Android Platform for Realtime Tracking of the Gait Using Inertial Measurement Units

Pablo Aqueveque, Sergio Sobarzo, Francisco Saavedra, Claudio Maldonado, and Britam Gómez

***Abstract*— This paper presents a system for tracking the gait through the use of Inertial Measurement Units (IMU) which are connected by a bluetooth link to a mobile device running an Android system for data acquisition. It also explains how the system works and the way the data gathering is analyzed. The preliminary measurement was made to test how the system works and to analyze the gait with the identification of its two principal stages and some others sub-stages of it. It shows that the system is a viable tool for the physical therapies to realize the measurement of the gait in a simple, comfortable way and with a low cost. We propose a tool to help physical therapists to evaluate in real time the performance of the gait of people with drop foot and compare with the gait when a drop foot stimulator is used.**

***Index Terms*—Inertial Measurement Units, Gait Analysis, Android platform.**

I. Introduction

Human locomotion have a series of alternating rhythmic movements of the low limbs and trunk which defines a forward movement of the body and therefore the center of gravity. Any alteration in that exercise can lead to discomfort and even injury in different levels of the body [1]. Normally, biomechanical gait analysis is done using optical motion capture systems with high-speed cameras and infrared markers [2]. Such systems are sensitive to light, obstacles and are expensive. However, some new systems for the optical motion analysis have been implemented [3] using commercial cameras [4] in order to reduce the costs associated with the system described above, but these systems are limited to indoor environments (laboratories or rooms) and need a high postprocessing time and resourses. Inertial Measurement Units (IMU) have been developed to measure navigation angles without the known problems of accelerometers and gyroscope. Comercial versions of IMU are a good option for movement analysis with a mechanical model of the body. In the field of medicine, these systems have been able to enter in the field of clinical assessment of movement, either complementing or replacing other widely used, for example video based capture analysis, simple visual observation and measurement of diagnostic methods postural stability using posturography. [5] For that reason, a system based on inertial sensors (accelerometers, gyroscopes and magnetometers) is proposed for gait analysis using navigation angles. Three sensors send the data wirelessly to a tablet (android device) and angles evolution of each step can be evaluated. This information permits calculate gait index and evaluate the gait quality on line while the physical therapist is working with the patient. We propose a tool to help physical therapists to evaluate in real time the performance of the gait of people with drop foot and compare with the gait when a drop foot stimulator is used [7], [8].

II. The Gait

In humans, gait involves a method in which, as bipedal species, use their lower limbs for make coordinated and cyclical movements to move. The gait period begins when the foot loose the contact with the floor and ends with the next contact with the floor of the same foot. [1] Thus, from the above definition it is possible to analyze the movement exerted in two phases: the support phase and the swing phase.(see Fig. 1) The support phase can be subdivided into four stages [1]:

- **Contact with the heel** is the initial contact were the gait analysis begins and occurs when the heel contact with the floor, keeping the hip flexed and the fully extended articulation of the knee, while the ankle keeps angle between the leg and the instep [1].
- **The response to the load** occurs in the moment when the heel touches the ground (plantar flexion) and lowering part of the foot begins to make full contact with the ground [9].
- **The stage of medium support** is given at the time when the opposite foot is in the air, so everything that the body supports is concentrated on the foot being analyzed. The knee joint reaches its peak bending at this stage, to result in the dorsiflexion of the ankle joint from plantar flexion [1].
- **The heel lift** is when the heel starts its descent to the floor, where the dorsiflexion of the ankle joint reaches its maximum at the moment when the heel is peeled completely off the ground, starting the foot swing phase [1].

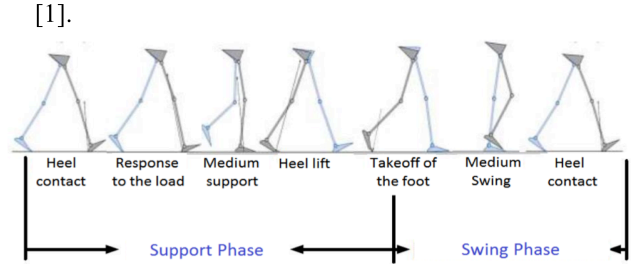

Figure 1. Phases of the gait.

