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

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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 arm-stroke 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-
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 biomechani-
cal 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) communica-
tion for a posterior analyses. The kinematic and an-
gular 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 communi-
cation bus (SPI), to be organized and stored
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 al-

ow 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 gener-
ated 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):

\[
Roll = \sin \left( \frac{a_z}{\sqrt{a_x^2 + a_y^2}} \right)
\]

A .mot file was generated for recreation of move-
ments 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 ro-
tated 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.

<table>
<thead>
<tr>
<th>Angle</th>
<th>Mean error</th>
<th>Error (Deg)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yaw</td>
<td>0.55 ± 4.80</td>
<td>±4</td>
<td>59%</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.27 ± 0.72</td>
<td>±1</td>
<td>80%</td>
</tr>
<tr>
<td>Roll</td>
<td>-3.62 ± 2.35</td>
<td>±4</td>
<td>52%</td>
</tr>
</tbody>
</table>

3 RESULTS AND DISCUSSION

During the first test, two gyroscopes in a state of in-
ertia 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.

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

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 sys-
tem could be implemented to complement the sports studies at high speed disciplines.

REFERENCES


