GERIATRIC FALL HIP INJURY PREVENTION DEVICE

(Personal airbag system to prevent hip fractures on geriatrics)

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ABSTRACT

Hip fractures can be a life-threatening injury among the elderly. Annually, thirty million falls are reported, of which two hundred and fifty thousand result in hip fractures. Medical costs for these fractures are estimated between seven and ten billion dollars annually. However, the number of hip fractures is expected to double in the next fifty years, which defines the current problem as critical and alarming. In order to provide a suitable solution to this problem, Dr. Jorge Santiago from the Electrical Engineering Department at the University of Pennsylvania has developed a project to build such device. The product will be a belt-like device that would prevent hip injuries by means of sensors that will recognize a potentially injurious fall and then trigger an inflatable cushion before impact.

1. INTRODUCTION

After age 65 the rate of hip fractures rises exponentially with age.[1] This rise is attributed to several factors, including loss of muscle mass which is necessary for balance; loss of bone mass which reduces the bone's tolerance for impact forces; and a greater probability of debilitating medical conditions.

In nursing homes, the most widely used monitoring devices are products that are activated by the patient when he has fallen and is in need of medical attention. Usually this device is an electronic button, worn around the neck, which when pressed sends a radio signal that summons on-duty nursing personnel. Other devices include pressure pads that are activated when a patient leaves a bed or chair. However, these devices cannot prevent an injury sustained in a fall, but only serve to inform and direct medical personnel to a potentially serious injury.

Hip protectors and floor padding are other accepted methods of preventing hip fractures. They seek to minimize injury that could be sustained in a fall by diminishing the energy created, thereby minimizing the force created on the hip. Hip pads have proven successful in reducing the incidence of hip fractures during falls. However, a study shows that only 25 percent of subjects voluntarily wore hip pads.[2]

This research focuses on a personally worn injury prevention device rather than an emergency device or a fall prevention strategy. Alerting personnel to the occurrence of a fall does not solve the problem associated with hip injuries. Preventive fall methods were also deemed unacceptable because they fail to prevent all falls. Hip pads, on the other hand, have proven success of reducing hip injuries, but had a low acceptability rate with the elderly community. Thus, there is a market for a Geriatric Fall Hip Injury Prevention Device that would be an improvement over hip padding systems if it is made compact, light, comfortable and unobtrusive in order to be accepted by the elderly wearer.

1.1 Background

Hip fractures, usually related to underlying osteoporosis, occur in more than 250,000 Americans per year, with 85 percent occurring in patients older than 65 years. Associated estimated medical costs are 7 to 10 billion dollars every year.

Hip fracture is all too frequently part of a progressive functional decline, resulting in immobility, institutionalization, and death.[3] Mortality is higher among patients who are very old, have little social support or live alone, or are in poor general medical condition; institutionalized patients, men, those with dementia, and especially those unable to walk because of the injury also experience higher mortality.[4,5]

In addition to mortality, there are serious morbidities associated with hip fracture. Of previously independent patients, 15 to 25 percent will need nursing home placement for at least 1 year, and less than 30 percent of patients fully regain their prefracture level of function. Aggressive geriatric assessment and rehabilitation will improve outcomes in selected patients.[6]

1.2 Types of Hip Fractures

There are two main types of fracture: femoral neck fracture and intertrochanter fractures of the neck, shown in Figure1. There are several accepted mechanisms to describe hip fracture. One is direct compressive impact to the greater trochanter and a second is a lateral rotation of the extremity. The average patient with intertrochanteric fracture is older than the patient with femoral neck fractures, and although nonunion and avascular necrosis is extremely uncommon, both short- and long-term mortality are higher for this fracture type. [7,8,9]

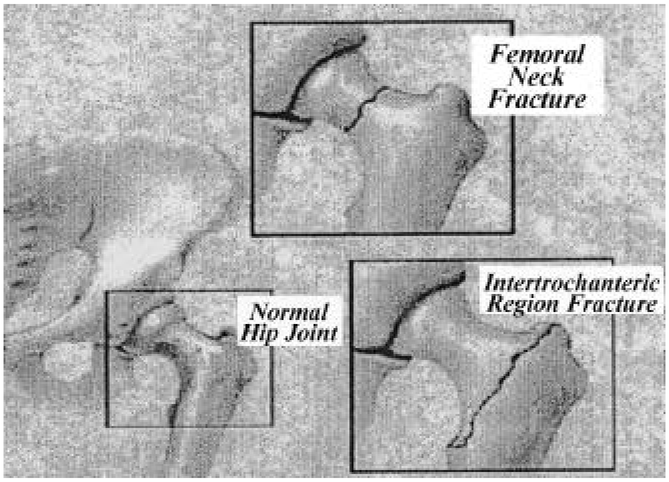

Figure 1. Types of hip fractures.

1.3 Causes of Falls

A fall can be described as "an event which results in a person coming to rest inadvertently on the ground or other lower level as a consequence of the following: sustaining a violent blow; loss of consciousness; sudden onset of paralysis as in a stroke; or an epileptic seizure."[10] A fall has four distinct phases: 1) instability that results in a loss of balance; 2) descent; 3) impact; and 4) post impact, when the subject comes to rest.

Causes of falls can be grouped into two main categories: extrinsic and intrinsic factors. Extrinsic factors are environmental hazards, such as loose carpeting, stairs, and poor footwear or lighting. Intrinsic factors are conditions that relate directly to a specific person, such as dizziness, use of medication, osteoporosis, and arthritis. A third category exists for all falls that are not classifiable due to lack of information. Of those falls that are classifiable, the numbers caused by intrinsic and extrinsic factors are split fairly evenly.[11]

1.4 Fall and Fracture Incidence

Hip fractures and falls both have high rates of occurrence during the day, with three quarters of fractures occurring during the daylight hours, and the other quarter taking place at night, usually when the person gets up to use the bathroom.[12]

Not unexpectedly, research shows that once an elderly person has fallen, he will likely experience more falls in the future. In one study of patients admitted to a Philadelphia emergency room due to falling, 40 percent returned for treatment from another fall within the same year. Correspondingly, patients with a previous hip fracture have a two- to ten-fold increased risk of a second hip fracture.[13]

1.5 Falls Resulting In Fractures

The majority of hip fractures occur from a sideways fall, starting from a standing position, which results in a direct compressive impact to the hip.[14] These falls have a six-fold increase in rate of hip fracture over other types of falls.[2]

Falls to the side usually result from loss of balance due to intrinsic factors. Extrinsic factors, such as tripping, usually cause forward or backward falls, which result in hip injuries much less frequently.

2. THE PRODUCT

The Geriatric Fall Hip Injury Prevention Device will focus on the prevention of hip injuries among the elderly. The product should be targeted at people who have identifiable intrinsic factors. This market is large enough to warrant the development of such a technical device. However, in order to solve the problem of hip injuries, it is crucial that the device be something that people will use. Otherwise, it will never prevent a single injury.