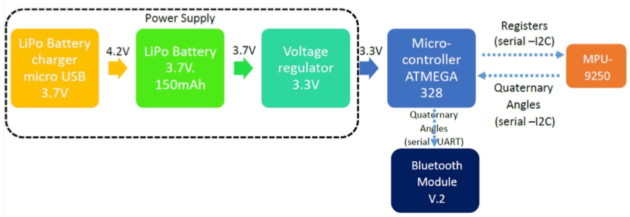

Figure 2. General hardware scheme of IMU sensor.

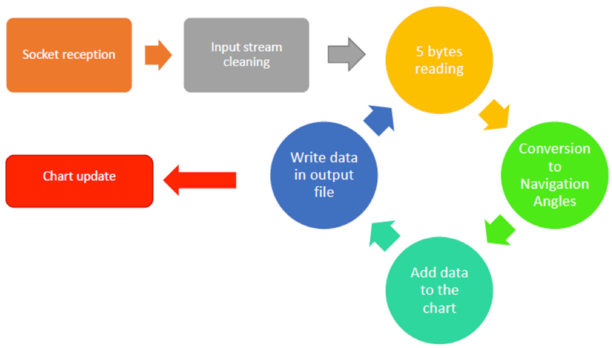

Figure 3. Scheme of data reception and charts update.

Foot swing phase consist in the movement forward of the foot, and is divided into two stages:

- **The takeoff of the foot** considers the time when the entire foot loses the contact with the floor and is the point where the ankle plantar flexion is maximum. To proceed ´ with pendulous movement of the leg forward.[1]
- **The medium swing** is the stage where the ankle passes from plantar flexion to dorsiflexion (to complete the movement of dorsiflexion) reaching this stage the closest approximation of the toes to the floor, to end contact heel on the floor and restart the gait cycle. [1]

III. System Design

A. Inertial Measurement Unit (IMU)

The design of the device should be simple, small, portable and autonomous. As a general outline, the diagram is shown in Figure 2. The system has its own battery charger for the power supply, a central processing for receiving and sending data, corresponding to the microcontroller, the sensor and the transmission system via Bluetooth. Sending format angles measured by the device is quaternary, which implies a transmission of 5 bytes per shipment, 1 per quaternary angle and 1 for an identifier indicating the start of a measurement.

Android Application

As every Android app, the developed application has the next technical requirements:

- Android 4.2 “Jelly Bean” or higher.
- Bluetooth device 2.0 or higher.

Starting the application, the device will ask for permission to activate the Bluetooth device, in case the device is not activated. If it is already activated it will generate a list containing the previously Bluetooth paired devices with the smartphone or tablet so the user can connect the android app with the sensors to receive data from the sensors and perform the tracking. The application has two main parts described below:

1) Sensor’s connection: Connection with Bluetooth devices in Android systems is a system blocking procedure, for this reason the connection is made in a different thread that manages the user interface (UI thread). In case that the connection fails, a screen message will inform the user in order to retry the connection, but if the connection is successful, the application asks the user in which part of the body the sensor is located: thigh, ankle or foot.

2) Data reception: Once all sensors needed to measure are connected, the user accesses to the data reception fragment. In this fragment sockets are received from the previous fragment where the connection was established. In the data reception fragment both threads and connected sockets are created. Each thread is in charge only of one connected socket, get its input stream and keeps reading it and recreating 5 bytes packets to pass them to a specific function. This function receives the raw data packet, writes the data in the output file and gets the three navigation angles from the raw data. Additionally this angles are added to the charts, then through the communication between the secondary threads and the UI thread the charts are updated every 10 samples. All this process is detailed in Figure 3, where the process is showed in a scheme for one single socket. If the user selects to work without charts, this scheme is enormously simplified deleting the blocks of conversion to navigation angles and the addition of data to the charts. Once the measure with the app is finished, a CSV file is saved on the Android device in the following format:

Sensor_Name,index_c,index_s,N_s,t_s,w,x,y,z

The indexes represent the order of connection (index_c) and the segment of the leg where the sensor was located (index_s). The fourth value corresponds to the sample number followed by the time when this sample was read. The last four values are the quaternary angles received from the sensor. Additionally Figure 4 shows three screenshots of the application.

