Analysis of a Mobile System to Register the Kinematic Parameters in Ankle, Knee, and Hip based in Inertial Sensors

Víctor H. Flores-Morales, Byron G. Contreras-Bermeo, Freddy L. Bueno-Palomeque and Luis J. Serpa-Andrade

Grupo de Investigación en Ingeniería Biomédica GIIB-UPS, Universidad Politécnica Salesiana, Cuenca, Ecuador

Keywords: Kinematic Parameters, Joint Angles, Wearable System, Inertial Sensors.

Abstract: Understanding the lower-extremity kinematic during daily and sport activities provides important information in order to detect abnormalities in human gait or analyse the execution of different sport techniques. Following this approach, this paper presents a kinematic data collection system of human gait in the lower extremities using six inertial sensors MPU 6050 and a microcontroller ATMEGA328P-PU. Six tests were performed and the angular variation was recorded during the execution. The curves obtained during the tests showed a maximum error of ± 4, ± 1, and -4 degrees at the Yaw, Pitch, and Roll angles respectively. This study proposes a mobile and inexpensive system for detecting the angular variation in reduced speed movements, ideal for goniometric measurement or analyse the techniques in certain sports.

1 INTRODUCTION

The biomechanical analysis of the human gait using optical tracking system has been widely applied to evaluate and diagnose different pathologies. Additionally to determine gait patterns in populations, monitor rehabilitation techniques, and analyse sport techniques. However, these systems have been used in controlled environments, limited by the study area, with restrictions in the person's movement, the equipment's weight, and the high cost of its implementation. As an alternative, in the last years, the accelerometers and gyroscopes have been used to measure the kinematics of the human body. These sensors located on the person's body allow extending the movement range in a larger amount of environments (Foerster et al., 1999; Rueterbories et al., 2010; Liu et al., 2009; Callaway, 2015; Mangin et al., 2015).

The biomechanical analysis of the human gait for clinic diagnosis has permitted to study pathological postures, measure or quantify the effects of a determined treatment, and compare the different protocols developed (Wong et al., 2007). Several methods have been proposed in the literature to address this subject such as the proposal to discriminate between asymptomatic patients and patients with Medial Knee Osteoarthritis using accelerometers and gyroscopes (Turcot et al., 2008) or the system to ambulatory monitor in Parkinson's patients (Hobert et al., 2014). Focusing in older people, an airbag mobile system for fall protection was proposed using a belt, inertial sensors and a compressed air actuator that activates two airbags for hips protection once the sensors detect an acceleration produced by the person fall (Shi et al., 2009).

The different tests developed to quantify the specific movements in contact sports have revealed the generation of errors in the contact and in the fast and abrupt change of speed during a collision (Chambers et al., 2015); it has motivated to search for new alternatives to improve the acquisition of kinematic data. Considering other sport, a wearable system was proposed for monitoring track cycling, using accelerometers to register speed, acceleration, and cadence during the development of the technique (Lattes et al., 2013).

Inertial method and an infrared camera system were compared using sensors located on the athlete's forearm to analyse the accelerations during the armstroke on a swimming bench (Lee et al., 2011). In the same way, the characteristic of the main temporal phases of front crawl on swimming were detected, through algorithm to determine angular velocities and accelerations. The method was compared with a video system showing similar results (Dadashi et al., 2011).

Recent technology miniaturization has motivated to propose smart new wearable systems for monitor-

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DOI: 10.5220/0005934800290033
In *Proceedings of the 4th International Congress on Sport Sciences Research and Technology Support (icSPORTS 2016)*, pages 29-33
ISBN: 978-989-758-205-9

ing continuously the patient's healthcare (Chan et al., 2012). This research presents a mobile system that captures and describes the angular variations in six different movements, performed by an asymptomatic person. The system features a quantification method that helps specialists to complement the biomechanical analysis.

2 MATERIALS AND METHODS

Adaptive physical and anatomical characteristics of a person outfit was designed, to acquire and register the angles of lower extremities during different tests. This outfit consists of: a hip girdle subject into the joint to prevent slipping, two knee supports without pad for a better mobility in the joint, and two open anklets to prevent slipping. The sensors were located where extended rotation occurs. The embedded system collects the data sent by the inertial sensors through an Inter-Integrated Circuit (I2C) communication for a posterior analyses. The kinematic and angular data receipted were used to generate a file to visualize, simulate and analyse the movements made by the individual using OpenSim.

