International Journal of New Technology and Research (IJNTR)
ISSN:2454-4116, Volume-2, Issue-9, September 2016 Pages 70-72

Vibrotactile Mechanism for Proprioceptive System

Sana M.K.

***Abstract*—Good balance and mobility are necessary in order to independently perform acts of daily living and to avoid falls causing injuries or hospitalization. Three sensory systems in the body are primarily responsible for detecting and maintaining balance. These are visual, vestibular and proprioceptive systems. They work together to maintain balance. In a normal individual, the existence of a sensatory pressure below the foot is indicative of his/her body balance. This sensatory pressure has a threshold value, below which the individual loses body balance and this threshold value increases with age.**

The project aims at improving the balance of elderly people by filling the sub threshold region, by providing a mechanical vibration to the foot. This is done with the help of a vibrator motor. Force sensors are used to measure the foot pressure. Vibrator is switched on, only when the output from force sensor is less than the threshold value of detection. Thus, output from the vibrator is given to the position where most crucial mechanoreceptors are located and they are the metatarsal phalangeal joint (MTP) region, the heel and the plantar side of the first toe. Hence, mechanical vibration can increase the intensity of signal and overcome the threshold value of detection and thereby help elderly people maintain body balance.

This device not only helps in improving body balance in elderly people but also finds its application in gait improvement, gait stabilization in Parkinson's patients and relaxation foot massages.

***Index Terms*— Gait, balance, vibrator, MTP.**

I. Introduction

Lack of good body balance can lead to falls causing injuries and hospitalization. Visual, vestibular and proprioceptive systems work together to determine body location, orientation, and total body stability. Among these, the pressure distribution of the foot is necessary for him/her to maintain body stability. Initially, the pressure distribution under different parts of the foot was measured using pressure transducer. The major problems faced during the measurements were huge size and discomfort for volunteers while embedding the sensor in shoe [1]. A capacitive pressure platform was used to find the pressure points of foot. With this the researchers found out that the highest pressure areas of the foot also have contribution from the mid forefoot beneath the second and the fourth Meta tarsal head (MTH) rather than only at the heels [2].

The sensatory pressure below the foot has a threshold value, below which the individual loses body balance. Detection threshold is the magnitude at which a stimulus can be detected by a person. As people grow older their detection threshold also increases.

Sana M.K., CMRIT, Bangalore, India

By applying a vibratory stimulus, it was seen that the detection threshold decreased by 20 mV in the foot and 1 mV on the fingertip for a diabetic patient [3]. Further studies were carried for finding out the relation between detection threshold and the noise signal applied. Gyroscope was used for measuring the postural sway of the body and a vibrotactile belt for providing noise. Vibrotactile belt was provided on waist for reducing the forward and backward body sway [4]. Electrical noise signal was input to the first MTH joint of the right foot and it was found that the detection was very high when compared to experiment done without the addition of stimuli [5].

Since there is non-linearity, hysteresis and drift shown by capacitive sensors, an instrumentation shoe was made with resistive transducer (eg. strain gauge) at eight different areas of the foot. Two transducers correspond to heel, two correspond to the external side of the sole, three under MTH and one under big toe. Pressure distribution pattern during the stance phase of gait was determined [6]. It was found that when the stimulus applied was greater than the threshold value of detection, there is a feeling of sensation. Also, if there is large amount of noise added to the signal there is a decreased sensation felt by the patient [7]. The most crucial mechanoreceptors for developing vibrating insoles were found to be in the MTH region, heel and first toe [8].

Researchers developed an inertial sensor unit comprising of accelerometer and angular rate sensor for analyzing gait and detecting fall. The large velocity developed prior to a fall was used for sensing and generating an alarm. Three types of falls were taken into consideration- forward, backward and sidewise falls [9]. The large size of the inertial sensor unit and the fact that they were wrapped around the waist of the patient caused disconfortance in normal locomotion. The air bladder sensors were used for measuring ground contact force (GCF). These sensors were placed at the heel, first MTH, fourth MTH and hallux of foot. Signals obtained from the sensors were used for classification of abnormal gait from normal gait using fuzzy logic [10], [11], [12].

The large size of the air bladder sensor and capacitive transducers is overcome by the flexi force sensors which cause less discomfort in patients, when embedded in the shoe. Pressure areas of foot were obtained by placing the sensors at the heel, MTH 1, MTH 5, toe and arch. Highest pressure point of foot was obtained at the heel [13]. An intelligent display module of mobile gait monitoring system was used to provide feedback to a patient with abnormal gait [14]. Computational detection of abnormal gait was carried out with Lab VIEW software. The input to the software was from the Force Sensitive Resistance (FSR) sensor placed at four different positions of the foot and an inertial sensor placed at the knee angle joint for measuring the degree of motion [15]. The pressure developed under the second MTH alone, was measured with a strain gauge sensor. Sensors sensed the Anterior posterior (AP), Medio lateral (ML) and vertical forces applied by the foot. Maximum force under the second

