REVIEW PAPER
International Journal of Recent Trends in Engineering, Vol 2, No. 4, November 2009

# Determination of Location and Orientation of 3-Axis Accelerometer for Detecting Gait phase, Duration, and Speed of Human Motion for Development of Prosthetic Knee

Neelesh Kumar[1*], Nissan Kunju[1], Amod Kumar[1] and BS Sohi[2]
[1]Central Scientific Instruments Organisation (CSIO), Chandigarh 160030, India
Email: *neel5278@rediffmail.com
[2]University Institute of Engineering & Technology (UIET), Chandigarh 160014, India

***Abstract*— The paper discusses results of experiments carried out at healthy individuals with an aim to establish an in-house developed sensor mechanism using ADXL 330 accelerometer. The sensor was developed in view to measure gait phases (heel strike & toe off), gait duration and gait speed. These findings were useful in understanding the range of normal gait though accelerometer and further used for control of indigenously developed artificial electronic knee.**

***Index Terms*— Accelerometer, Orientation, Location, Gait phases, Prosthetic Knee**

## I. INTRODUCTION

Measurement of normal gait parameters through various instrumentation and sensor mechanism are developed [1, 2]. Accelerometer is among one to measure these. They are used to determine walking speed, and gait phases. These findings have clinical use they are limited use in prosthetic control [3. 4]. An intelligent prosthetic device like electronic knee requires knowing in real time the activity of amputee so as to control the prosthetic device to match his gait close to normal. There are sensors embedded in artificial leg which gives sensory inputs decided the walking phase and speed of amputee wearing the prosthetic and invariably determines the appropriate control for the knee. Sensing mechanisms like accelerometer, electro-goniometer, tilt sensor, force sensor are used to record kinematic parameters [5, 6]. Literature reports use of multi-axis accelerometers to calculate the gait phases and walking speed [7]. Authors are actively involved in development of electronic knee joint for above knee amputee patients. For this indigenous development we are working out on optimal sensor mechanism for determining the kinematic and kinetic parameters of walking [8, 9]. In the process we developed sensor mechanism for speed and phase detection using accelerometer and electro-goniometer. For our experiments for acceleration measurement we have developed electronic prototype using ADXL330 tri axial accelerometer from Analog Devices was used. Control of knee is divided into swing phase control and stance phase control [10]. For these control approaches determination of heel strike and toe off is important. The findings will helpful in developing these control algorithms.

## II. METHOD AND MATERIALS

Experiments were done on healthy individuals using in-house developed accelerometer prototyping board for detection of heel strike and toe off (gait phases), walking speed, duration of stance phase (gait parameter). The healthy subjects of similar weight height ratio with prior verbal consent were selected. They were asked to walk on level surface (bare footed) with slow, normal & fast speed according to their own comfort level. Data was acquired as the accelerometer sensor mechanism was attached to different locations of leg. The accelerometer prototype board was designed, fabricated and tested in-house. Voltage output of the accelerometer was calibrated into corresponding human limb movement.

Accelerometer measures acceleration in terms of voltage in X, Y, Z coordinate directions. Output voltage clearly depends on the orientation and position of accelerometer attached on the limb. We have attached the accelerometer to calf muscles (below knee joint) or shank and at ankle point (frontal and sideways) as shown in Figure. 1.1-1.3 respectively. The data was also recorded by placing sensor at thigh and shank of lower limb simultaneously.