MPU 6050 inertial sensors were used as the basis of the system to acquire the angles, a microcontroller ATMEGA 328P-PU to collect and process the data, a Max 485 to communicate, and a secure digital (SD) card as storage device. A bidirectional I2C communication for sending and receiving data alternately was used between the microcontroller and the inertial sensors. The income data was transformed into angles before sending it through a Serial Peripheral Interface communication bus (SPI), to be organized and stored in different files in a SD card.

The MPU 6050 contains a gyroscope to measure the angular velocity on three axis independently. It allows to calculate the rotate angle on each axis (Euler's angles: ϕ, θ, and ψ) using the uniform linear motion equation. Gyroscope quaternion accumulates an error in the course of time (drift). To complement data, a global frame was used. A gravity vector was generated with the real values obtained in each instant of time by the accelerometer to calculate the Pitch and Roll angles through the equations 1 and 2. The gravity quaternion contains information about the orientation of the relative sensor's axis to the ground reference frame. The resultant quaternion is used to calculate the angles compensating the drift error (Eq. 3):

$$Roll = sin\left(\frac{a_y}{\sqrt{a_y^2 + a_z^2}}\right) \tag{1}$$

$$Pitch = sin\left(\frac{a_z}{\sqrt{a_z^2 + a_x^2}}\right) \tag{2}$$

$$\begin{bmatrix}\phi \\ \theta \\ \psi\end{bmatrix} = \begin{bmatrix}\arctan\frac{2(q_0q_1+q_2q_3)}{1-2(q_1^2q_2^2)} \\ \arcsin[2(q_0q_2 - q_3q_1)] \\ \arctan\frac{2(q_0q_3+q_1q_2)}{1-2(q_2^2q_3^2)}\end{bmatrix} \tag{3}$$

A *.mot* file was generated for recreation of movements in OpenSim with data from the SD card. Data was processed by a low-pass Butterworth filter with ten poles, with a sampling frequency of 100 Hz and a cutoff frequency of 10Hz.

To determine the system's error, a MPU 6050 rotated about a fixed axis. Real data was recollected and compared against the angles given by the algorithm loaded in the microcontroller in different positions. Error measured is presented in table 1.

Table 1: Measurement of error in the system.

	Mean error	Error (Deg)	Probability
Yaw	0.55 ± 4.80	± 4	59%
Pitch	0.27 ± 0.72	± 1	80%
Roll	-3.62 ± 2.35	-4	52%

3 RESULTS AND DISCUSSION

During the first test, two gyroscopes in a state of inertia were connected to a microcontroller. Figure 1 shows the real obtained data by the sensor and after to use the Butterworth filter with a cutoff frequency of 10 Hz. During the second test, one gyroscope with rotational motion was connected to a microcontroller. Figure 2 shows the real obtained data and after to use the filter.

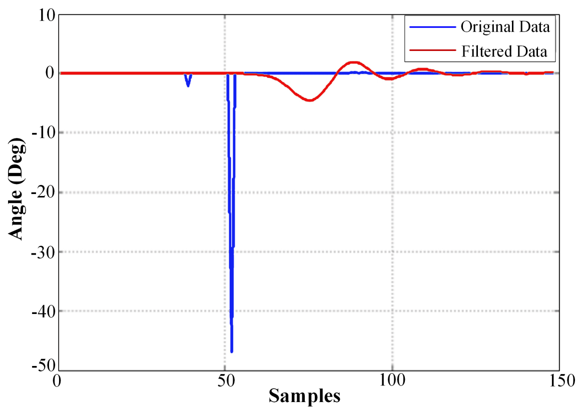

Figure 1: Inertial stability test.

Six tests were performed with the system. All of which were taken from a 24 years-old healthy man

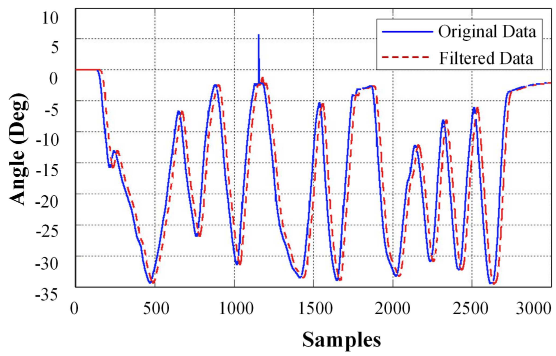

Figure 2: Filtering test with one gyroscope.

using the proposed system Figure 3 shows the different tests developed using the system and the motion's curves generated.