2.1 General Specifications

The product will consist of four main parts:

1) A belt with small pager-sized containers over each hip.
2) Two inflatable cushioning chambers, each folded up inside one of the pager-sized containers, which are connected to a means of automatic inflation.
3) An accelerometer and a tilt sensor, to acquire and transmit information about body movement, accompanied by a power source, preferably a lightweight, long-life, perhaps rechargeable, lithium battery.
4) A microprocessor to receive the body movement data, compare it with precalculated data for normal body motion, and then transmit the “positive fall” signal to the inflatable chamber when the incoming data exceeds a predetermined “fall threshold.”

It is assumed that the belt and microprocessor circuitry would not present any insurmountable obstacles to completing the design. Therefore, my research was focused on finding, putting together and testing the accelerometer and tilt sensor.

2.2 Cushioning Chamber

An inflatable cushioning chamber is the best way to dissipate energy during a fall. It provides a softer landing than passive hip pads because it can expand to a greater volume, giving the hip more distance to decelerate before hitting the ground. In addition, before deployment, it is much smaller and more comfortable than hip pads because of its expandable nature.

2.3 Method of Inflation

There are two possible methods for inflation: explosive reaction or the release of compressed gas. Explosive reactions are used to inflate automotive airbags. Before deployment, the airbag is folded up inside the steering wheel and the chemical reactants are stored in the reaction chamber. When the signal for deployment is sent, the sodium azide (NaN_3) is ignited by an electrical impulse from the microprocessor. This inflation takes approximately 0.015 seconds for the airbag is fully expand to meet the rapidly approaching person. Inflation reaction is followed by a deflagration that turns the remaining resultants into a stable glass compound. This reaction takes slightly longer, allowing the airbag to decelerate the driver to a relatively safe speed over the course of approximately two feet and 30 milliseconds.

However, an airbag is not a nice soft pillow. It is a hard canvas-like material that may cause more damage than impact with the floor. The hip absorbs no more than 6 Gs of force in a fall. This is insignificant compared to the 60 Gs of force created by an automotive airbag.

Compressed gas inflation is more promising. Currently, carbon dioxide gas (CO_2) cartridges are used to inflate many objects, such as personal flotation devices. Argon is also used in compressed cartridges in the automotive industry to inflate side impact airbags. Though these applications do not have the time constraint that our device has for inflation, the chamber's smaller size of approximately 1 to 1.2 liters will allow inflation in about 0.03 seconds. The slower inflation brings down the created force to a range of 4 to 5 Gs. This will also reduce the risk of injury in the case of a false “positive inflation”.

3. ACCELEROMETER TECHNOLOGY

3.1 Principles of A Suspended Mass Accelerometer

An accelerometer can be considered as nothing more than a weight on a spring, which is connected to a frame; this is shown schematically in Figure 2. When the frame is moved, the mass will tend to stay at rest until the spring, being stretched, exerts enough energy on the mass to make it move.

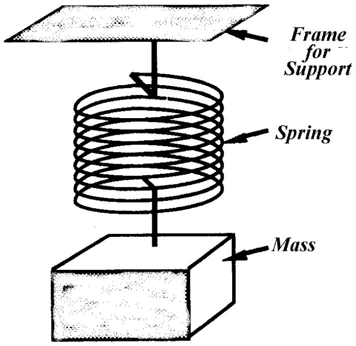

Figure 2. Suspended mass accelerometer.

With the addition of an electrical pickup, a signal can be generated that will be proportional to the relative motion between the mass and frame. Masses in constant acceleration fields, such as the Earth's gravity, tend to move in one direction away from the frame, while a mass in an oscillating accelerometer field tends to move in both directions.

In an accelerometer system, two components store energy, the mass and the spring. Under these conditions, once moving, the mass and spring will tend to resonate at some frequency set by the square root of the spring constant divided by the mass.

3.2 Basic Accelerometer Design

Piezo (from the Greek piezein, to press or squeeze) refers to a basic characteristic of the material: when pressed or subjected to force, piezoelectric materials develop an electric charge and piezoresistive materials exhibit a change in resistance. These are the principles of operation of the vast majority of accelerometers in use today.

3.2.1 Piezoelectric

The simplest piezoelectric accelerometer consists of a base of some stiff material. For example, a disk of piezoelectric crystalline material, either natural (quartz) or man-made ceramic (e.g., lead zirconate titanate), can be combined with weight or seismic mass, with the whole assembly fastened together with a through bolt. Electrical contact is made by means of two electrodes, one on each side of the disk. The base of the accelerometer is attached to the test object, whose movement exerts a force on the seismic mass and induces stress into the piezo disk. The electrodes detect the resultant electric signal and convey it to the readout device. Piezoelectric sensors can also be made from certain plastic materials that have piezoelectric properties (so-called piezofilm accelerometers), but the basic mechanical idea remains the same.[15]

Whatever piezo material is used, these devices, when excited, produce an electrical output. For this reason, piezoelectric accelerometers are sometimes referred to as "self-generating" sensors. Their raw, unconditioned output is of very high impedance and while it can be treated as either a voltage or a charge, most sensors must be used with special “charge amplifiers” before the signal is suitable for further analysis. Some piezoelectric accelerometers are available with an internal impedance to drive the instrumentation connected to them. This option reduces the cost of measurement channel, but involves compromise that can affect low-frequency response and high-temperature measurement capability.

3.2.2 Piezoresistive

This technology also involves the movement of a mass, but in a traditional device the piezoresistive element is a strain gage bonded to a mass-loaded cantilever. As the beam bends, as seen in Figure 3, in response to acceleration forces, the material is stressed and changes its resistance. Four individual sensing elements are often arranged in a Wheatstone bridge configuration, providing high-level output and the possibility of canceling cross-axis, temperature and other spurious inputs.

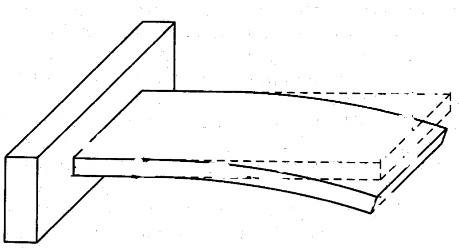

Figure 3. Bending of a Cantilever

Because they are passive devices, these sensors must be supplied with an excitation voltage. The output is then routed to an amplifier or directly to an indicating device. Piezoresistive sensors have recently been made of micromachined silicon, using batch fabrication processes and economies of scale made possible by the semiconductor nature of the process. With this technology, piezoresistors are implanted into support beams connecting the seismic mass to a frame or support structure as shown in Figure 4. The resulting semiconductor die can then be packaged in various of ways. Silicon accelerometers can be lighter, smaller, and much less expensive than traditional piezoelectric or piezoresistive units.[15]

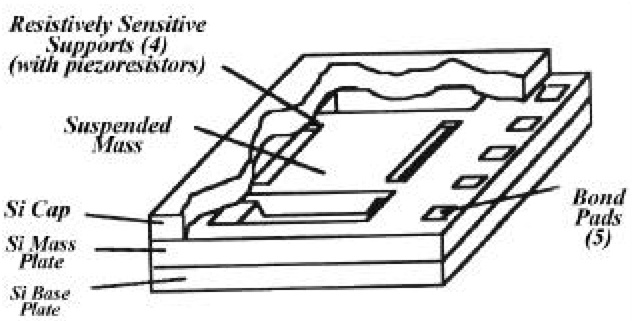

Figure 4. The piezoresistors supporting the mass in a piezoresistive accelerometer exhibit a change in resistance when subjected to a force. These passive devices must be supplied with an excitation voltage before the signal is routed to an amplifier or indicator.