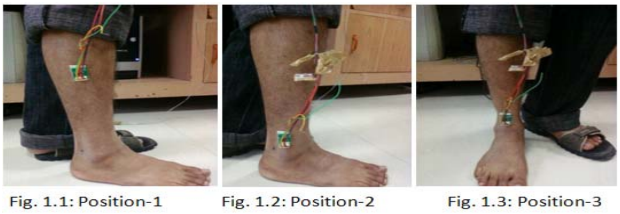


Figure 1. Position of the accelerometer sensor

## III. RESULTS

### *A. Detection of Gait Phase (Heel Strike, Toe off)*

The first aim was to detect the gait phase i.e. heel strike HS and toe off TO. By comparing Fig. 2 and Fig. 3 which is the Y axis output voltage at position 1 and position 2. At position 1 there is very less information (separation between HS and TO) available. Fig. 4 gives the output voltage curve at X axis on position 2. There was remarkable change in the peaks in voltage corresponding to HS and TO but the change is not similar thus no inferences for gait phases can be drawn. We are able to detect heel strike and toe off with the output of X axis at position-2 of accelerometer and that can be done by setting 1750 mV as the barrier for toe off and 1900 mV as the barrier for heel strike. It was also observed that at position 2, Y axis output voltage also give HS and TO (200 mV difference in peaks) but the zero reference line has been shifted from 1.5 V to 1.8V. As more number of experiments are performed it was observed that when the individual was walking slowly some time toe off TO was misinterpreted from X axis output. In order to ensure high reliability and accuracy in gait phase determination data from Y axis was taken for TO and data from X axis was taken for HS. In Fig 5, we concluded that we can detect toe off by setting 2100 mV as the barrier and heel strike cannot be detected because we are getting two peaks at the time of heel strike.

From figure 6, from this data, we concluded that we can detect heel strike by setting 1850 mv as the barrier. Fig 7 shows the output voltage of Z axis at position 3 which is a sinusoidal wave which can't be used for any conclusions.

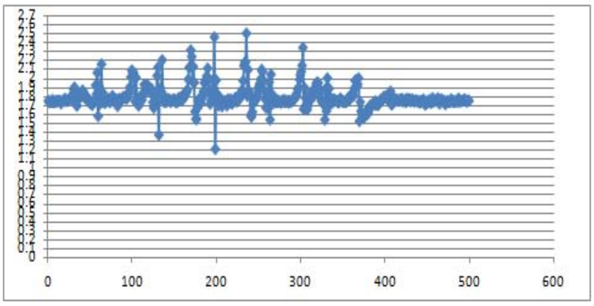

Fig. 2: Output of Y axis at Position-1

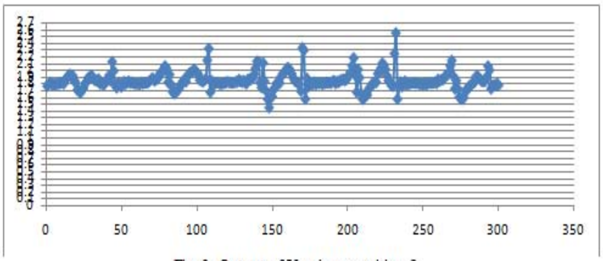

Fig. 3: Output of Y axis on position-2

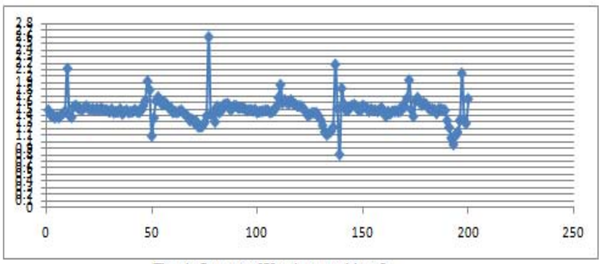

Fig. 4: Output of X axis at position-2

### A. *Detection of Speed*

With the Biomechanics analysis of the knee joint movement and lower limb movement it was found that the acceleration was lower in thigh (upper) segment as compared to that of shank (lower) segment. The range of movement is more at shank segment thus contributing in more acceleration. From Fig 8, 9 and 10, it can be observed that the peak amplitude on the Y axis changes significantly with the change in the speed. The peak amplitude for slow mode was around 2.2 volts; it was 2.3-2.4 volts for normal mode and greater than 2.4 for fast mode. This clearly indicates that there is significant different in the output voltage values for slow normal and fast speed.

