degrees. In the standing posture, the outputs at the abdomen, thigh and lower leg are 90, 90, 90-

degrees respectively. In the lying posture, the output at every accelerometer was 0-degrees as shown in Figure 2.11.

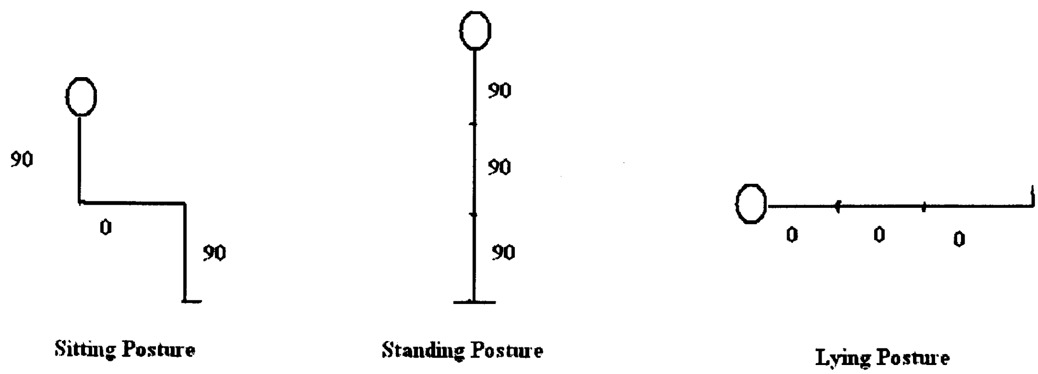

Figure 2.11 Angle representation at different positions.

There are many postures that come under standing, sitting and lying. The different body positions that occur in normal daily life were taken into consideration. These cases fall either in standing, sitting, lying positions. For example, if a person sits relaxed with his/her legs on a table or ottoman, the posture was shown as sitting.

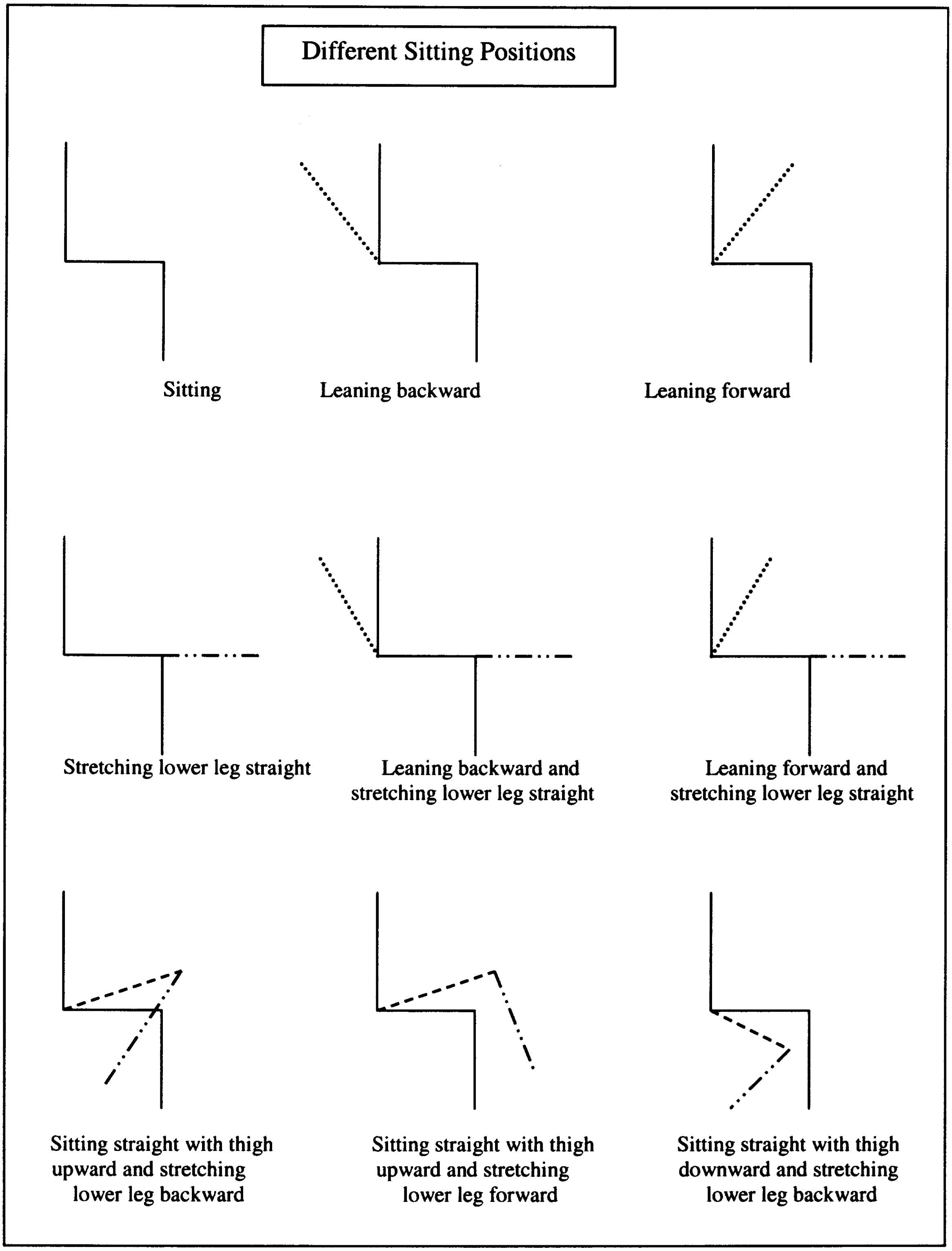

Figure 2.12 Different sitting positions.

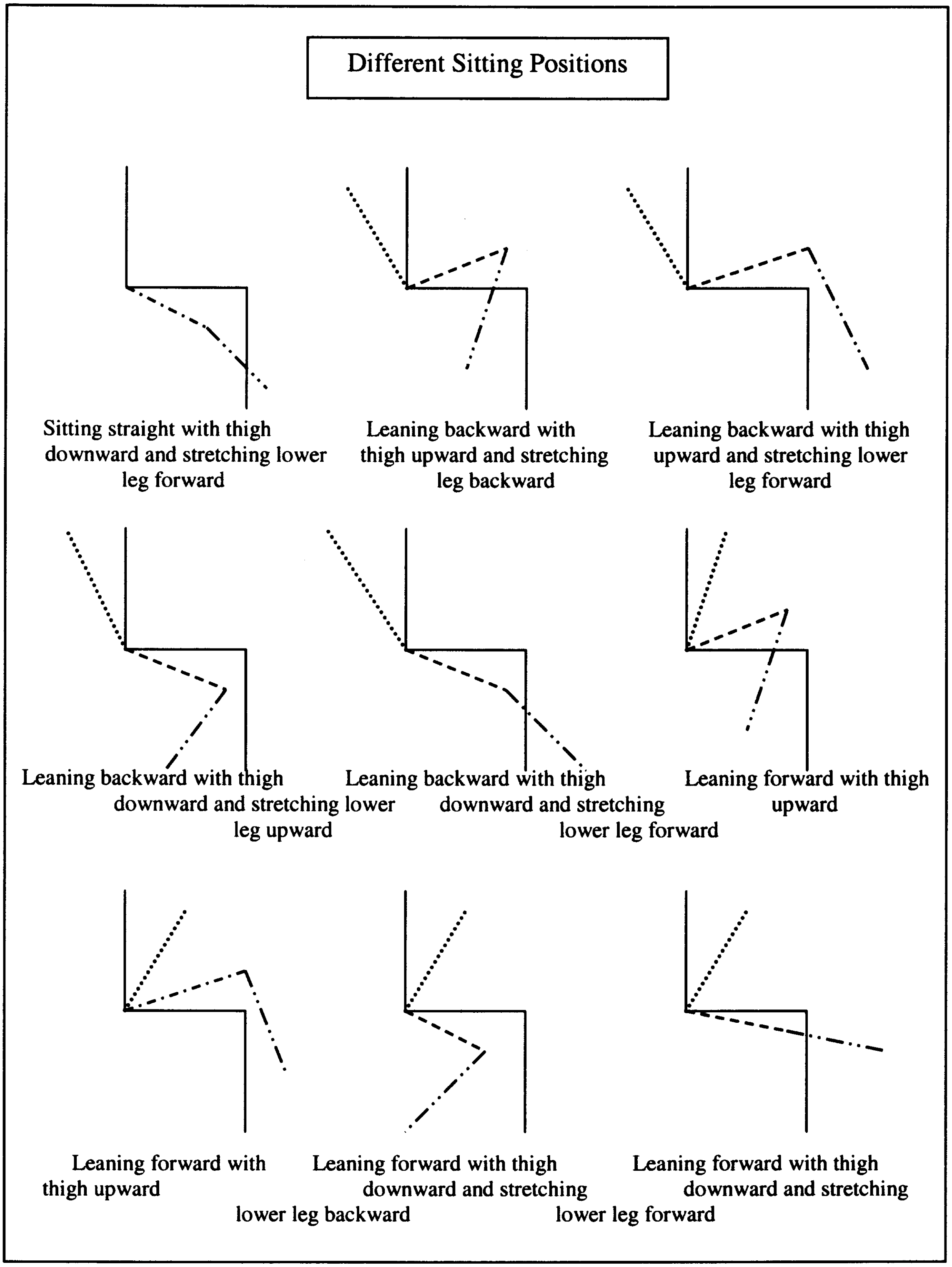

Figure 2.13 Different sitting positions (continued).