- Figure 3-A shows the hip flexion of 48 degrees.
- Figure 3-B shows the angular variation during a hip abduction of 22 degrees and an adduction of 0 degrees.
- Figure 3-C shows the angular variation during a hip rotation of -25.
- Figure 3-D shows a knee flexion of -73 degrees from rest.
- Figure 3-E shows an angle variation of 32 degrees during the dorsal flexion and -10 degrees during the plantar flexion.

Finally, the figure 4 shows curves corresponding to the hip, knee and ankle during a complete gait cycle in the right leg. The measurements were all made in the sagittal plane using our proposed system and the motion tracking software Kinovea 0.8.15 for Windows, considering that this method is reliable and valid (Balsalobre-Fernández et al., 2014).

This study presents a system based on inertial sen-

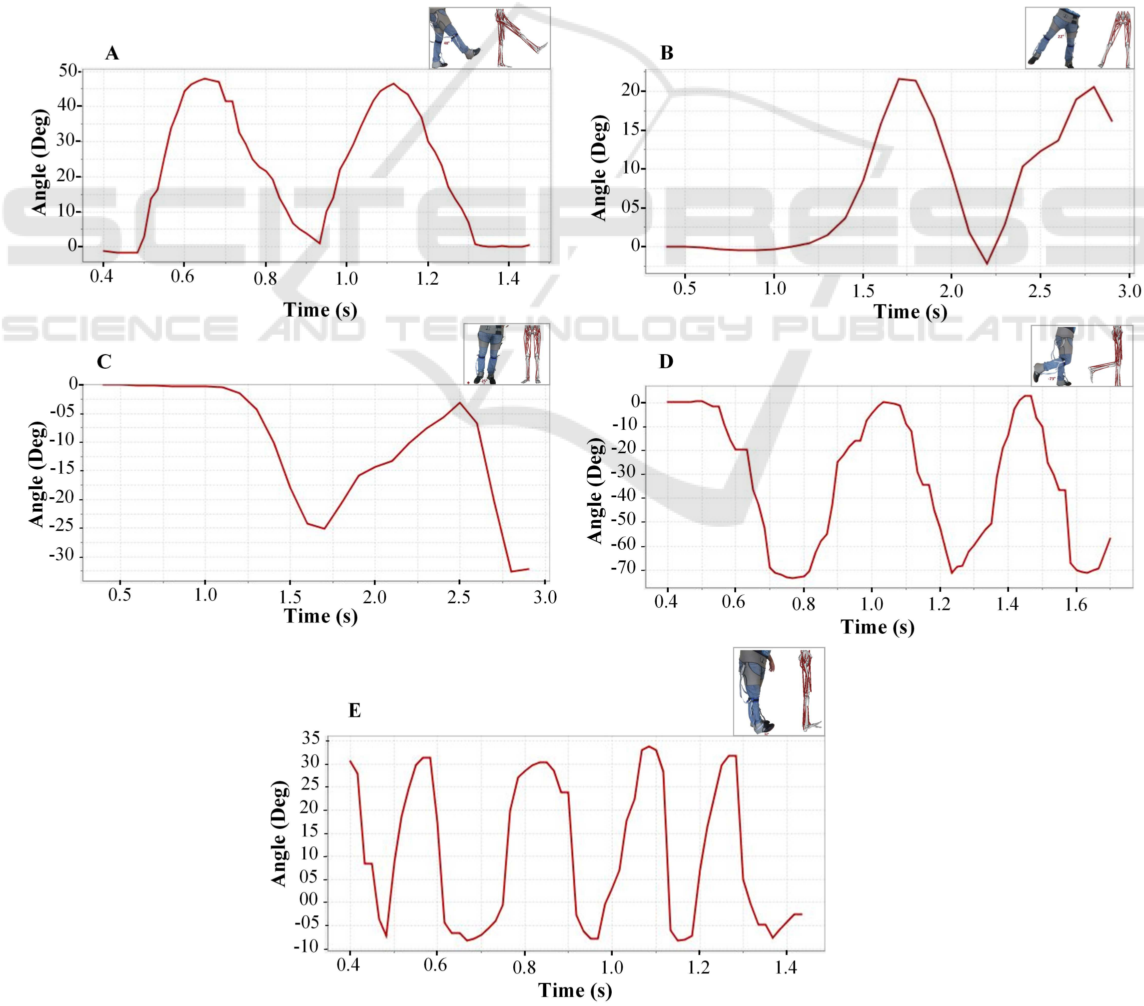

Figure 3: Curve describing: A) flexion in the hip, B) abduction and adduction in the hip, C) rotation in the hip, D) flexion in the knee, and E) dorsal flexion and plantar flexion in the ankle.