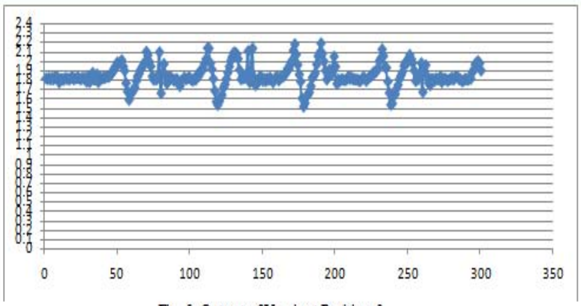

Fig. 5: Output of Y axis at Position-3

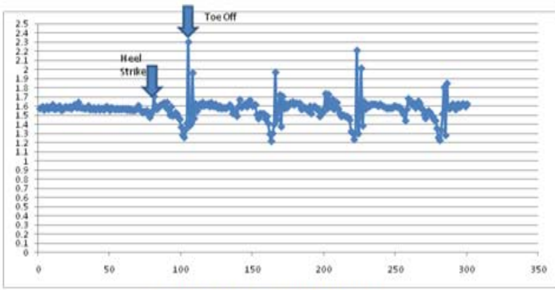


Fig 6: Output of X axis at Position 3

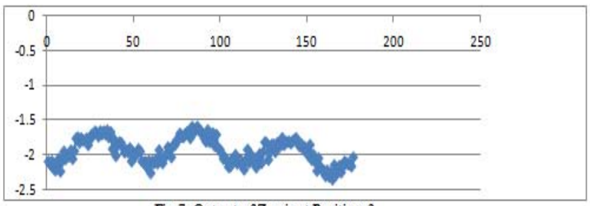

Fig 7: Output of Z axis at Position-3.

### B. *Duration of Stance phase (Gait phase)*

Another way to detect walking speed is to calculate the duration of stance phase. Duration of the stance phase is the time between heel strike and toe off. This time varies with the variation in the walking speed i.e. as the speed increases the stance phase duration decreases. We were able to measure the stance phase duration with the help of software program and it was observe decrement in stance phase duration with the increment in walking speed. The timer that calculates the duration between heel strike and toe off reads around 160 for fast speed, 190 for normal speed and 240 for slow speed. These findings prove that the developed accelerometer sensor mechanism can be used for determining the speed and phase of the walk. The obtained parameters can be used for programming a electronic knee for slow, normal and fast speed control.