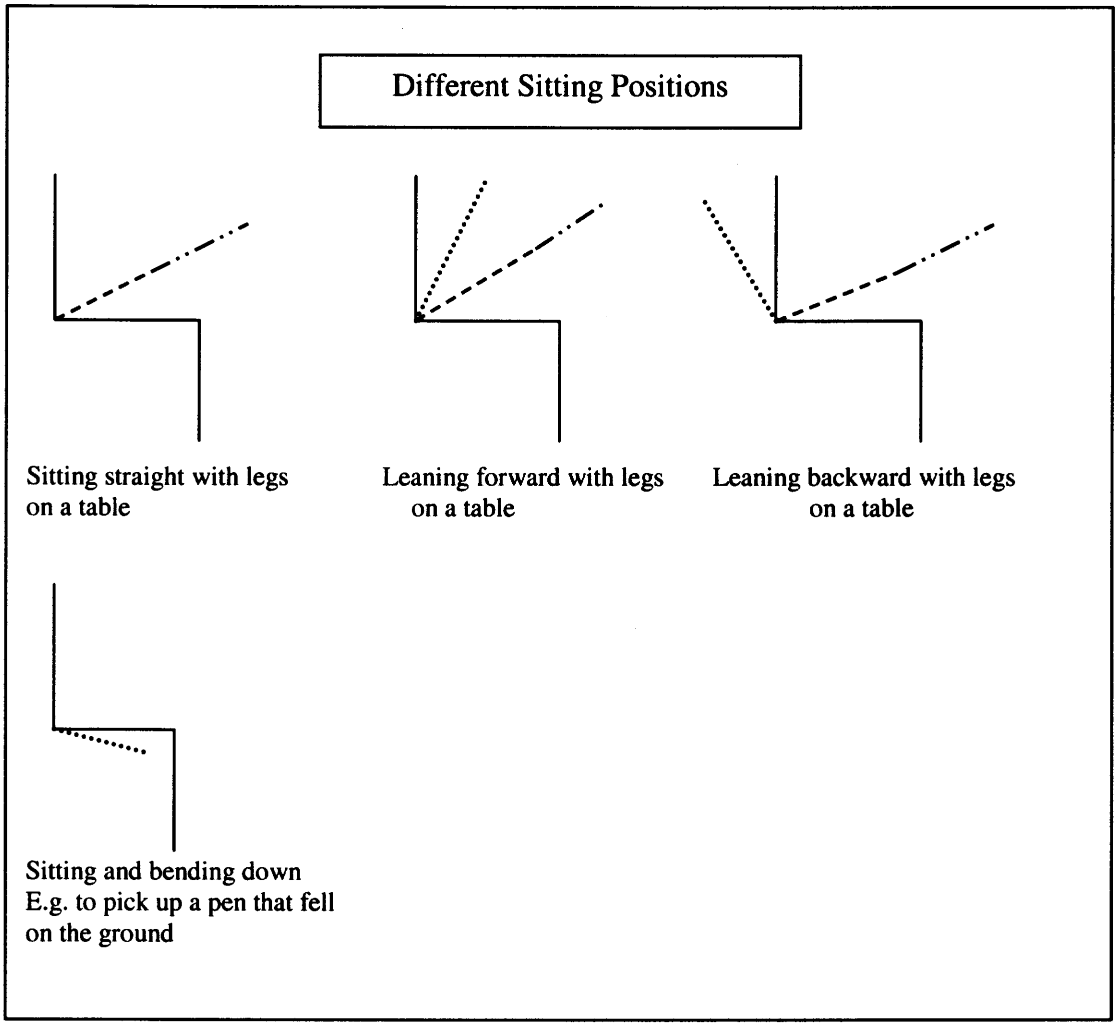

Figure 2.14 Different sitting position (continued).

Considering all the cases, a program was written that only displays standing, sitting or lying. All the cases that were taken into consideration are explained below in detail. Care was taken to consider all the cases that happen in daily life. The positions that were considered are shown below along with diagrams in Figure 2.12, Figure 2.13, Figure 2.14, Figure 2.15 and Figure 2.16.

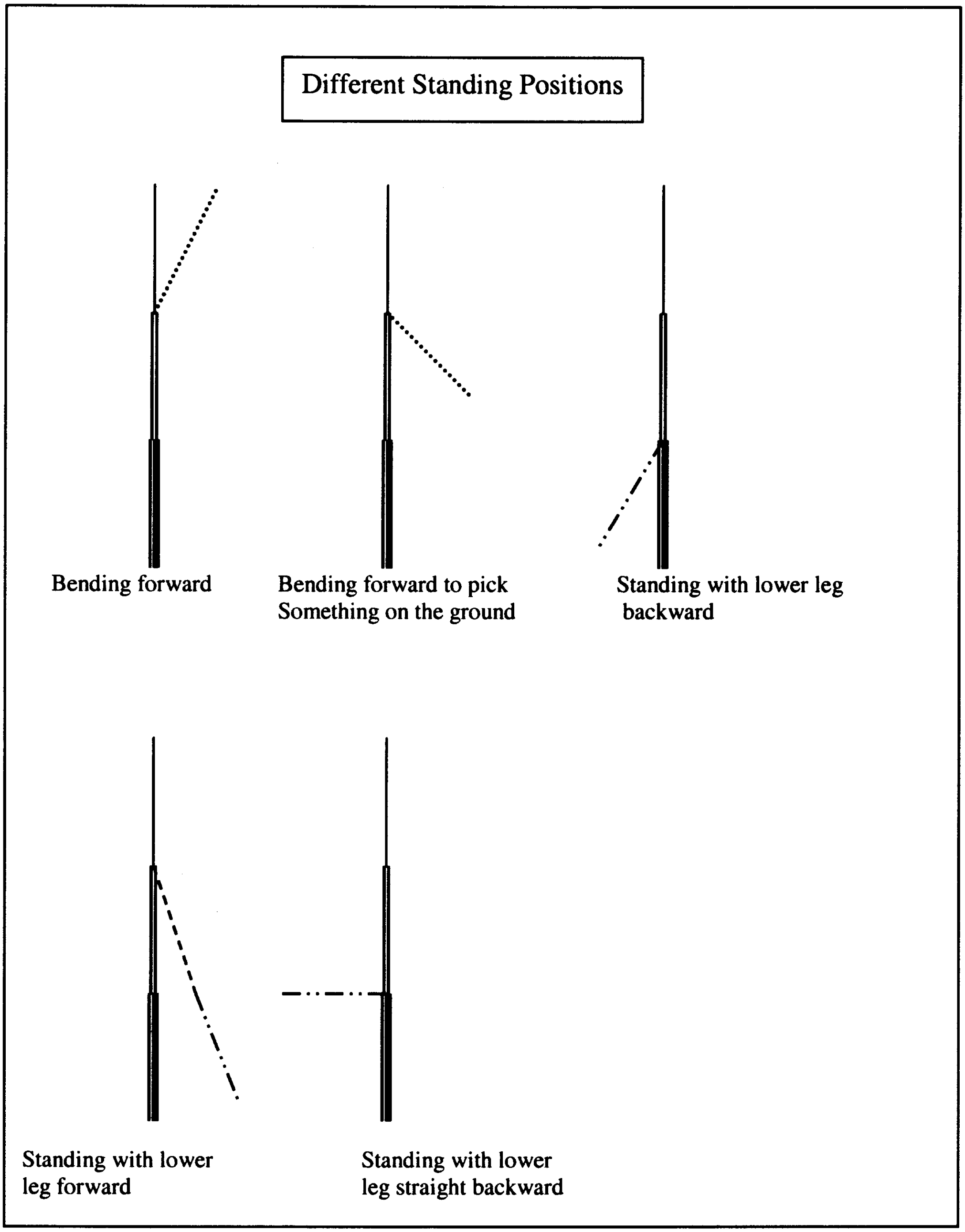

Figure 2.15 Different standing positions.

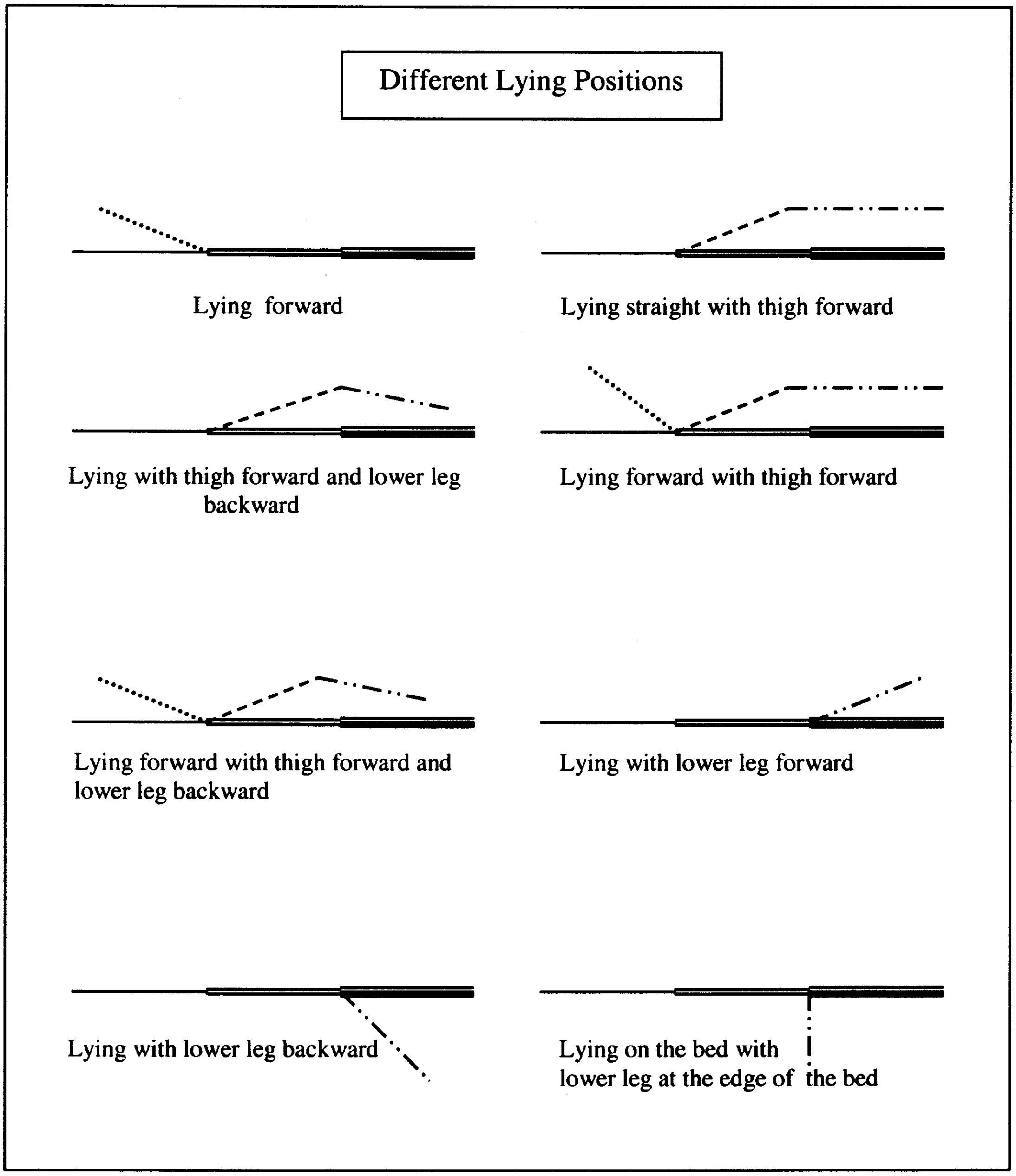

Figure 2.16 Different lying positions.

Considering the angle at each position, a range was given at each position. The ranges are defined in the formula loop. The first block in Figure 2.17 shows the ranges. In the first block "a" is the sensor on the trunk of the body, "b" is the sensor on the upper part of the leg and "c" is the sensor on the lower part of the leg.