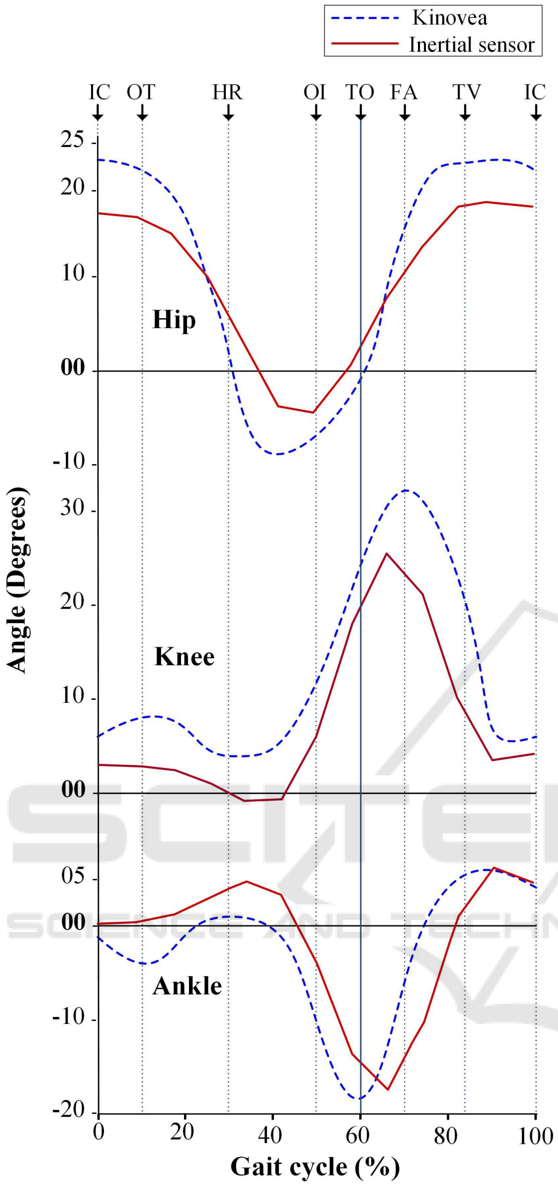

Figure 4: Angular variation of the right leg during a gait cycle on the sagittal plane. IC = initial contact, OT = opposite toe-off, HR = heel rise, OI = opposite initial contact, TO = toe-off, FA = feet adjacent, and TV = tibia vertical.

sors to collect data from the kinematics of a person and represent them graphically in an environment where it is possible to make a detailed biomechanical analysis. The wearable system allowed located the sensors on the hip, knee, and ankle joints in order to develop the different tests on an asymptomatic person. The system has limitations in certain conditions where movement and speed are high and complex.

Different studies have focused in decrease and to eliminate the drift error occasioned by the use of gyroscopes (Alonge et al., 2014). In this field our study used a gravity vector to decrease the accumulate error as shown in table 1. This error is negligible considering the gyroscopes range used. The margin of error as the mean were increased due to false information caused by noise. The results obtained during the static tests (Figure 2) show that the angular variation on the joints have a small variation comparing with the final angle reached during the six tests. The use of the filter caused a shift in the curve of movement on the time axis which is interpreted as a delay episode. As the filter is the same for all the signals, the time delay is the same for all of them. This shows that the delay is irrelevant in this application since they are not being displayed in real time (Figure 2).

Figure 3 shows the angle variation of the volunteer's right leg registered with our system during the execution of six different tests. To validate the value obtained, we used a graduated device to compare the measurements registered. Additionally, figure 4 shows the average angle obtained during a gait cycle test, considering it as a normal speed activity. Our system shows a delayed measurement, comparing it with the results provided by Kinovea system. Particularly, in the hip joint, the maximum angular variation registered is 7.0° at the initial contact. The maximum variation on the knee is 9.1° on the feet-adjacent phase and finally, on the ankle, the maximum variation is 5.0° on the opposite toe-off phase. The gait cycle time of 1.44 s affects directly on the measurements of our system, although the curves have the same pattern, our system registered a lower and delayed angle than the Kinovea system. The microcontroller responsible for data storage and transmission coordination, optimizes the largest amount of data collected considering the complexity in handling serial communication, i2c, SPI, and data processing in the memory space available. To achieve higher speed data capture, it is important to improve the data management; additionally, the calculation should run in a processor of higher capacity.