3.2.3 Micromachined Accelerometers

Micromachined accelerometers require a more complex structure than do pressure sensors made using micromachining. A number of technologies are needed to achieve a viable silicon piezoresistive accelerometer structure. These include ion implanted piezoresistors for resistor matching and off-axis sensitivity reduction, wet and dry silicon etching to create the mechanical structure, viscous Air-Damping to provide a controlled frequency response and to eliminate the risk of breakage at resonance, and sealed capping to minimize obstruction of motion due to particulate contamination during assembly.

3.2.4 Fabrication of Silicon Accelerometers

Etching away areas of the silicon wafer to form three-dimensional structures forms micromachined silicon accelerometers. A number of bulk and surface micromachining techniques are available: time etching with precision flat wafers, electrochemical etch-stops, and even oxide etchstops by silicon-silicon fusion bonding. The fundamental consideration in the choice of these various approaches is whether the process control and yield improvement, introduced by increasing the complexity of the process, result in a better part.

Typically, a wafer might be etched to define the silicon mass, and then the wafer would be processed to add the piezoresistors using ion implantation of boron. These resistors are then diffused deeper into the wafer to achieve an optimum performance. Following that step, contact is made to the resistors and the wafer is metalized and patterned. Throughout this period, the wafer has been processed with complete diaphragms supporting the mass so that the wafer is reasonably rugged. The final step frees the masses by etching away the diaphragms in all the areas except where the springs are. With this approach, the wafer is relatively fragile only at the last processing step. Concurrent with this processing, for those accelerometer structures with caps, a mesa etch is done to create the over-force stops, and the depression in the cap is then etched in order to set the damping parameters for the particular acceleration range in process. The higher the sensitivity, the wider the gap must be between the mass and the cap to maintain a constant damping. The wafers are subsequently bonded together to form the three-layer sandwich structure shown below in Figure 5.

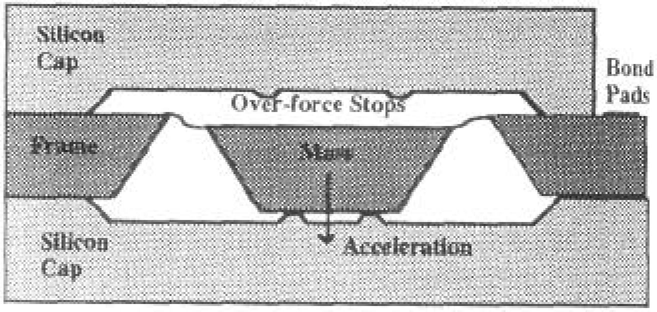

Figure 5. The thin layer of air between the mass and the cap acts as a “squeeze-film” that damps the motion of the mass. Unlike oil-damped devices, air damping is not temperature dependent.

The wire bond pads are then exposed and the wafer is probed for electrical parameters. After reject sensors are marked, the wafer is subsequently sawn to produce accelerometer dice. The dice are then packaged in a number of different packages, based upon customer needs.

3.3 Our Accelerometer

Analog Devices’ ADXL05 is a complete acceleration measurement system on a single monolithic IC. It contains a polysilicon surface-micromachined sensor and signal conditioning circuitry which implements a force-balance control loop. The ADXL 05 is capable of measuring both positive and negative acceleration to a maximum level of ±5 G.

Figure 6 is a simplified view of the ADXL05’s acceleration sensor at rest. The actual sensor structure consists of 46 unit cells and a common beam. The differential capacitor sensor consists of independent fixed plates attached to the main beam, which moves in response to an applied acceleration. The two capacitors are series-connected, forming a capacitive divider with a common movable central plate. The sensor’s fixed capacitor plates are driven differentially by a 1 MHz square wave: the two square wave amplitudes are equal but are 180° out of phase from one another. When at rest, the values of the two capacitors are the same and therefore, the voltage output at their electrical center is zero.

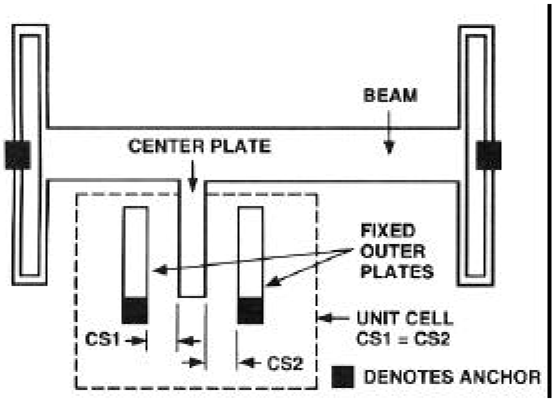

Figure 6. A simplified diagram of the ADXL05 sensor at rest.

Figure 7 shows the sensor responding to an applied acceleration. When this occurs, the common central plate or "beam" moves closer to one of the fixed plates while moving further from the other. This creates a mismatch in the two capacitances, resulting in an output signal at the central plate. The output amplitude of the signal varies directly with the amount of acceleration experienced by the sensor.

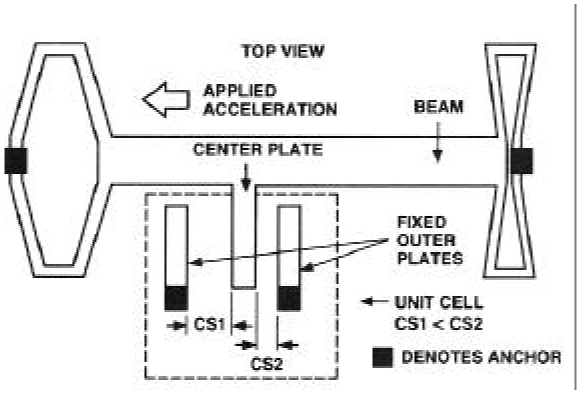

Figure 7. The ADXL05 responding to an externally applied acceleration.

Figure 8 shows a block diagram of the ADXL05. The voltage output from the central plate of the sensor is buffered and then applied to a synchronous demodulator that is clocked, in phase, with the same oscillator that drives the fixed plates of the sensor. If the applied voltage is in sync but 180° out of phase with the clock, then the demodulator's output will be negative. All other signals will be rejected. An external capacitor, C1, sets the bandwidth of the demodulator.