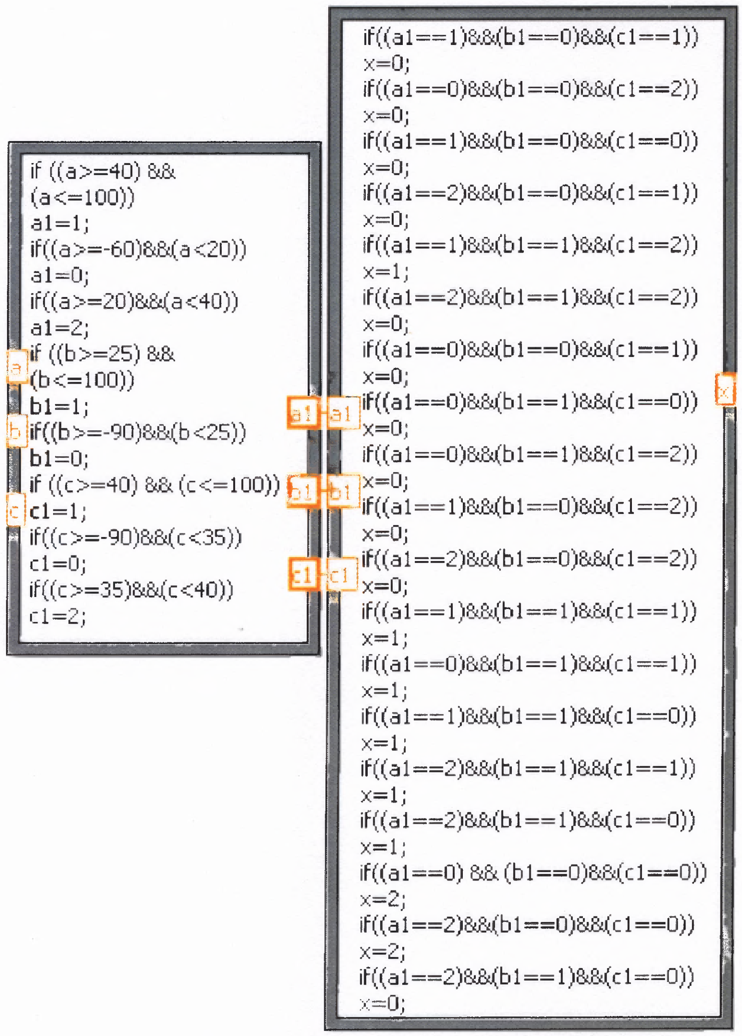

Figure 2.17 Ranges and conditions defined in the program.

After defining the ranges, conditionals when the three sensors are in a particular range are defined. In the second block of Figure 2.17, "x=0" was represented as "sitting", "x=1" was represented as "standing", "x=2" was represented as "lying" and "x=3" was represented as "not known". Displaying the case as a text was obtained using a case structure. So if x=0, the program will take the case 0, which is sitting and will display "sitting" as output as shown in Figure 2.18. This output is seen on the pocket PC screen and is also stored. If x=1, the program will take the case 1, which is defined as standing and will display "standing" as output. In the similar fashion, the other cases are defined as shown in Figure 2.18.

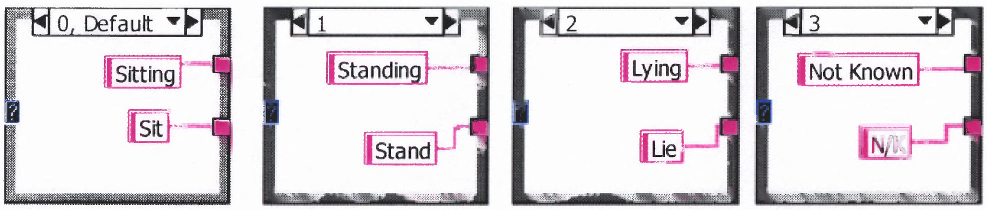

Figure 2.18 Case structures at each case.

Then the last task was to store the data along with date and time. The date and time was obtained using "get date and time" VI. This VI gives the date and the time as on the pocket PC. Then the data was stored along with date and time in a file. The data was stored using the VI's "new file", "write file" and "close file". First the file name should be given. A block will be seen on the pocket PC that asks for a file name and one has to enter the file name in that block. Then the data is written into that file using the "write file", after the data is written into a file, the file should be closed using "close file". The "new file" and "close file" should always be outside the loop of the "write file" loop. If it is in the same loop as the "write file", each time the loop runs, it will be asking for a file name and stores in a different file each time the loop runs. The program for defining the angle, ranges, conditions, data, time and storing them in a file is shown in Figure 2.19.

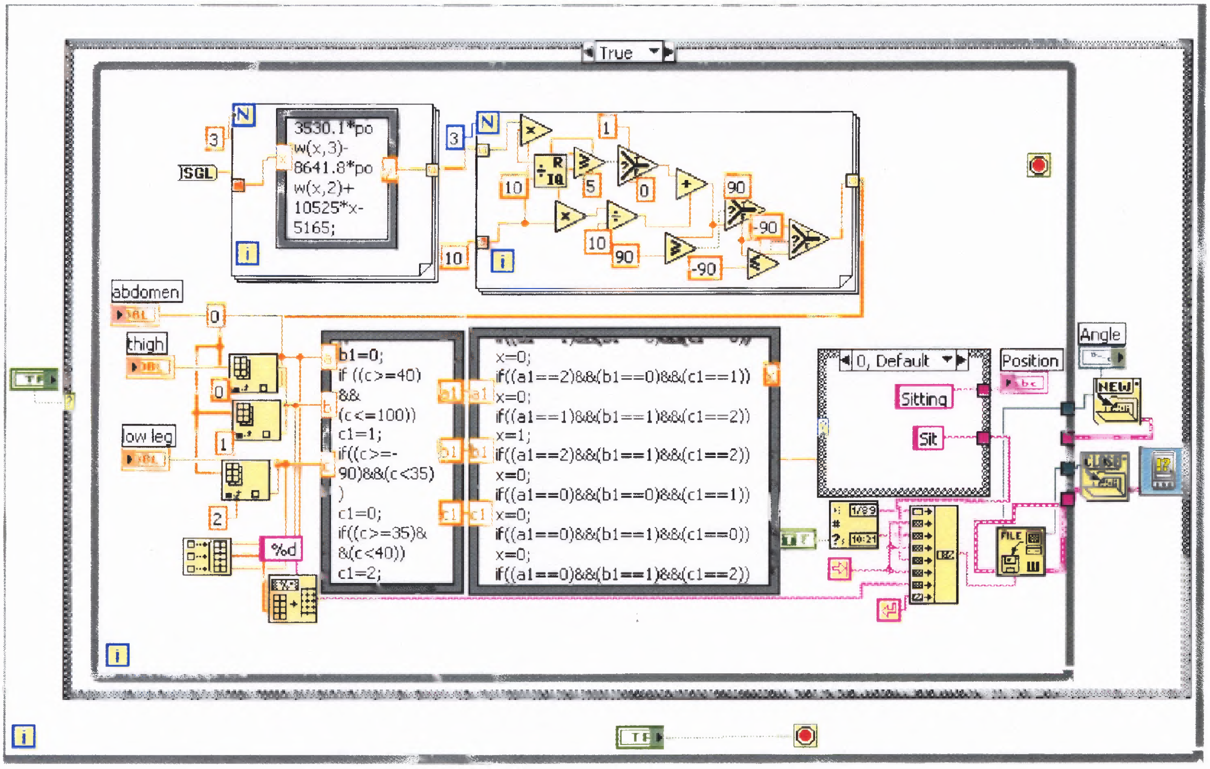

Figure 2.19 Block diagram for representing angle, ranges and conditions and storing in a file.

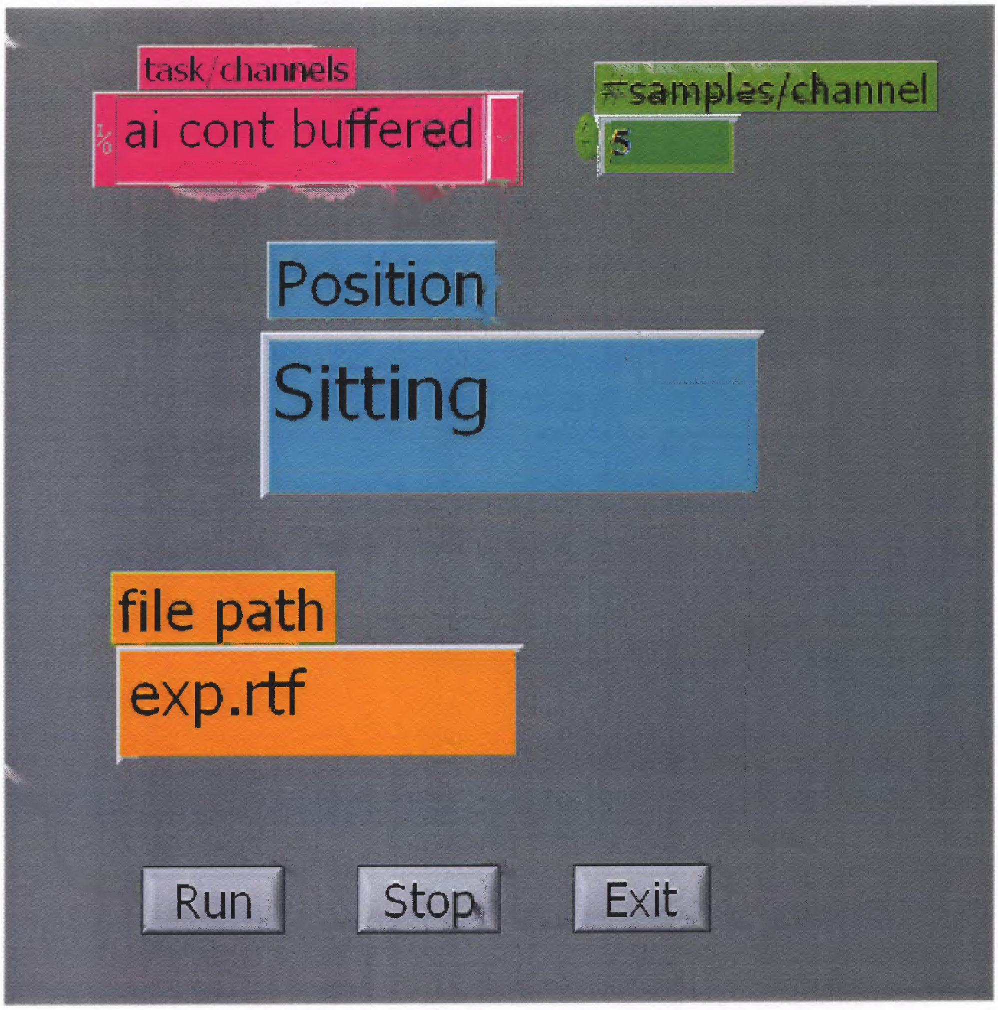

Figure 2.20 The front panel of the program and the pocket PC.

The front panel of the LabVIEW program and the display screen of the pocket PC is shown in Figure 2.20.

CHAPTER 3

EXPERIMENTAL PERFORMANCE

3.1 Hardware Testing

3.1.1 Accelerometer Testing

The accelerometer was tested in different places like in a car, in an elevator, near a refrigerator, near a microwave. This test was performed to check whether gravity has an effect on the accelerometer. With this test we can know how the output of the accelerometer is changing in different situations.