4 CONCLUSIONS

An embedded system was developed that can be used as orthopaedic tool for recording and analysing kinematic data of a person. The static tests demonstrated that the system can be used for goniometric measurements, to perform outdoor tests, and analysis in certain sporting techniques. The results presented in this study could contribute to the development of a low cost wearable system for the gait analysis using accelerometers. With the respective corrections in the time of data collection and improving the filtering system could be implemented to complement the sports studies at high speed disciplines.

REFERENCES

Alonge, F., Cucco, E., D'Ippolito, F., and Pulizzotto, A. (2014). The use of accelerometers and gyroscopes to estimate hip and knee angles on gait analysis. *Sensors*, 14(5):8430–8446.

Balsalobre-Fernández, C., Tejero-González, C. M., del Campo-Vecino, J., and Bavaresco, N. (2014). The concurrent validity and reliability of a low-cost, high-speed camera-based method for measuring the flight time of vertical jumps. *The Journal of Strength & Conditioning Research*, 28(2):528–533.

Callaway, A. J. (2015). Measuring kinematic variables in front crawl swimming using accelerometers: A validation study. *Sensors*, 15(5):11363–11386.

Chambers, R., Gabbett, T. J., Cole, M. H., and Beard, A. (2015). The use of wearable microsensors to quantify sport-specific movements. *Sports Medicine*, pages 1–17.

Chan, M., Estève, D., Fourniols, J.-Y., Escriba, C., and Campo, E. (2012). Smart wearable systems: Current status and future challenges. *Artificial intelligence in medicine*, 56(3):137–156.

Dadashi, F., Crettenand, F., Millet, G., Seifert, L., Komar, J., and Aminian, K. (2011). Front crawl propulsive phase detection using inertial sensors. *Port. J. Sport Sci*, 11:855–858.

Foerster, F., Smeja, M., and Fahrenberg, J. (1999). Detection of posture and motion by accelerometry: a validation study in ambulatory monitoring. *Computers in Human Behavior*, 15(5):571–583.

Hobert, M. A., Maetzler, W., Aminian, K., and Chiari, L. (2014). Technical and clinical view on ambulatory assessment in parkinson's disease. *Acta Neurologica Scandinavica*, 130(3):139–147.

Lattes, M., Gatti, R., Roa, Y., Fruett, F., and Cunha, S. (2013). Assessment of micro sensor (sm-mae) in monitoring of cycling. In *XXIV Congress of the International Society of Biomechanics*.

Lee, J. B., Burkett, B. J., Thiel, D. V., and James, D. A. (2011). Inertial sensor, 3d and 2d assessment of stroke phases in freestyle swimming. *Procedia Engineering*, 13:148–153.

Liu, K., Liu, T., Shibata, K., Inoue, Y., and Zheng, R. (2009). Novel approach to ambulatory assessment of human segmental orientation on a wearable sensor system. *Journal of biomechanics*, 42(16):2747–2752.

Mangin, M., Valade, A., Costes, A., Bouillod, A., Acco, P., and Soto-Romero, G. (2015). An instrumented glove for swimming performance monitoring. In *Proceedings of the 3rd International Congress on Sport Sciences Research and Technology Support*, pages 53–58.

Rueterbories, J., Spaich, E. G., Larsen, B., and Andersen, O. K. (2010). Methods for gait event detection and analysis in ambulatory systems. *Medical engineering & physics*, 32(6):545–552.

Shi, G., Chan, C. S., Li, W. J., Leung, K.-S., Zou, Y., and Jin, Y. (2009). Mobile human airbag system for fall protection using mems sensors and embedded svm classifier. *Sensors Journal, IEEE*, 9(5):495–503.

Turcot, K., Aissaoui, R., Boivin, K., Pelletier, M., Hagemeister, N., De Guise, J., et al. (2008). New accelerometric method to discriminate between asymptomatic subjects and patients with medial knee osteoarthritis during 3-d gait. *Biomedical Engineering, IEEE Transactions on*, 55(4):1415–1422.

Wong, W. Y., Wong, M. S., and Lo, K. H. (2007). Clinical applications of sensors for human posture and movement analysis: a review. *Prosthetics and orthotics international*, 31(1):62–75.