MTH was found to be 3.7%, 9.2% and 8.9% of body weight in the vertical, AP and ML direction respectively [16]. Output obtained from force sensors placed at eight different areas of the foot, mainly, hallux, third toe, fifth toe, first MTH, third MTH and fifth MTH, mid foot and heel, were amplified and low pass filtered and then digitised for studying the pressure distribution pattern for diabetic patients [17]. The contribution of each body segment to the angular momentum of five healthy adults was determined by placing 39 spherical markers at different parts of the body. It was seen that the contribution of upper distal segments of the body (level of wrist) and upper trunk showed significant changes with gait and help in detecting fall [18]. Gait analysis of patient with Alzheimer's disease (AD) was performed using a triaxial accelerometer mounted on a shoe. AD patients have shorter mean stride length and lower gait speed. Also the time spent by the AD patient in standing was more when compared to a healthy patient [19]. Acceleration and pressure distribution during slow, normal and fast walking were obtained using three FSR sensors located at ball, lateral border and heel [20]. Stimuli of a sinusoidal nature caused an increase in vibration threshold while reducing the foot sensitivity. So it was concluded that only a stochastically resonant signal can cause an increase in foot sensitivity and decrease in vibration threshold [21]. Recently, it was found that the use of a gyroscope can lead to an increase of 2 % accuracy, in distinguishing between the swings 1 and swing 2 phases of gait [22].

All attempts, so far, have been in reducing the detection threshold by means of an external electrical or mechanical stimulus. The work presented in this paper, focuses on developing a low cost device, which will provide an external mechanical stimulus, when the foot pressure is sensed to be below a predetermined threshold. This is specifically meant for improving the balance of elder by providing a mechanical vibration to the foot with the help of a vibrator motor. Force sensors are used to measure the foot pressure. Vibrator is switched on, only when the output from force sensor is less than the threshold value of detection. The output from the vibrator is given to the position, where crucial mechanoreceptors are located. The mechanical stimulus provided can increase the intensity of the signal and overcome the threshold value of detection.

II. Methodology

A. Subjects

Pressure distribution pattern for 20 healthy volunteers were studied. All subjects were free of any current or prior orthopedic and neurological disorders or injuries. The volunteers belonged to age groups between 23-30 years. A set of 5 trials were carried out for each person with five different body postures. Five postures chosen were the normal balance state for the individual. They are mid stance of gait, the pre-swing phase, foot dragging condition, swing phase and initial contact phase of gait.

B. Data collection

Flexi-force sensor A201 and A401 was taken for the measurement of foot pressure. The sensor was mounted under the shoe at heel (A201), first MTP and toe (A401). The output from the sensor was fed to microcontroller unit. Microcontroller used is NXP LPC1768 which is a 32-bit ARM processor. This is a 40 pin controller and includes 512KB FLASH, ADC, DAC, PWM and interfaces including built-in Ethernet applications. According to the decisions taken from the controller unit, the vibrator part is switched ON/OFF. The vibrator used is basically a DC motor which is used in cell phones, massagers etc (Voltage rating of 3V and maximum current of 0.3A). The complete hardware set up was build and placed inside the shoe. The simulation of each circuit was first designed and simulated using the simulation software Proteus ®. you submit your final version, after your paper has been accepted, prepare it in two-column format, including figures and tables.

III. Results

The threshold value of individuals where done from the foot sensor output. For all the sensor positions the maximum and minimum values as a percentage of total body weight was calculated for each body postures. This will help to decide the switching ON/OFF of vibrator.

Table 1

Position of sensor	Postures	Maximum % of total body weight	Minimum % of total body weight
Toe	1	7.091	1.14
	2	7.90	1.52
	3	8.25	1.10
	4	9.77	1.11
	5	8.104	1.28
MTP	1	6.82	1.66
	2	7.88	1.43
	3	8.01	1.56
	4	8.73	1.38
	5	9.68	1.6
Heel	1	71.4	13.15
	2	70.2	11.59
	3	69	8.26
	4	62.89	8.414
	5	55	7.735

The threshold values were initialized and given as input to the microcontroller unit to trigger the vibrator switching. There is a look-up table used for mapping the weight portion in terms of percentage to output voltage from sensor. These readings were obtained during the characterization of sensors.

This analog value from the sensors is converted to its ADC value. Then, comparison is made with respect to the sensor output voltage and range of threshold values. Whenever the sensor value is not within the range of threshold vibrator is switched ON and if it is within the range of threshold the vibrator is switched OFF. After the operation a feedback is provided to the foot whenever sensor value is not within the range of threshold.

Table 1 shows the threshold values of the individual for different body postures. The maximum and minimum percentage of body weight was calculated for all different postures. The average maximum and minimum percentage of threshold at toe is in the range of 7%-10% and 1%-2%. Similarly, maximum and minimum percentage of threshold at MTP is in the range of 6%-10% and 1%-2%. Finally, maximum and minimum percentage of threshold at heel is in the range of 55%-72% and 7%-13%.

IV. Conclusion

Balance of the body is necessary in order to perform daily acts of living and avoid injuries. There are three sensory systems that are responsible for detecting and maintaining body balance. They are visual system, vestibular system and proprioceptive systems. All these systems work properly to attain a stable position. But due to aging, peripheral neurons become weak and they won't be able to sense the changes. In the case of foot, as a result of aging the peripheral neurons gets completely inactive and pressure distribution on foot doesn't take place properly. Hence, an imbalance is created which causes the individual to fall. So, by providing an external stimulus to the neurons can help the foot to regain its sensation and this signal can be send to brain for proper processing. With the help of vibrators an external stimulus is given to the foot.

Sensation felt on the foot were checked with many volunteers with different body weight. Whenever the foot pressure given on the sensor is not within the range of threshold an indication to switch ON the vibrator was shown on the display and a feeling of sensation was felt by the person. Similar testing was carried out for many volunteers and all were able to feel the sensation of stimulus given with the help of vibration.

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