Three accelerometers were placed on a ridged frame; each accelerometer was set to a particular initial angle. One accelerometer was set to 90 degrees, other was set to 50 degrees and the last was set to 0 degrees. The ridged frame was assumed as a subject and was tested in different environments like driving a car, going up and down the elevator, standing near a microwave and standing near a refrigerator. A rigid frame was used to check whether the change in the accelerometer output was due to the above environments or due to moments (the rigid frame cannot move when driving, whereas subjects can move when driving). The results obtained in these environments are shown in Figure 3.1, Figure 3.2, Figure 3.3, Figure 3.4 and Figure 3.5. The rigid frame was placed in front of the microwave and refrigerator with their power turned on. As seen in the figures, the accelerometer output did not change when standing near a microwave or near a refrigerator, but there was a change to be seen when driving and when in an elevator.

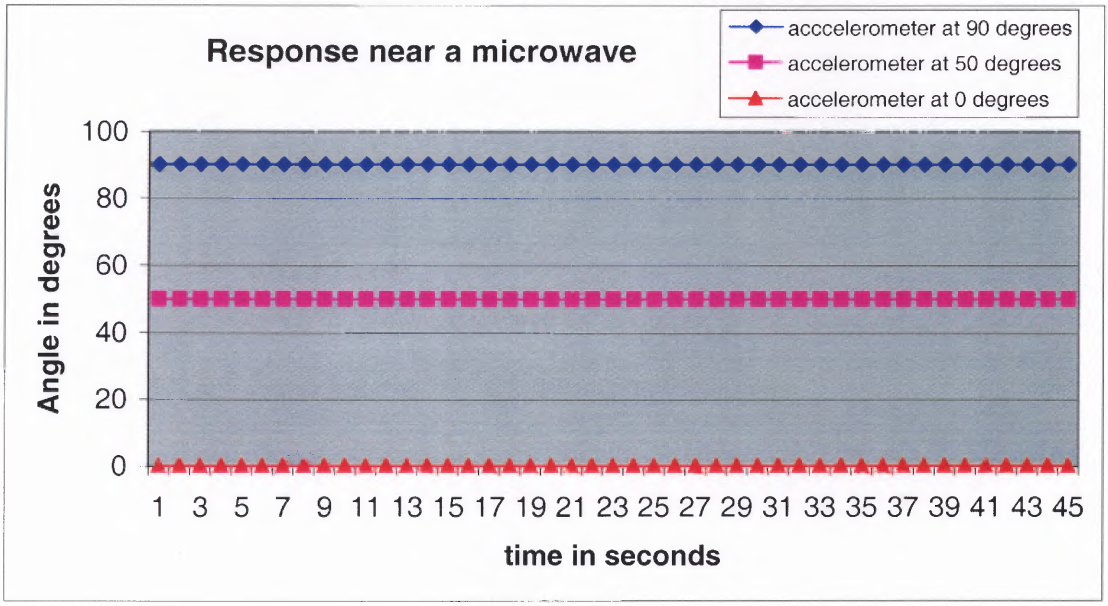

Figure 3.1 Response near a microwave.

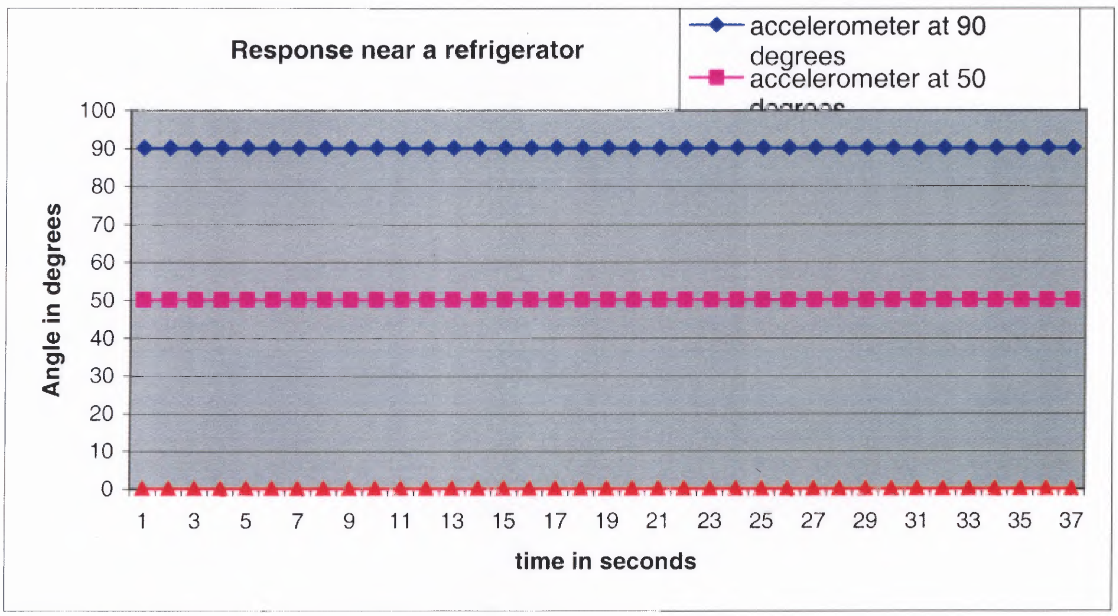

Figure 3.2 Response near a refrigerator.

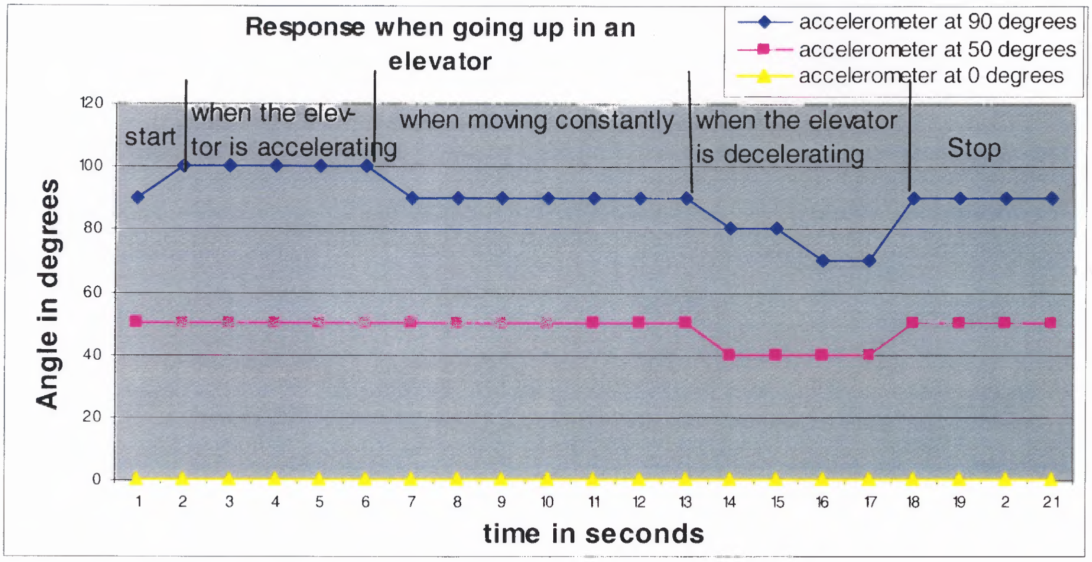

Figure 3.3 Response when going up in an elevator.

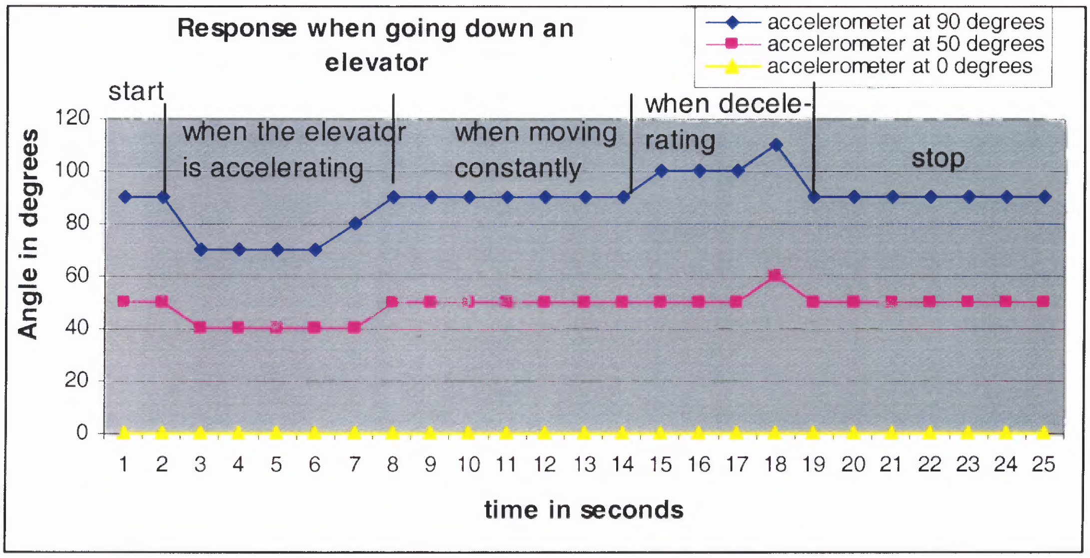

Figure 3.4 Response when going down in an elevator.

As seen in Figure 3.3 and 3.4, when in an elevator, there is no change in the output when the accelerometer is at 0 degrees. Since, 0 degrees is perpendicular to gravity, it is not affected whereas, the other accelerometers are affected by 10 or 20 degrees because they were moving in the direction of gravity or against the direction of gravity. The change in the output angle is constantly increasing and decreasing.

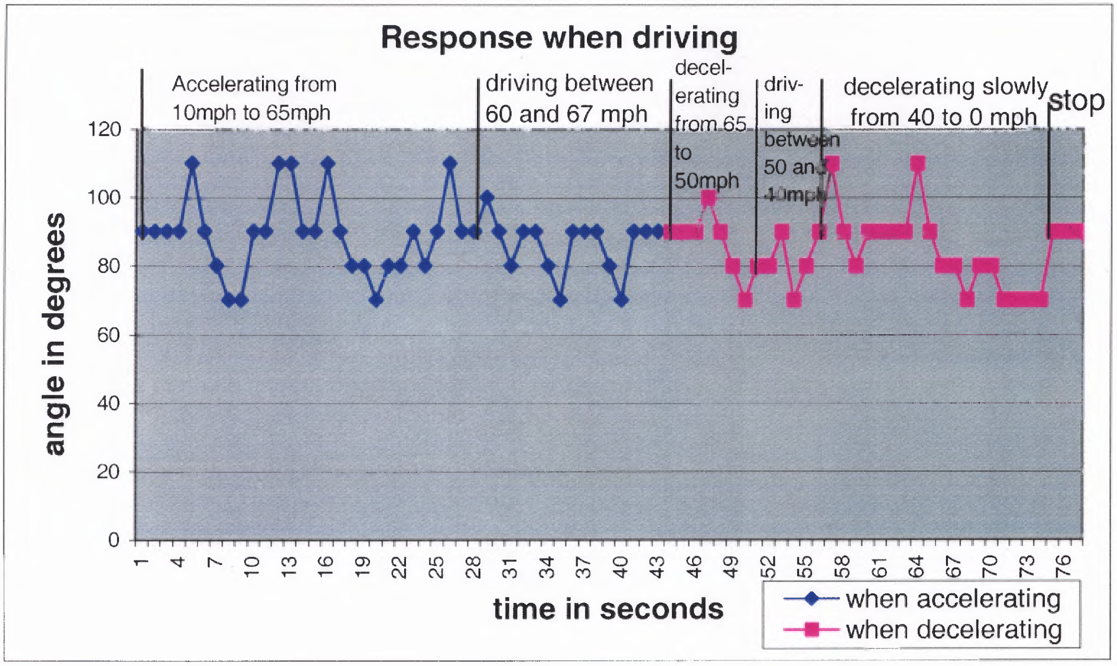

Figure 3.5 Response when driving.