IV. Testing and Gait Analysis

For gait analysis, the measurement protocol is to locate the three sensors in the positions shown in Figure 5, connect them with the application and then wait for the stabilization of measurements, i.e. the graphic lines remain for calibration and after this the march consisting of three to five steps, after which terminates the test. In Figure 6 the angles described by the three joints of the leg during measurement of the walk are observed. Data that is subsequently processed in Matlab for analysis. According to the arrangement of the sensor and in this case, the Yaw curve represents the lateral movement of each segment of the leg, the Roll curve rotational movements and the Pitch curve the movements to front and back, the latter being the most variable during a march in a straight line (see Fig. 7). To make a little deeper in the analysis of the data

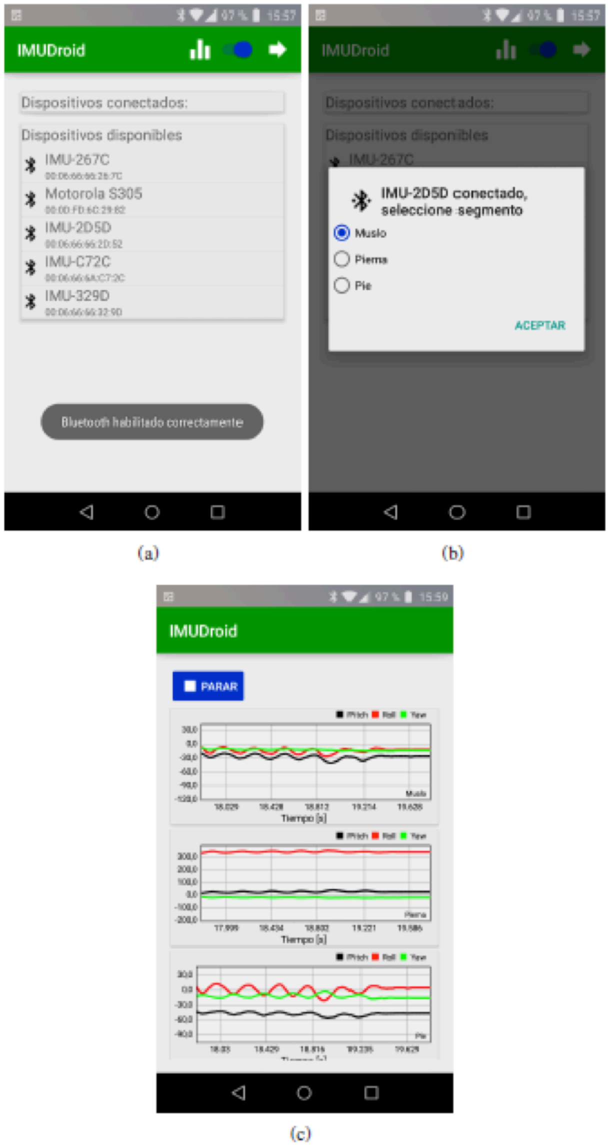

Figure 4. Screenshots of the application, (a) Connection fragment showing the list of devices, (b) connection fragment showing the selection of segment, (c) Reception data fragment showing graphics.

TABLE I
GAIT CYCLE INDEX (GCI) FROM FIGURES 6, AND 8

Index	Value
Time of toe off (% gait cycle)	51.54
Cadence (step/s)	1.60
Minimum hip flexion (°)	1.61
Range of hip flexion (°)	29.88
Peak abduction in swing phase (°)	3.27
Range hip rotation in support phase (°)	18.13
Knee flexion at initial contact (°)	22.60
Time of peak flexion (% gait cycle)	53.60
Range of knee flexion (°)	49.24
Peak dorsiflexion in support phase (°)	8.68
Peak dorsiflexion in swing phase (°)	3.15

Values calculate from measures acquire with the system proposed, and shown in the figures 6 and 8. The GCI in the table were calculated considering a total cycle time of gait of 1.94 seconds. The indexes of the pelvis as pelvic tilt and pelvic rotation could not be calculated because a sensor was not placed in the pelvis zone.

obtained is selected a step in the march of the subject, as shown in Figure 5.8, where it is possible to identify two major stages of walking, and some sub-phases (9). In addition, Figure 8 can dislodge some interesting data to analyze the amplitudes achieved in some movements that are part of the walk, such as:

- Hip flexion: 29.8766 °
- Knee flexion: 49.2409 °
- Dorsi-flexion of the foot: 8.6835 °
- Plantar flexion: 24.2326 °

By reference [10], the above results are within the normal amplitude range of movements of the joints measurements. From figures 6 and 8, can be measure some interesting Gait Cycle Index (GCI) [6], shown in the Table I.