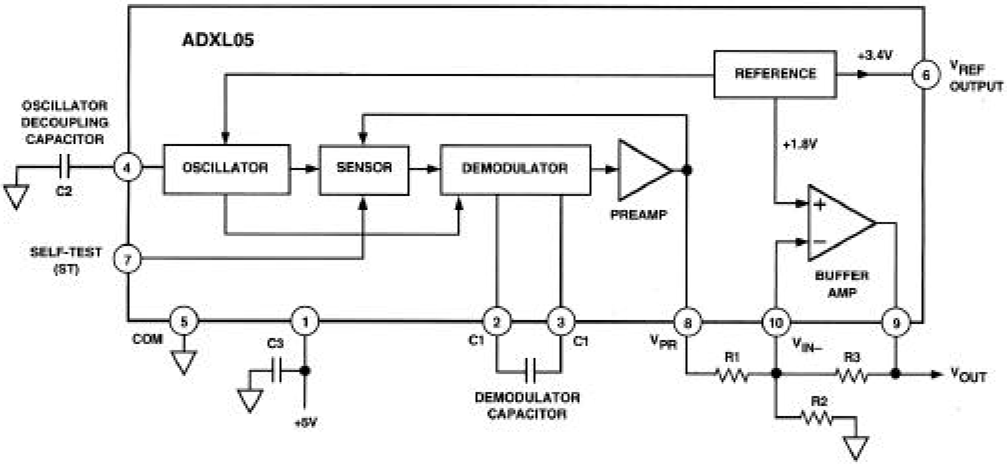

Figure 8: Functional block diagram for the ADXL05

The output of the synchronous demodulator drives the preamp – an instrumentation amplifier buffer - that is referenced to +1.8 volts. The output of the preamp, V_{PR}, is fed back to the outer plate of the sensor through a 3 MÙ isolation resistor. The V_{PR} voltage electrostatically resets the sensor back to its 0 G position and is a direct measure of the applied acceleration.

The output of the ADXL05 preamplifier is 1.8 V ± 200 mV/G, with an output range of ±1V for a ± 5G input. An uncommitted buffer amplifier provides the capability to adjust the scale factor and 0 G offset level over a wide range. An internal reference supplies the necessary regulated voltages for powering the chip and +3.4 volts for external use. A self-test is initiated by applying a “high” level voltage (> +2.0 V dc) to the ADXL05’s self-test pin, which causes the chip to apply a deflection voltage to the beam. The voltage moves it an amount equal to –5 G (the negative full-scale output of the device).

The physical diagrams of the ADXL05 are shown in Figures 9 and 10 below. The pin descriptions are as follows:

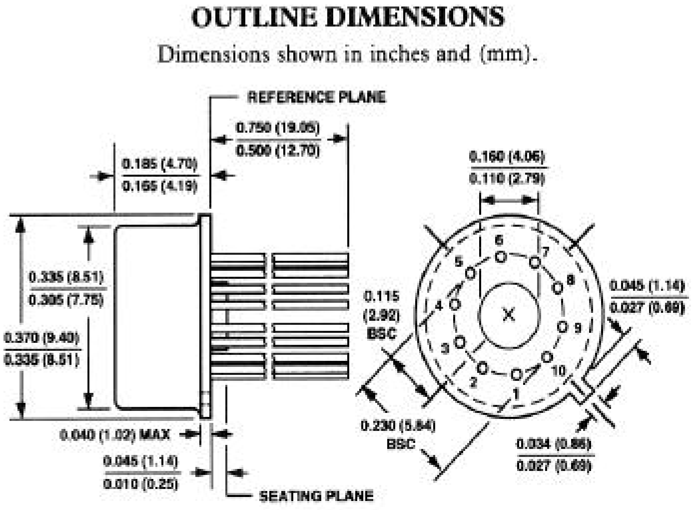

Figure 9: External dimensions of the ADXL05

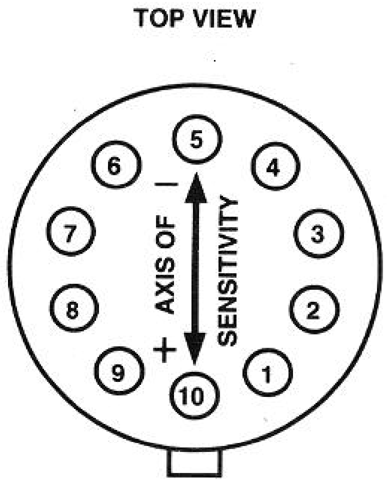

Figure 10: Location of pins on the ADXL05 Sensor

3.3.1 Our Connection of the ADXl05

The accelerometer chip was soldered onto a prototyping board. The 10 pins, 3 capacitors, and 4 resistors were connected in the following manner, shown on Figure 11.

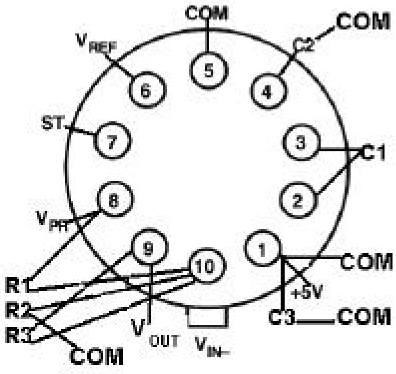

Figure 11 Connection diagram of the ADXL05

3.4 Experiments

Once the ADXL05 connection was completed, it was connected to LabVIEW, where some experiments were made according to the future usage of the accelerometer. For example, I obtained data for walking, sitting, standing, and other everyday motions that would help me define whether this accelerometer would fit the purpose that we have in mind.

3.4.1 What Is LabVIEW

LabVIEW stands for Laboratory Virtual Instrument Engineering Workbench. It is a development environment based on the graphical programming language G. Using LabVIEW, you can create programs that give you the fast execution speeds needed for custom data acquisition, test, and measurement solutions empowering you to build your own solutions for scientific and engineering systems. LabVIEW gives you the flexibility and performance of a powerful programming language without the associated difficulty and complexity. By using LabVIEW to prototype, design, test, and implement your instrument systems, you can reduce system development time and increase productivity.

3.5 Data

The following data was obtained from experiments performed while the accelerometer was connected through wires to a computer and power supply, restraining the amount of space to carry out each trial as well as their duration. Thus, it is possible that the data will change if the experiments are done under different circumstances. Four trials of the ADXL05 were performed for each action in order to see data changes due to the offset of the accelerometer as it was shifted 90 degrees counterclockwise each time, from its original position, with the positive sensitive axis facing forward.

3.5.1 Still

Figure 12 represents data from four trials while subject is in place without making any movement at all.