The results of acceleration and deceleration when driving are shown in Figure 3.5. It was known from these results that the accelerometer output is changing when accelerating or decelerating the vehicle. The output of the accelerometer at 90 degrees was randomly increasing or decreasing by 20 degrees when driving as shown in Figure 3.5. The output was changing because the direction of acceleration or deceleration of the vehicle is perpendicular to gravity. The output of the accelerometer at 50 degrees and 0 degrees did not change during acceleration and deceleration of the vehicle. The change was because the acceleration or deceleration of the vehicle is perpendicular to gravity but not because of the interference of the electronics in the vehicle because when the vehicle is constant and turned on, there was no change in the angle.

To overcome the error in the accelerometer caused by the above results, a program was developed so that the output will be shown as desired (that is the output will be displayed as standing when standing in an elevator, even though the output increases and shows sitting when driving).

3.1.2 Voltage Regulator

A fixed +5V voltage regulator 7805, used to regulate 5 volts voltage to the accelerometer, was tested to see the maximum and the minimum input voltage the regulator can hold to provide 5 volts voltage output. It was found that the minimum voltage that should be supplied to the voltage regulator to output 5 volts was 6 volts and the maximum was 35 volts. If the input voltage to the regulator is less than 6 volts, the output of the regulator falls below 5 volts.

3.2 Software Testing

The software testing process involved checking whether the "DAQmx base Read" VI was reading the output of the accelerometer correctly and also checking displays and recordings on the pocket PC with the position. The mathematics in the program was also checked to verify that they were working correctly. Each of these parts was tested separately to make sure that they were functioning correctly.

CHAPTER 4

RESULTS

Five healthy control subjects, two males and three females with ages ranging from 22 to 35 years were asked to participate in this experiment. All subjects were asked to wear the sensors, one on the abdomen, one on the thigh and one on the lower leg. The subjects were asked to sit, stand and lie down in different possible positions as shown in Table 4.1 Detailed results of one subject with graphs at each position are shown in Figures 4.1, 4,2, 4.3, 4.4, 4.5, 4.6 and 4.7.

Table 4.1 Different Positions

	Different Sitting Positions		**Different Standing Positions**
1	Sitting straight	14	Standing straight
2	Sitting and leaning forward	15	Standing and bending forward
3	Sitting straight with one leg on the other	16	Standing and bending backward
4	Sitting and leaning forward with one leg on other	17	Standing and stretching the leg forward
5	Sitting straight and bending leg backwards	1	Standing and stretching the leg backward
6	Sitting and leaning forward by bending leg downwards	19	Standing and stretching the lower leg backward
7	Sitting straight and stretching leg forward	20	Walking fast
8	Sitting and leaning forward by stretching leg forward	21	Walking slow
9	Sitting straight and keeping legs on ottoman	22	Walking down stairs
10	Sitting and leaning forward by keeping legs on an ottoman	23	Walking up stairs
11	Sitting straight and keeping legs on a table		**Different Lying Positions**
12	Sitting and leaning forward by keeping legs on a table	24	Lying straight
13	Sitting and bending to pick up something on the floor	25	Lying folded
		26	Lying on one side
		27	Lying on the belly

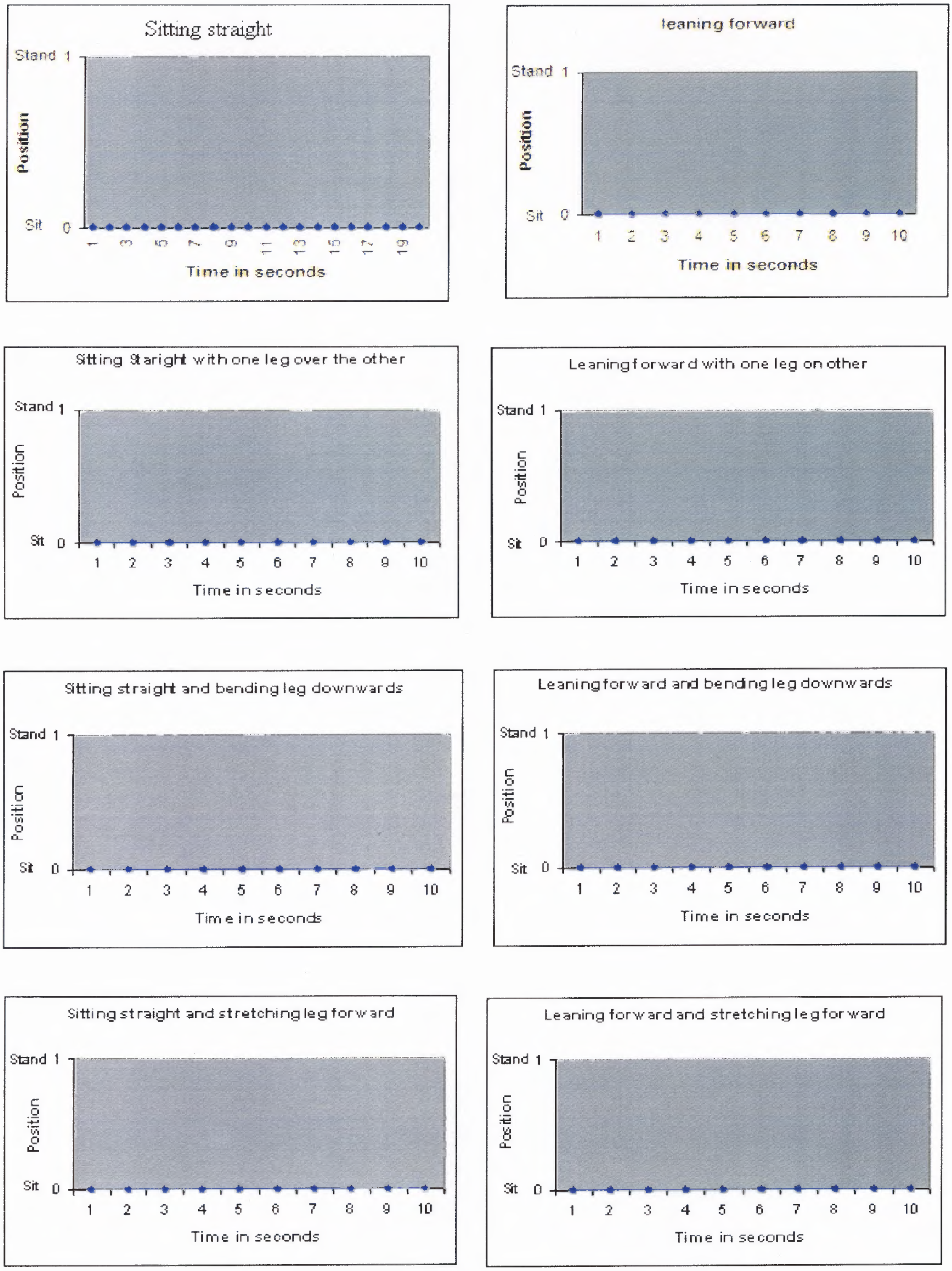

Figure 4.1 Results obtained during different activities.

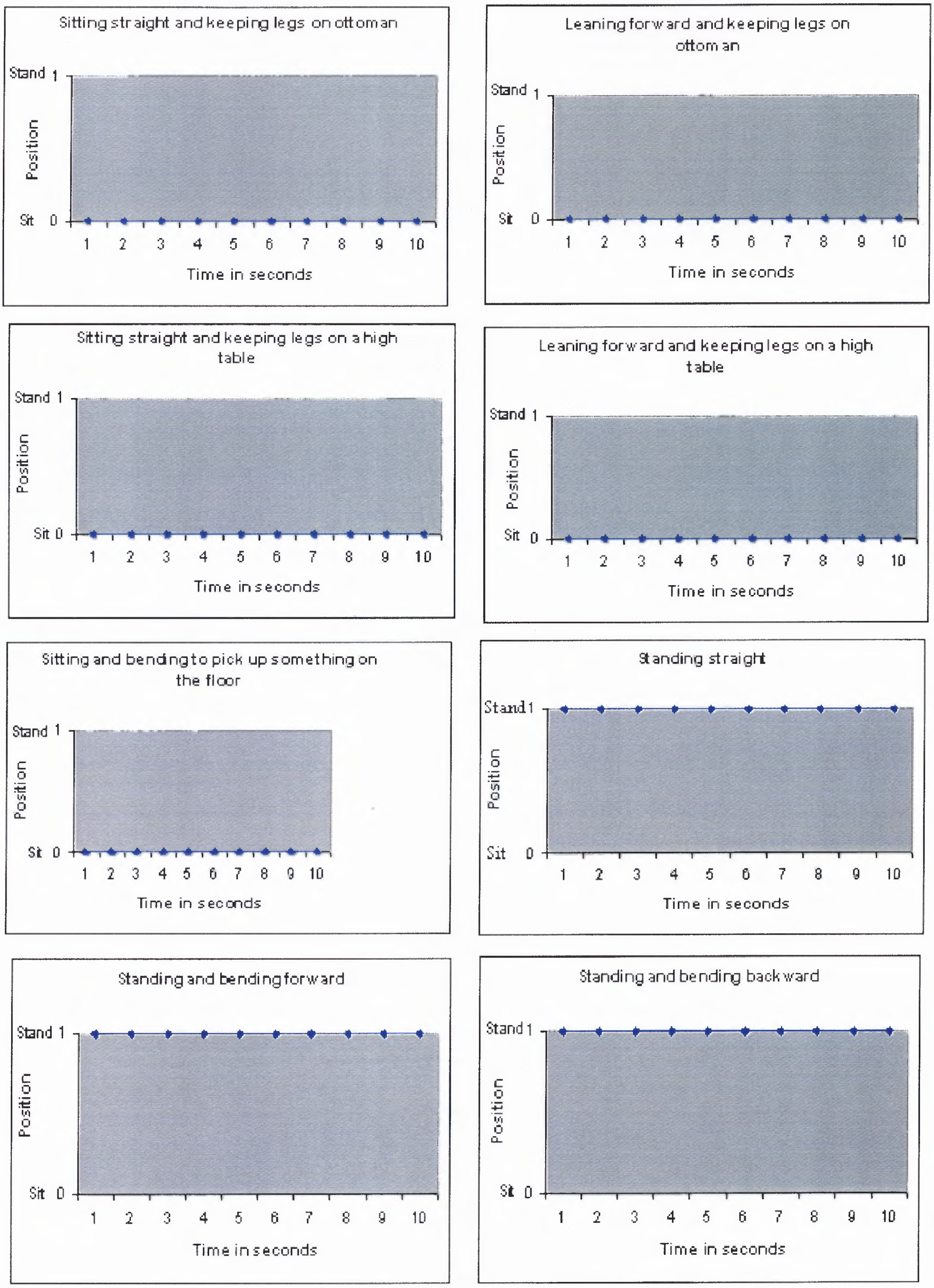

Figure 4.2 Results obtained during different activities (continued).