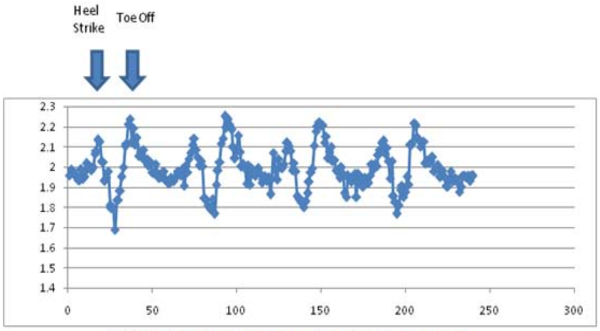

Fig 8: Output Y axis at position-3; walking in **slow speed**

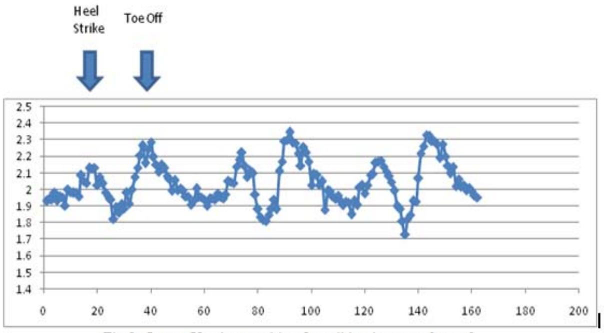

Fig 9: Output Y axis at position-3; walking in **normal speed**

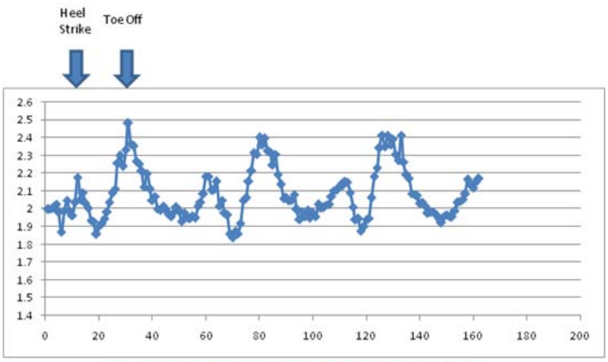

Fig. 10: Output Y axis at position-3; walking in **fast speed**

## IV. CONCLUSIONS

A sensor mechanism for measuring gait phase i.e. heel strike and toe off, gait phase duration and walking speed of individual was developed. Experiments were conducted for optimization of location and orientation of the sensor attached to the human body. Result successfully shows the accuracy, reliability and repeatability of indigenously developed sensor mechanism. It shows concurrence with the theoretical concepts of biomechanics that there is more range of movement in the lower segment (ankle) as compared to that for upper segment (stump). This gives us insight for placement of sensors, acceleration at various body segments during motion and calculation of kinematic and spatiotemporal parameters during gait at different speed. The sensor mechanism can be used in controlling the behavior of prosthetic knee joint. On the basis of these parameters the artificial knee joint will help to amputee patient to walk more near natural gait.

## ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support of CSIR through the project SIP 0022.10 (Development of Electronic Knee).

## REFERENCES

[1] Moe-Nilssen R.1; Helbostad J.L., "Estimation of gait cycle characteristics by trunk accelerometry", Jour of Biomechanics, **37** (2004) pp 121-126
[2] Yoonseon Song, Seungchul Shin, Seungwhan Kim, Doheon Lee, Kwang H. Lee "Speed Estimation From a Tri-axial Accelerometer Using Neural Networks", Proceedings of the 29th Annual International Conference of the IEEE EMBS Cité Internationale, Lyon, France August 23-26, 2007 pp 3224-3228
[3] Matthew Darra, William Eppersonb "Embedded sensor technology for real time determination of animal lying time", Computers and Electronics in Agriculture **66** (2009) pp106-111
[4] Akin O. Kapti, M. Sait Yucenur, "Design and control of an active artificial knee joint", Mechanism and Machine Theory **41** (2006) 1477–1485
[5] Liang Song, Xitai Wang, Siyuan Gong, Zengguang Shi, Lingling Chen, "Design of Active Artificial Knee Joint" APCMBE 2008, IFMBE Proceedings 19, pp. 155–157
[6] Gopalai A. A., Arosha Senanayake S. M. N., "2D Human Motion Regeneration with Stick Figure Animation Using Accelerometers" Proceed. World Academy Sci. Engg. Tech. **29** (2008) ISSN 1307-6884
[7] Saeed Zahedi OBE, Andrew Sykes, Stephen Lang, Ian Cullington, "Adaptive prosthesis – a new concept in prosthetic knee control", Robotica **23** (2005), pp. 337–344
[8] Andreas Heyn, Ruth E. Mayagoitia, Anand V. Nene, Peter H.Veltink, "The Kinematics of the Swing Phase obtained from Accelerometer and Gyroscope Measurements", 18th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Amsterdam 1996, pp 463-464
[9] Teunis Cloete, Cornie Scheffer, "Benchmarking of a full-body inertial motion capture system for clinical gait analysis" 30th Annual International IEEE EMBS Conference Canada, August 20-24, 2008 pp 4579- 4583
[10] H.J H. J. Luinge P.H. Veltink, "Measuring orientation of human body segments using miniature gyroscopes and accelerometers", Med. Biol. Eng. Comput. (2005) 43 pp 273-282