Figure 5. Location of sensors for measurements, A: Hip sensor, B: Knee sensor, C: Ankle sensor

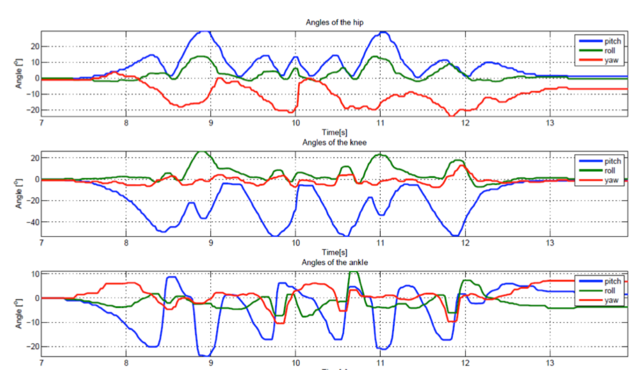

Figure 6. Graphics obtained from the gait test subject.

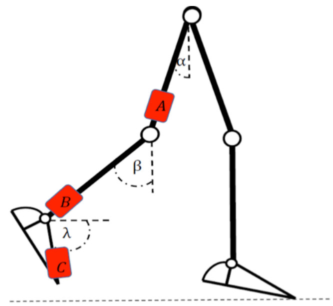

Figure 7. A representation of the sensors measures with its reference axis in sagital plane, where α is the pitch angle of the hip, β is the pitch angle of the knee and λ is the pitch angle of the ankle. A, B and C are the locations described in Figure 5

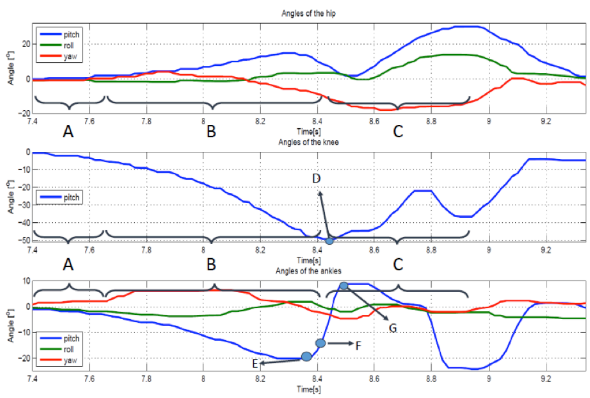

Figure 8. One step of the gait test subject. Where A: Rest, just before the subject begins to walk, B: swing phase when the foot is in the air, C: Support phase when the foot returns to the floor, D: Medium support, E : takeoff of the foot, F: medium swing, G: heel lift

V. Conclusion and Future Works

A system for measuring and evaluating the gait based in inertial sensors was implemented. The system is simple, inexpensive, convenient, easy to use and flexible. The system consists in inertial measurement devices and an Android application for the acquisition and display of data in real time. The use of this application for data collection and the realtime evaluation of gait, is beneficial for professionals in a cheap way to evaluation and monitoring of patients objectively. The system also involves a great help to patients suffering dropped foot, because represents a good option for an objetive evaluation of the gait. Since the portable feature of the system, it becomes easy to move by a treating physician or physical therapist. The system is small (35 x 35 mm), has a calculated 7.8 hours of autonomy, a resolution of 0.01°in their measurements and proves to be an effective alternative for evaluation and analysis of movement at low cost and close to the user. It is proposed as a future work to increase the processing performed by the developed application [11] [12] to provide more clear and direct information for the professional that is using the system to evaluate the gait performance by indexes, to eliminate the post-processing of the data acquired in another platform, and implement an automated web platform that receives the file with the data saved by the application and submit a full report analyzed the patient's condition to record it. In this way, the compatibility of the system is secured in different operative systems.

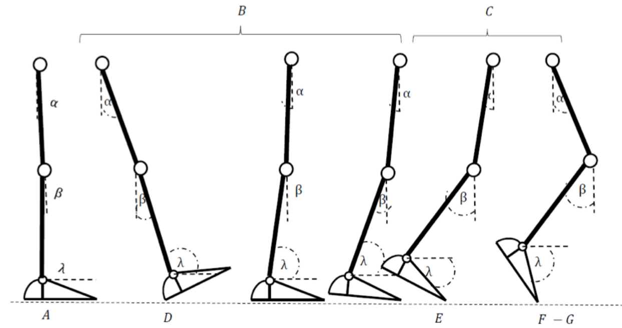

Figure 9. Representation of the phases identify in the test. Where A: Rest, just before the subject begins to walk, B: swing phase when the foot is in the air, C: Support phase when the foot returns to the floor, D: Medium support, E: takeoff of the foot, F: medium swing, G: heel lift

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