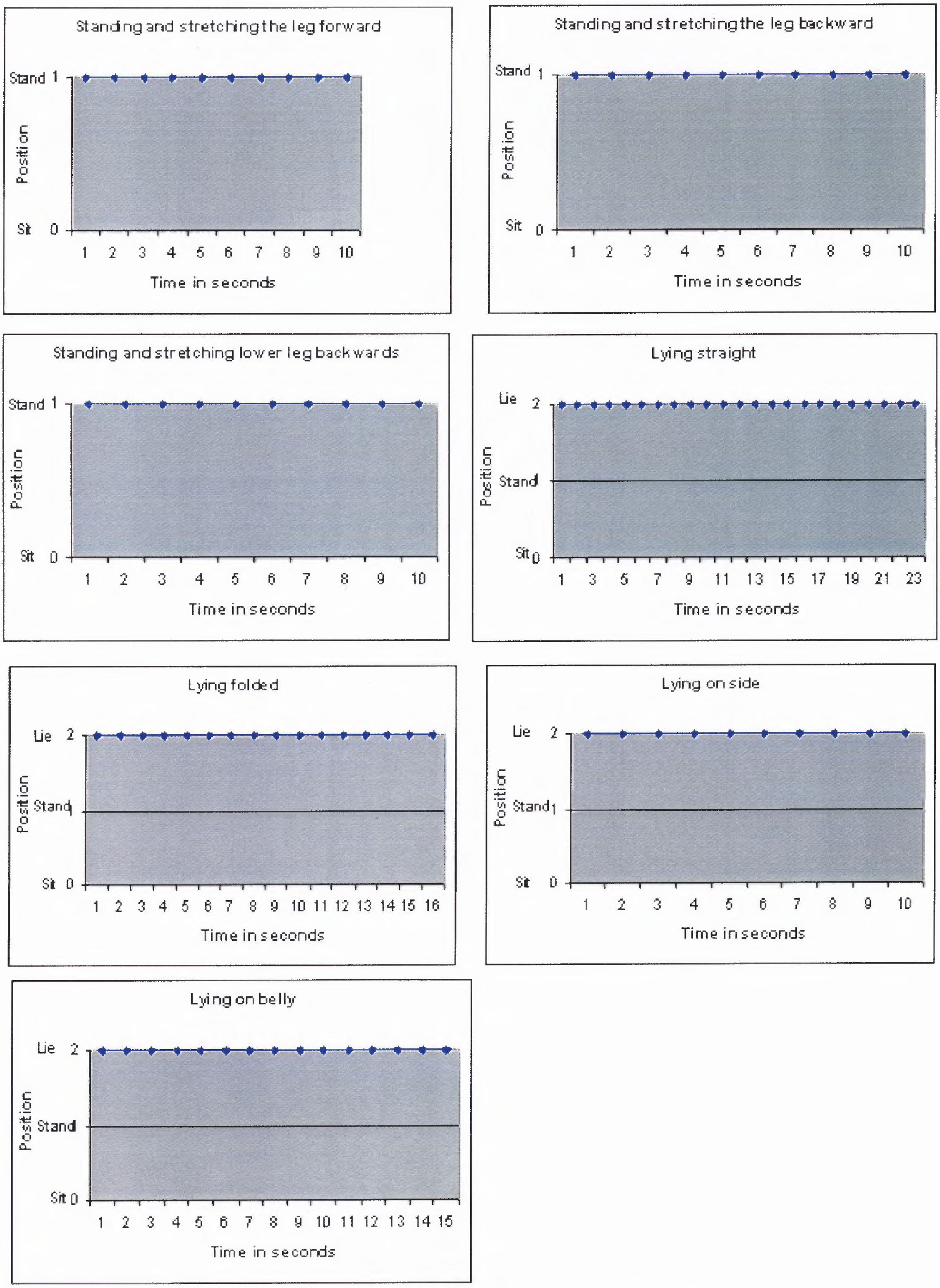

Figure 4.3 Results obtained during different activities (continued).

From the above results it seen that the device worked properly as programmed. In all the different sitting positions output was sitting, for all the different standing positions the output was standing and for all the different lying positions the output was lying. The data was 100 % accurate for all the above results. It is 100% accurate because there were no errors in the collected data. The accuracy was calculated using the Equation 4.1

$$\text{Accuracy of the data} = (\text{good data points}/\ \text{total data points})^{*}\ 100 \tag{4.1}$$

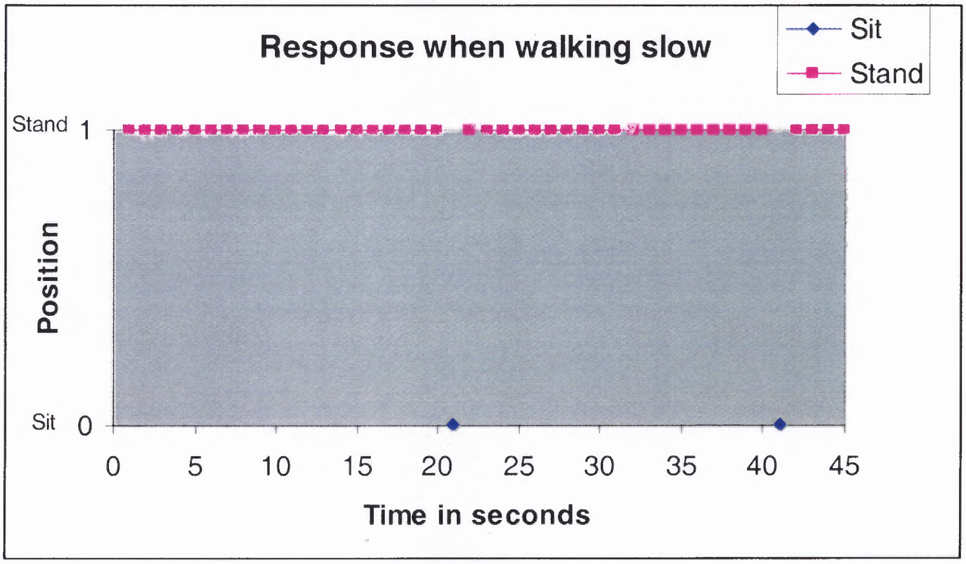

Figure 4.4 Results obtained when walking slowly.

Figure 4.4 shows the results when walking slowly for 45-seconds. As seen in Figure 4.4 there are some errors (points that show sit) when walking slowly. These errors are caused because when walking, at some points, the angles of all three sensors are the same as the angles when sitting. When walking by lifting the thigh high these errors are seen. As discussed in Subsection 2.2.1.2 the errors occurs because the voltages are the same in 0 to 90, 90 to 180 degrees ranges and also the same in 180 to 270 and 270 to 360 degrees ranges. The output voltage of the accelerometer is the same at: 10 degrees and

170 degrees, 20 degrees and 160 degrees and so on. This is the reason for getting errors in the data.

Figure 4.5, Figure 4.6 and Figure 4.7 show the response when walking fast, walking up stairs and walking down stairs respectively. In these figures also, we can see errors. These errors are the same as explained for walking slowly.

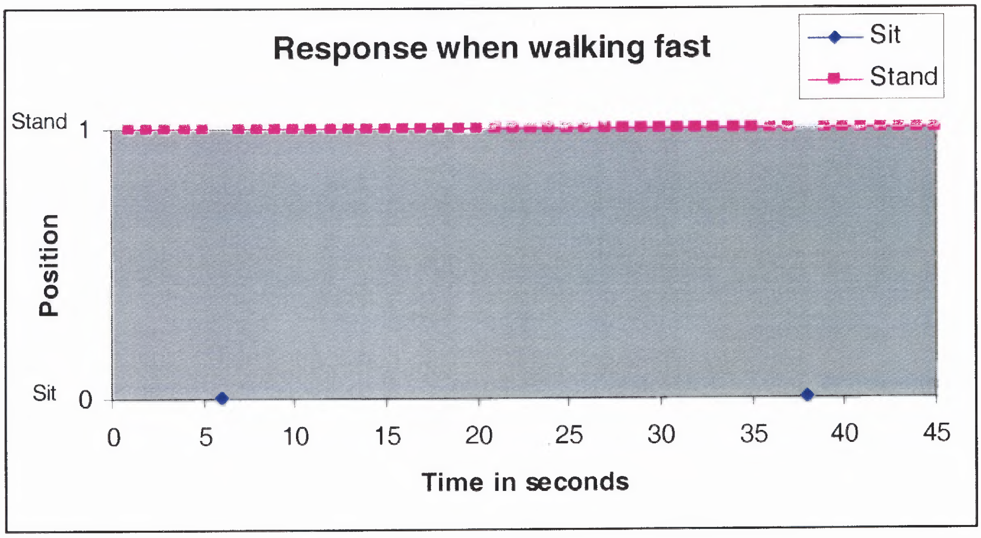

Figure 4.5 Results obtained when walking fast.

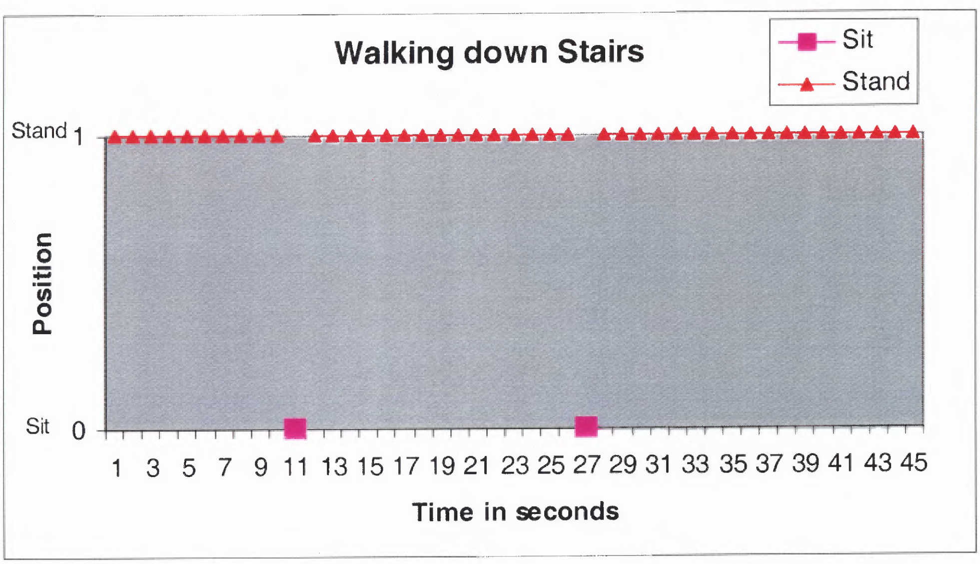

Figure 4.6 Results obtained when walking down the stairs.