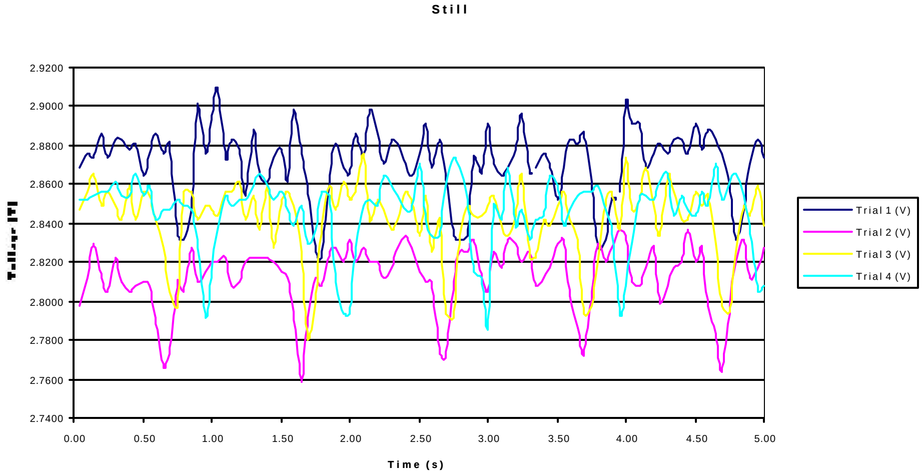

Figure 12 Data for holding the accelerometer still

3.5.2 Sitting

Figure 13 represents the data from four trials as the accelerometer is held at waist level (where the device will eventually be worn) and the subject sits down on a chair. The first trial seems to be extremely high. However, it was a matter of procedure, not of a defect on the accelerometer.

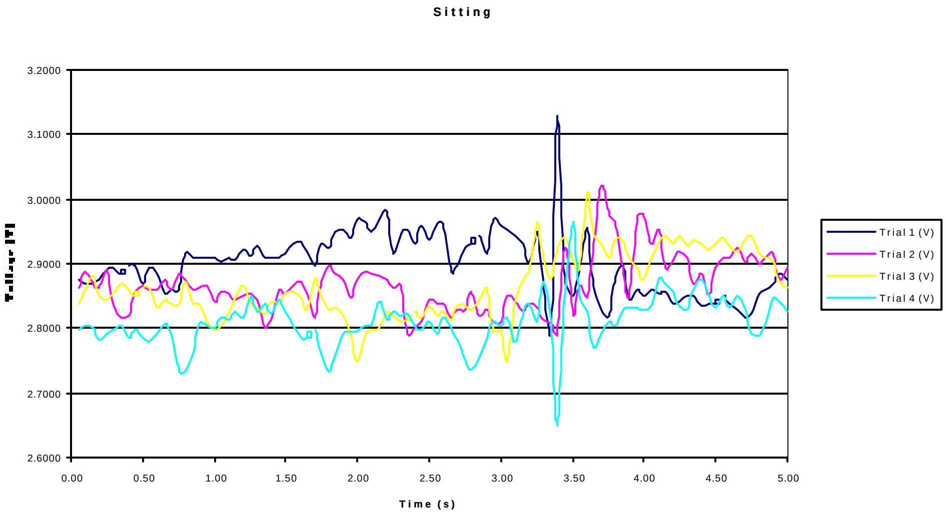

Figure 13 Data for sitting

3.5.3 Standing

Figure 14 represents data from four trials as the subject stands up from a chair.

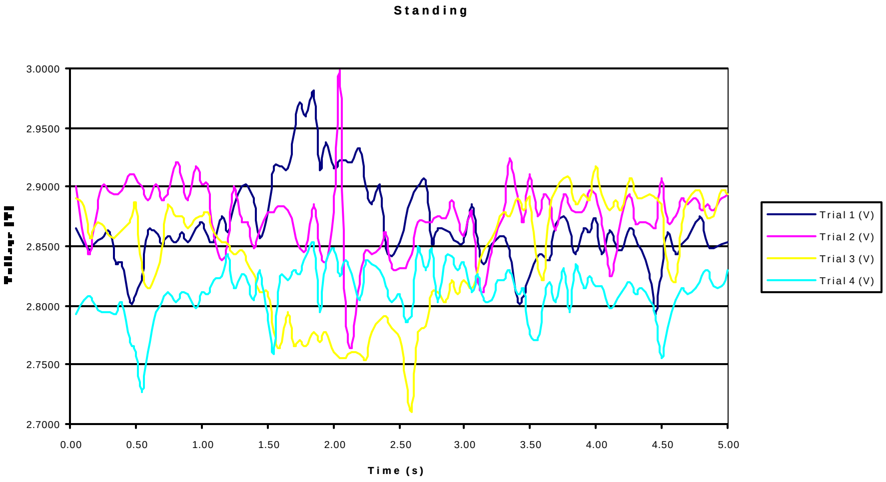

Figure14: Data for standing.

3.5.4 Walking

Figure 15 represents data from four trials as the subject walked in one direction.

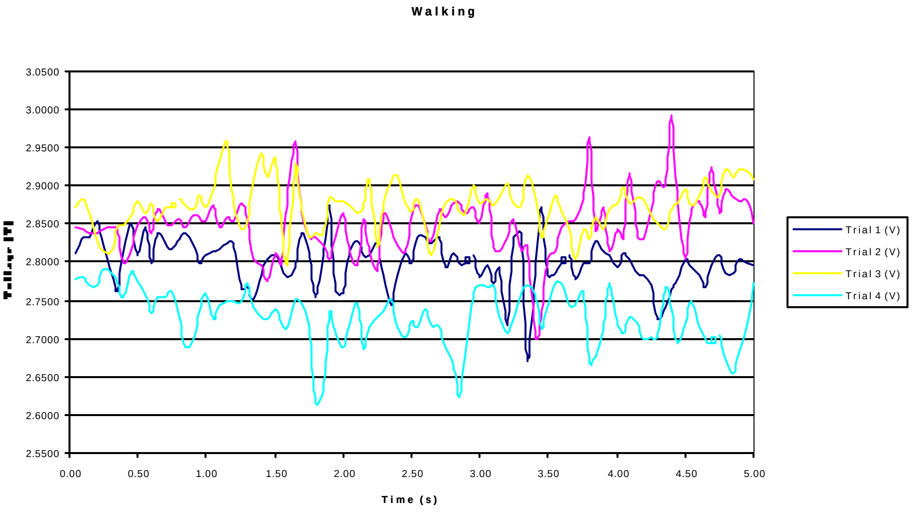

Figure15: Data for walking.

3.5.5 Falling

Figure 16 represents data of the ADXL05 in two falling situations. The first one took place as the subject attempted to fall “safely” sideways to the right side. The second was simply letting the accelerometer free fall onto a soft surface to avoid breakage.