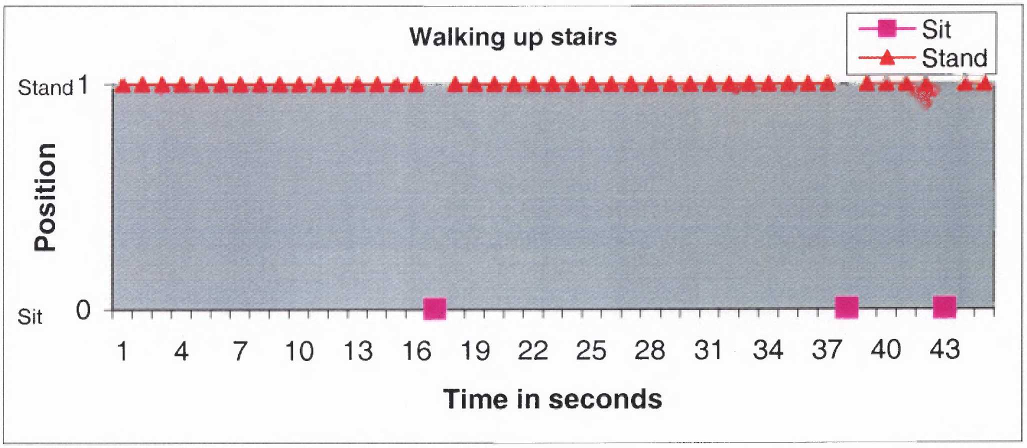

Figure 4.7 Results obtained when walking up the stairs.

The data accuracy when walking slow, walking fast, walking down stairs and when walking up stairs was calculated using Equation 4.1.

Table 4.2 Accuracy of the Activities

Activity	Total points	Subject 1		Subject 2		Subject 3	
		Good points	Accuracy	Good points	Accuracy	Good points	Accuracy
Walking slow	45	45	100%	43	95.5%	45	100%
Walking fast	45	45	100%	43	95.5%	44	97.7%
Walking up stairs	45	45	100%	43	95.5%	45	100%
Walking down stairs	45	45	100%	42	93.3%	43	95.5%

Activity	Total points	Subject 4		Subject 5	
		Good points	Accuracy	Good points	Accuracy
Walking slow	45	45	100%	45	100%
Walking fast	45	45	100%	44	97.7%
Walking up stairs	45	45	100%	44	97.7%
Walking down stairs	45	45	100%	44	97.7%

Readings during twenty-seven positions as shown in Table 4.1 were taken for the calculation of the accuracy of the system. At twenty-three positions the data was 100% accurate. When walking slow (99% accurate), walking fast (98% accurate), walking down stairs (98.6% accurate) and when walking up stairs (97.3% accurate) the data was not as accurate as other positions because when walking, some people walk with an increase in knee height from the ground and since the accelerometers angles are in the same range as when sitting with thigh up and lower leg backwards as shown in Figure 2.12. This was the reason for the system to show the output as sitting.

The results of the five subjects who participated in this experiment are shown in Figures 4.8, 4.9, 4.10, 4.11 and 4.12. The subjects were asked to assume different positions for 10 seconds except walking slow, walking fast, walking downstairs and walking upstairs, which was assumed for 30 seconds. A graph with time in seconds as the X-axis and position as the Y-axis was plotted for each subject. The task performed in a particular time is indicated in Table 4.3.

Table 4.3 Task Performed in Specific Time

Time in Seconds	Task Performed
2 to 11 seconds	Sitting straight
12 to 21 seconds	Leaning Forward
22 to 31 seconds	Sitting straight with one leg over the other leg
32 to 41 seconds	Leaning forward with one leg over the other leg
42 to 51 seconds	Sitting straight and bending leg downwards
52 to 61 seconds	Leaning forward and bending leg downwards
62 to 71 seconds	Sitting straight and stretching leg forward
72 to 81 seconds	Leaning forward and stretching leg forward
82 to 91 seconds	Sitting straight and keeping legs on ottoman
92 to 101 seconds	Leaning forward and keeping legs on ottoman
102 to 111 seconds	Sitting straight and keeping legs on a high table
112 to 121 seconds	Leaning forward and keeping legs on a high table
122 to 131 seconds	Sitting and bending to pick up something from the ground
132 to 141 seconds	Stand straight
142 to 151 seconds	Standing and bending forward
152 to 161 seconds	Standing and bending backward
162 to 171 seconds	Standing and stretching the leg forward
172 to 181 seconds	Standing and stretching leg backward
182 to 191 seconds	Standing and stretching lower leg backward
192 to 221 seconds	Walking slowly
222 to 251 seconds	Walking fast
252 to 281 seconds	Walking down the stairs
282 to 310 seconds	Walking up the stairs
311 to 320 seconds	Lying straight
321 to 330 seconds	Lying as a ball
331 to 340 seconds	Lying on any side
341 to 350 seconds	Lying on belly

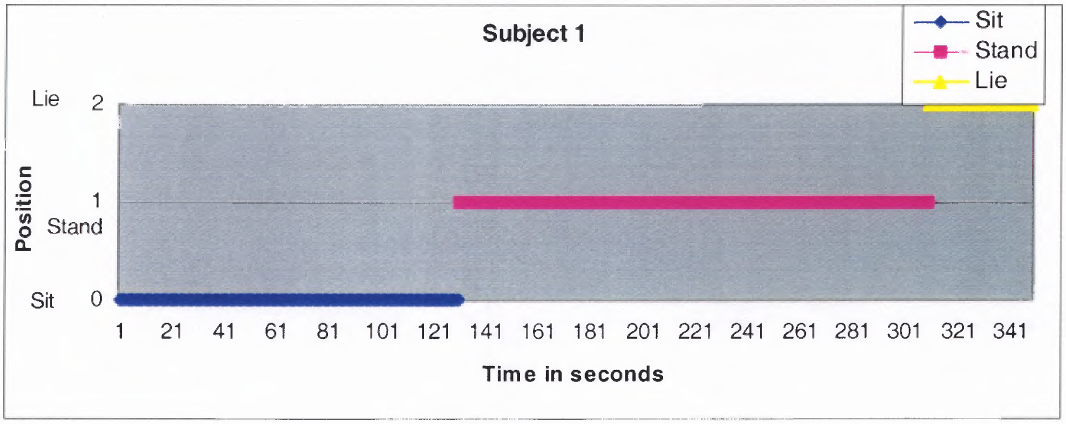

Figure 4.8 Results of subject 1.

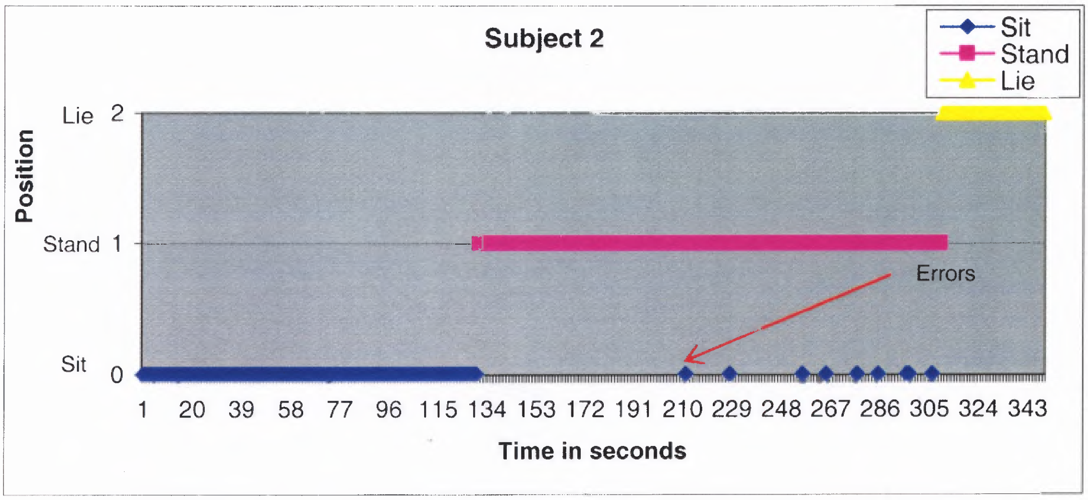

Figure 4.9 Results of subject 2.

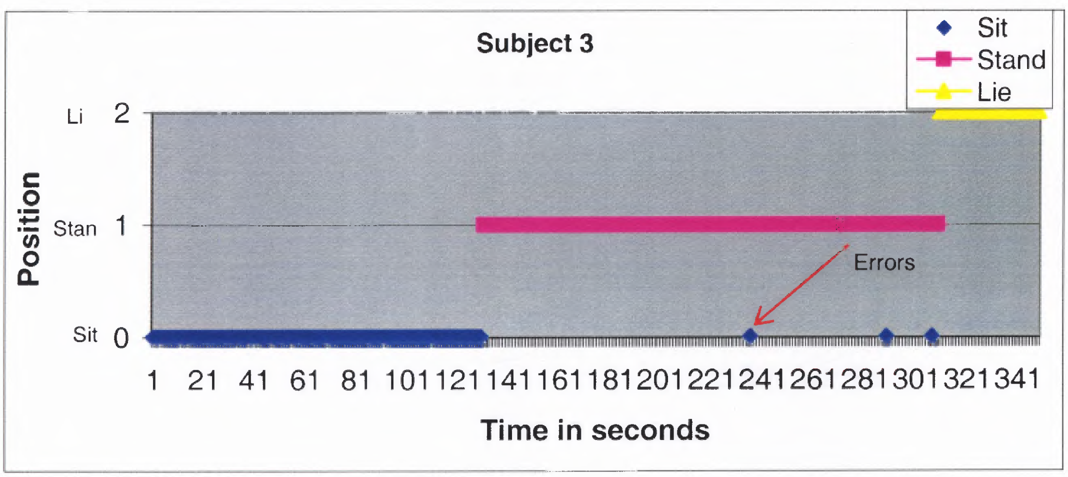

Figure 4.10 Results of subject 3.

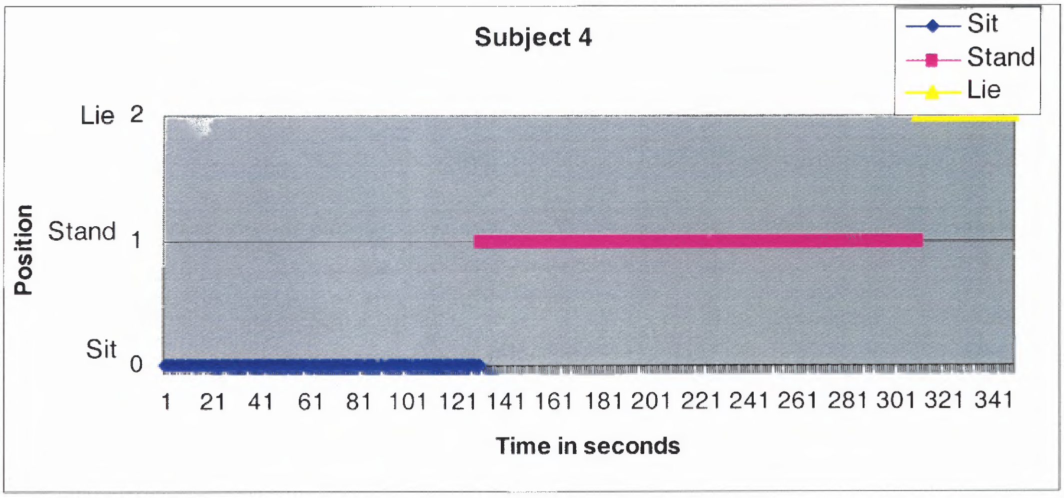

Figure 4.11 Results of subject 4.

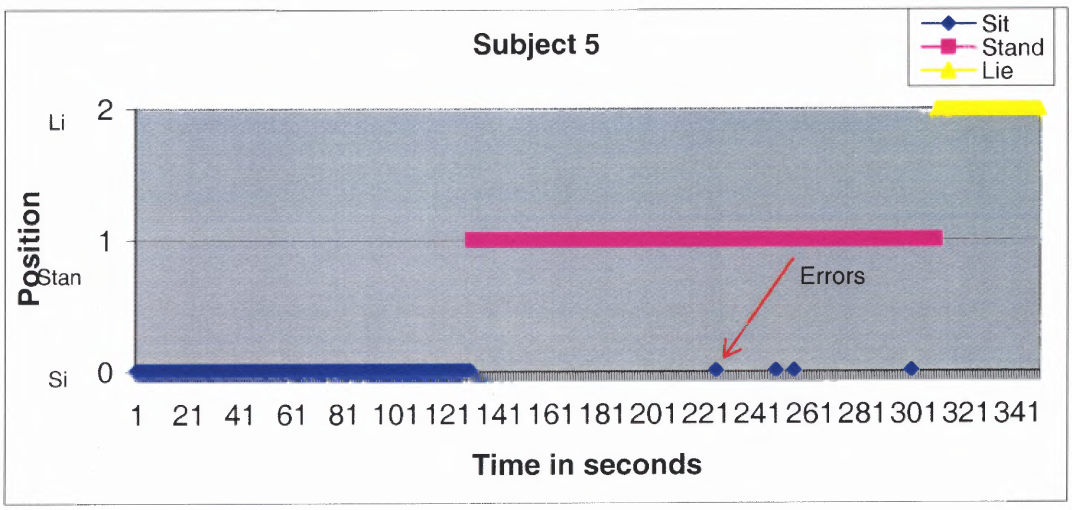

Figure 4.12 Results of subject 5

From the above results, it can be seen that the output (i.e. the posture) is determined correctly with the change in position. From these results the experiment can be concluded to be successful.

CHAPTER 5

DISSCUSSION

Variation of heart rate, blood pressure and change in ECG waveform and many other cardiac and pulmonary responses are associated with postural changes [14]. In accord with previous research by others, it is known that the heart rate was highest in standing compared to sitting or lying positions. It is hypothesized that the increase in heart rate with standing follows a decease in venous return due to "venous pooling" in the lower limbs due to gravitational effects [5]. The increase in peripheral venous volume is accompanied by an increase in both venous and arterial pressure in the lower extremities. The shift in blood volume from the central to the peripheral system induces a decrease in venous return and central venous pressure. The smaller the venous return, the smaller the end-diastolic and subsequent stroke volume. A reduction in venous return will lead to a reduced cardiac output, which in turn will lead to a reduction in baroreceptor stimulation in the aorta and carotid arteries [15]. This reduction in baroreceptor firing results in decreased parasympathetic and increased sympathetic activity [6, 10].

These two actions directly affect the cardiovascular center in the medulla oblongata, which increases the heart rate, the arteriolar and venous tones, and the cardiac contractility to compensate for the decrease in stroke volume and provide a cardiac output, which can meet body demands. Upon returning the posture from sitting to lying, the increase in venous return increases the stroke volume, thus a lower heart rate is sufficient to maintain the cardiac output demanded by the body. Pump and colleagues reported a decrease in heart rate, with a decrease in the blood pressure, when the subject changed from a sitting to supine posture [8, 9, 11]. It was these authors view that the blood pressure and heart rate changes were due to a posture-induced stimulation of the carotid and aortic pressure receptors.

The main focus of this research was to develop an ambulatory system that measured body position/posture and also stores the measured position along with the date and time. The response of heart rate and blood pressure with change in the body position were not measured, because their relationships are well documented [5,6,7,8,9,10,11].

Most of the time in this research was spent to find, implement and test a small sensor that can measure body position and to develop a software program in the LabVIEW PDA to analyze the output data from the accelerometer. Using accelerometers, the body position was known. The output of the accelerometer is voltage and voltage is directly proportional to angle. Voltage is converted into angle using the LabVIEW PDA for each sensor.

The output voltage of the accelerometer was measured and noted at every 10 degrees. The angles were considered by hanging a weight on a string and suspending it in the direction of gravity, the angle in the direction of gravity was considered as 90 degrees and the direction perpendicular to gravity was considered as 0 degrees. The values obtained during the measurement were fed into Microsoft Excel to plot a transfer function. A formula that represents the relation between voltage and angle along the graph was obtained using Microsoft Excel. This formula was fed into the formula node in the LabVIEW program for real-time processing.

In this pilot three accelerometers were used in order to know the body position more accurately. If only one accelerometer is used, the body position cannot be known, that is, if the accelerometer is placed on the abdomen the output of the accelerometer is the same at sitting or standing positions and if the accelerometer is placed on the thigh the output of the accelerometer is the same at sitting and lying positions and if the accelerometer is placed on the lower leg the output of the accelerometer is same at sitting and standing positions. When two accelerometers were used, initially by placing one accelerometer on the abdomen and other on the lower leg, the output of the accelerometer is the same when sitting and when standing, secondly by placing one on the thigh and other on the lower leg, the output is the same when lying and when placing legs on a ottoman and thirdly by placing one on the abdomen and other on the thigh, the output was the same when walking and when sitting with one leg on the other. Due to these conditions, three accelerometers were used in this design.

In the LabVIEW PDA a program was developed to convert the output voltage of the accelerometer into angle. In the program a range of angles were defined for each position. Depending upon the angle of the accelerometers, a position was displayed and stored in the PDA.

The system was tested under some situations where it was hypothesized that a problem might exist because of the method of operation of the accelerometer. The situations where the accelerometer was tested were driving, in an elevator, near a microwave and near a refrigerator. In the case of driving, it was tested to verify whether the output changes due to acceleration and deceleration, for an elevator it was tested to see if there is a change in the output when going down (the same direction as gravity) and going up (the opposite direction to gravity) and whether there is any error in identifying the postures, it was tested near a microwave and near a refrigerator to see whether the accelerometer output changes due to vibrations or electromagnetic fields.

Results showed no change in the accelerometer output compared to the ideal output when the accelerometer was near a microwave or near a refrigerator. There was a change in the output of the accelerometer when in a car during driving or in an elevator. Results showed that when accelerating and decelerating in an elevator and during driving the accelerometer output was changing. The accelerometer, according to the tested results showed that the output was increasing by 20 degrees when in an elevator and when driving. Initially the maximum angle of the accelerometer was considered as 90 degrees. By testing the accelerometers under different conditions it was observed that the maximum angle was different from the theoretical value. The maximum angle while developing the software program was taken as the maximum angle obtained from the results, which was 110 degrees. By modifying the accelerometer angle, the accuracy of the whole system was increased.

To test the whole design, data was collected from five subjects under conditions of sitting, standing and lying in different positions and even when the subjects were lying on their belly. The results showed no errors in all the cases except in the result when subjects were walking, going up and down the stairs. These errors were only for a second (i.e. one sample). These errors can be handled by assuming that the subject did not go from standing to sitting and back to standing within one second or a post acquisition software program to filter the data could be used. When subjects lift their thigh high and walk, these errors were caused. When they lift their thigh high, the position goes to sitting because the angles at that position fall into the sitting range.

Some postures overlapped with each other. The more occurred posture during daily living was taken into consideration when developing the software program. For example, certain cases, which overlap each other, are: sitting with the lower leg backwards and walking, walking by lifting the legs high. When sitting with the lower leg backwards, the output of the accelerometers fall in the same range as when walking. Since in daily activity walking occurs more frequently than sitting with the lower leg backwards, walking was given more importance and the output when sitting with lower leg backward was displayed as standing whereas it should display sitting.

CHAPTER 6

CONCLUSION

The main goal of this project was to develop a device that can measure body position ambulatory and to write a software program that would acquire, display, and store the data. Based on the goals that were originally set, this project was a successful one. The author was able to develop a system that would measure body position ambulatory and was able to collect the data to verify the accuracy of the system.

Through a series of tests, the system was shown to be accurate and reliable. The results from this experiment showed that as there is a change in body position, the system shows the change. This device is called reliable because it works almost in all normal daily living environments. The software program stores the data for every one second in the PDA. The PDA has a capability to store the body position, angle at the three accelerometers along with date and time in the memory without additional memory storage cards for at least 20 days. The memory occupied to store the data for single day is 3.278 MB. With this it can be said that care has been taken in designing the software program to store data without occupying much memory for the PDA to store data for long periods.

CHAPTER 7

LIMITATIONS AND FUTURE DEVELOPMENTS

The limitation of this system is that one cannot store the dynamic representation of the position of the subject due to the memory in the pocket PC. If in future, if the memory of the pocket PC increases, one can store the dynamic picture of the subject (in this study only a text that represents standing, sitting or lying was stored), which would give the exact information of the subject's body position. Another limitation of the system is the battery life of the expansion pack, which last for only eight hours and the battery life of the PDA, which last for eight to ten hours.

The future development for this system is to avoid the use of the expansion pack by building an analog to digital converter by other circuitry. By placing another accelerometer on the other leg, the errors seen in the results when walking, can be reduced. With the information got from the sensors at the two legs, we can know whether the subject is walking. Another development is to increase the sampling rate to know the movements.

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