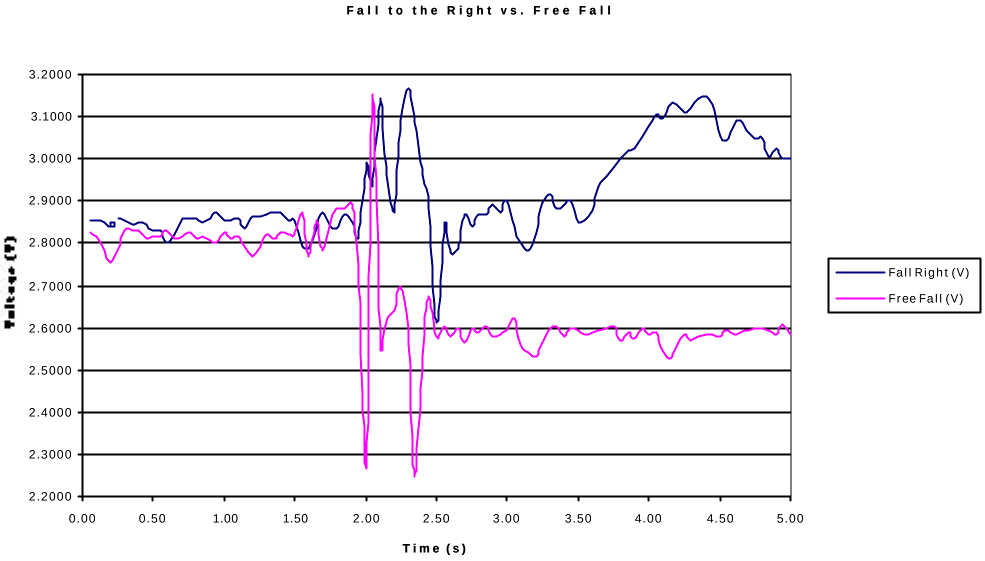

Figure 16. Data for falling.

3.6 Data Comparison

Figures 17, 18, 19 and 20 compare the data obtained for still, sitting, standing, and walking against the data for falling, according to each trial. This allows us to see that the voltage change obtained in response to a fall is different from those obtained for all the other actions; therefore, drawing a clear threshold, which may be used in configuring the microprocessor in later stages of this project.

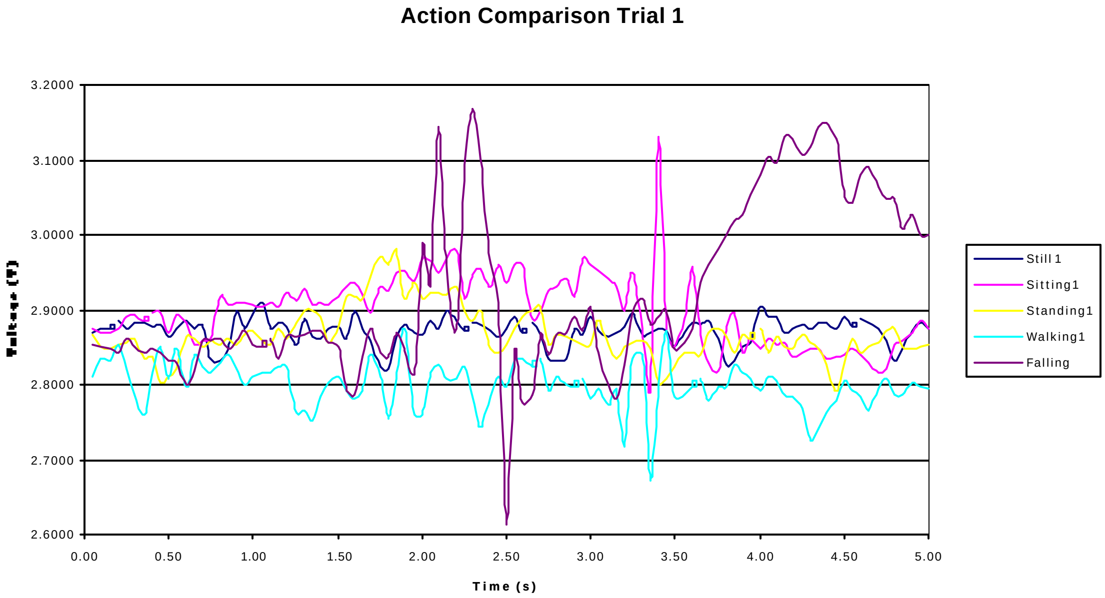

Figure 17. Data comparison for trial 1.

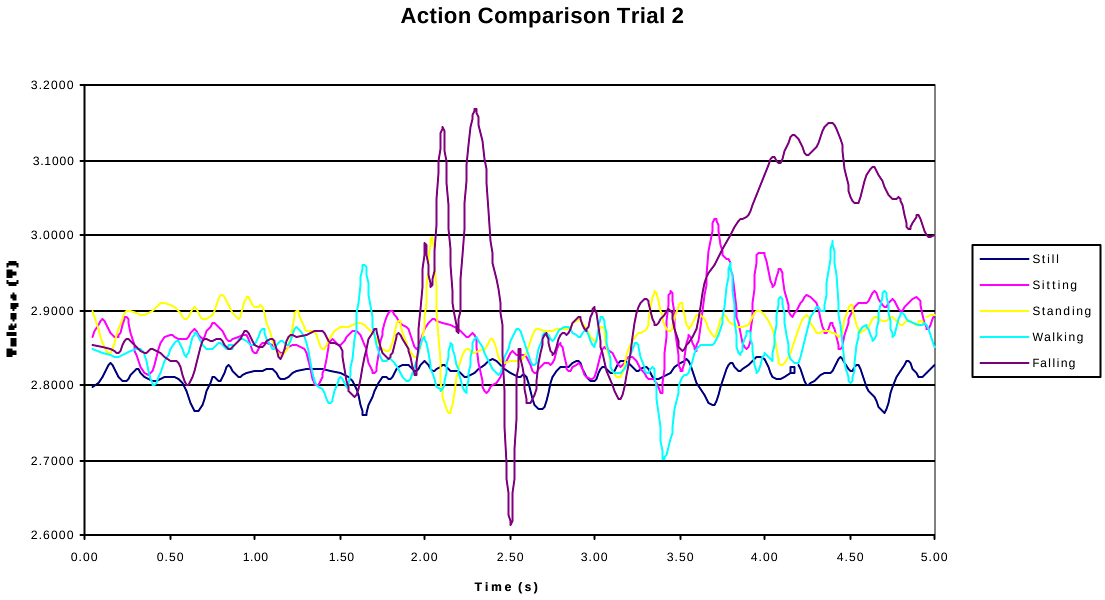

Figure 18. Data comparison for trial 2.

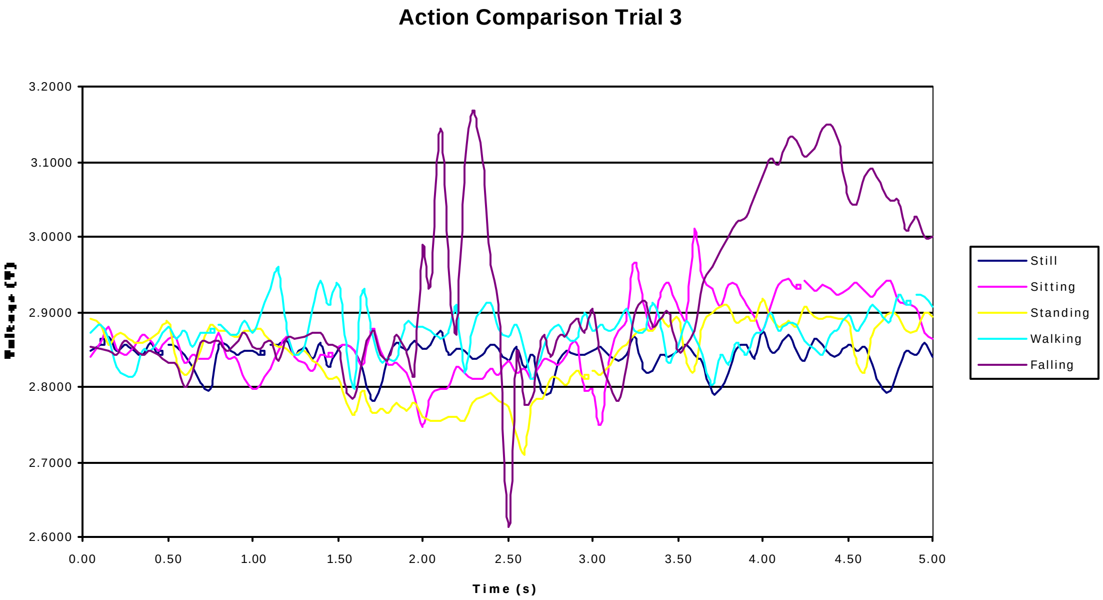

Figure 19. Data comparison for trial 3.

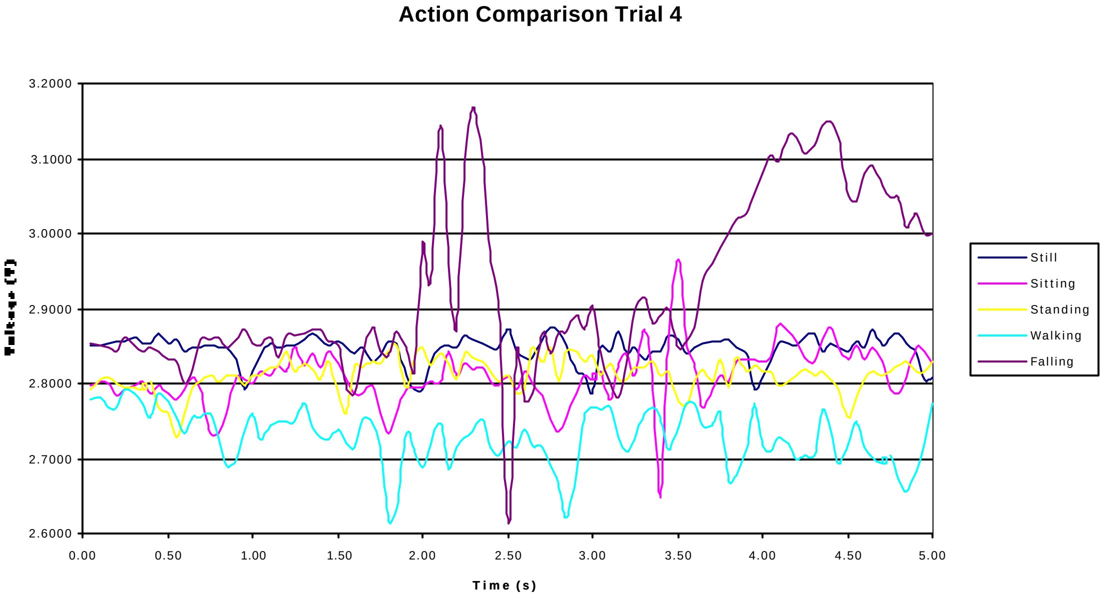

Figure 20. Data comparison for trial 4.

3.7 Mathematical Values

Previous to performing these experiments, a mathematical model of a falling person was done in order to obtain the time of fall. This will be used in later stages of the project when reaction times come into play and must be kept at much less than the falling time of the person. Because of the individuality of the values according to height, perhaps future options may lead to the development of the device in different sizes. The values obtained, assuming the hip to be a point, and using the physical formulas for a projectile, are presented in Tables 1 and 2 for men and women individually.

Height (ft' in")	Men Avg. Weight (lb)	Effective Height (m)	Time of Fall (s)	Impact Velocity (m/s)
4' 10"	-	-	-	-
4' 11"	-	-	-	-
5' 0"	-	-	-	-
5' 1"	-	-	-	-
5' 2"	139.0	0.79	0.4001	3.92
5' 3"	141.5	0.80	0.4039	3.96
5' 4"	144.0	0.82	0.4076	4.00
5' 5"	147.0	0.83	0.4101	4.02
5' 6"	150.0	0.84	0.4138	4.06
5' 7"	153.0	0.85	0.4163	4.08
5' 8"	156.0	0.87	0.4199	4.12
5' 9"	159.0	0.88	0.4224	4.14
5' 10"	162.0	0.89	0.4260	4.18
5' 11"	165.0	0.90	0.4284	4.20
6' 0'	168.5	0.92	0.4319	4.24
6' 1"	172.0	0.93	0.4343	4.26
6' 2"	176.0	0.94	0.4378	4.29
6' 3"	180.0	0.96	0.4412	4.33
6' 4"	184.5	0.97	0.4436	4.35

Table 1. Mathematical values for men

Height (ft' in")	Women Avg. Weight (lb)	Effective Height (m)	Time of Fall (s)	Impact Velocity (m/s)
4' 10"	116.5	0.74	0.3871	3.80
4' 11"	118.5	0.75	0.3910	3.84
5' 0"	120.5	0.76	0.3936	3.86
5' 1"	123.0	0.78	0.3975	3.90
5' 2"	125.5	0.79	0.4001	3.92
5' 3"	129.0	0.80	0.4039	3.96
5' 4"	132.5	0.82	0.4076	4.00
5' 5"	136.0	0.83	0.4101	4.02
5' 6"	139.5	0.84	0.4138	4.06
5' 7"	143.0	0.85	0.4163	4.08
5' 8"	146.5	0.87	0.4199	4.12
5' 9"	149.5	0.88	0.4224	4.14
5' 10"	152.5	0.89	0.4260	4.18
5' 11"	155.5	0.90	0.4284	4.20
6' 0'	158.5	0.92	0.4319	4.24

Table 2. Mathematical values for women

4. USING THE ADXL05 AS A TILT SENSOR

The ADXL05’s precision characteristics make it suitable for tilt measurement also. It can directly measure the earth’s gravity and use this constant force as a position reference to determine inclination. The accelerometer should be mounted so that its sensitive axis is perpendicular to the force of gravity. In this manner, it will be most sensitive to changes in orientation. Conversely, for a given acceleration signal, assuming no other changes in the axis or interfering signals, the tilt angle is proportional to the voltage output.

The use of an accelerometer in tilt applications has several advantages over the use of a traditional tilt sensor. A traditional tilt sensor consists of a glass vial filled with a conductive liquid, typically a mercury or electrolytic solution. Besides being larger than an ADXL05, it requires additional signal conditioning circuitry. The settling time and frequency responses are limited by the amount of time required for the liquid to stop sloshing around in the vial. In high vibration environments, or where high lateral accelerations may be present, it may not be possible to resolve the tilt signal above the “slosh” noise. The accelerometer has faster frequency (up to 50 X) response and settling time. Interfering vibrations may be filtered out if necessary, an impossibility with a liquid tilt sensor, since liquid cannot be filtered.

Finally, in the presence of lateral accelerations, an accelerometer provides more useful information which, if cleverly signal processed, can provide both a tilt and acceleration output. A single accelerometer can be used to measure tilt over a 180° range; two accelerometers give a complete 360° of measurement.

An important characteristic for an accelerometer used in a tilt application is its 0 G offset stability over temperature. The ADXL05 typically exhibits offsets that deviate no more than 0.1 G over the 0° C to +70° C temperature range, corresponding to a 5° tilt error over the entire temperature range.

4.1 Tilt

Figure 21 represents the data obtained from tilting the accelerometer from the original position (sensitive axis facing forward), 45 and 90 degrees to the right and to the left. Each movement is graphed separately below. This data will be used in determining the tilt angle of the person once a threshold is calculated.

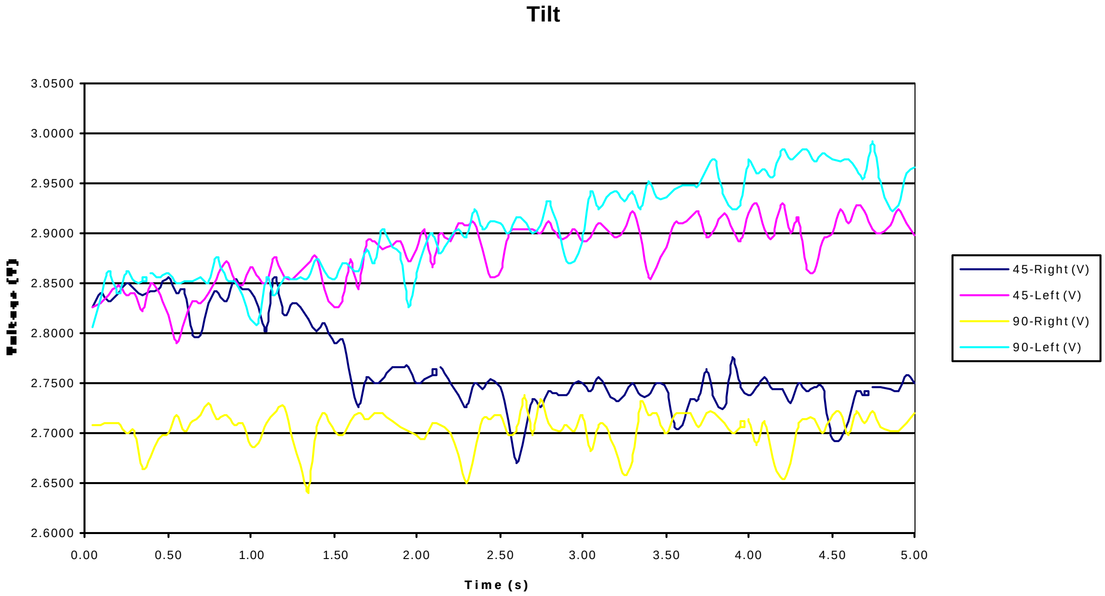

Figure 21. Data for tilt.

5. DISCUSSION AND CONCLUSIONS

As previously stated, this research was focused on finding, putting together and testing an effective accelerometer and tilt sensor to obtain body movement data. The gathered data for the testing of the accelerometer shows that the change in voltage for a fall is higher than the change in voltage for any of the other experimental actions. This means that an accelerometer may be used effectively in determining whether a person is falling by measuring the change in the subject’s acceleration and resulting in an output voltage exceeding the predetermined threshold. The same accelerometer may also be used as a tilt sensor by using the earth’s gravity as a position reference to determine a tilt angle. Thus, simplifying the mechanics of the system by using the same component twice to achieve greater accuracy.

6. RECOMMENDATIONS

The resultant data proves that these devices meet the required specifications in order to be implemented in the design of the Geriatric Fall Hip Injury Prevention Device. Therefore further research should be continued on the implementation of the microprocessor and its programming.

Towards the end of this research program, I was notified that the ADXL05 will no longer be manufactured. However, there is a replacement with greater capabilities that meets all the requirements. Hence, new testing should be performed with the new ADXL105 to ensure data accuracy.

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8. REFERENCES

1. G.S. Sorock, Falls among the elderly: epidemiology and prevention, *Am J Prev Med*, 4 (1988) 282-8.
2. W.C. Hayes, E.R. Myers, S.N. Robinovitch, A. Van Den Kroonemberg, A.C. Courtney and T.A. Mc Mahon, Etiology and Prevention of Age-Related Hip Fracture, *Bone*, 18 (1996) 775-865.
3. R.A. Marottoli, L.F. Berkman and L.M. Cooney Jr, Decline in physical function following hip fracture, *J Am Geriatr Soc*, 40 (1992) 861-6.
4. L. Ceder, K.G. Thorngren and B. Wallden, Prognostic indicators and early home rehabilitation in elderly patients with hip fracture, *Clin Orthop*, 152 (1980) 173-84.
5. R.G. Wallace, J.H. Lowry, N.W. Mc Leod and R.A. Mollan, A simple grading system to guide the prognosis after hip fracture in the elderly, *Br Med J Clin Res Ed*, 293 (1996) 665.
6. L. Ceder, B. Stremqvist and L.I. Hansson, Effect of strategy changes in the treatment of femoral neck fractures during a 17-year period, *Clin Orthop*, 218 (1987) 53-7.
7. J.D. Zuckerman, Hip Fracture, *N Engl J Med*, 324 (1996) 1519-25.
8. G.L. Lu-Yao, J.A. Baron, J.A. Barrett and E.S. Fisher, Treatment and survival among elderly Americans with hip fracture: a population-based study, *Am J Public Health*, 84 (1994), 1287-91.
9. M. Thorngren, L.T. Nilsson, andK.G. Thorngren, Prognosis-determined rehabilitation of hip fractures, *Compr Gerontol A*, 2 (1988) 12-7.
10. R.W. Sattin, Falls Among older persons: A public health perspective, *Annual Review of Public Health*, 13 (1992) 489-508.
11. W.A. Hale, M.J. Delaney and W.C. Mc Gaghies, Characteristics and predictors of falls in elderly patients, *J Fam Prac*, 34 (1992) 577.
12. G.B. Aharonoff, G.M. Dennis, A.Elshinamy, J.D. Zuckerman and K.J. Koval, Circumstances of Falls causing Hip Fractures in the Elderly, *Clinical Orthopedics and Related Research*, 348 (1998), 10-4.
13. J.B. Lauritzen, Hip Fractures: Incidences, Risk, Factors, Energy Absorption, and Prevention, *Bone*, 18 (1996) 655-755.
14. L. Clemenson, R.G. Cumming and M. Roland, Case-Control Study of Hazards in the Home and Risk of Falls and Hip Fracture, *Age and Aging*, 25 (1996) 97-101.
15. S. Middelhoek and S.A Audet, *Silicon Sensors*, Academic Press Limited, San Diego, CA, 1989, 128-149.