DEVELOPMENT OF A DEVICE FOR CLINICAL QUANTITATIVE ANALYSIS OF MOVEMENTS OF THE ANKLE-FOOT COMPLEX DURING GAIT

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Abstract. *The human gait is a functional repetitive daily task and, it complies that altered pattern of movement occur with greater frequency, leading to repeated application of excessive stress on the musculoskeletal tissues predisposing to orthopedics lesions. The excessive internal rotation of the lower limbs related to the movement of excessive pronation of foot is an example of movements dysfunctions during the stance phase of gait. These inadequate movements of ankle-foot complex are accessed in ambulatory environment through qualitative analysis, which leads to inaccurate and subjective conclusions. In researches these movements are quantified by video photogrammetry, which due to the high cost of equipment prevents the clinician application. In this context, the objective of this study was to develop and validate a low cost device based in accelerometers and gyroscopes to quantitatively assess the movements of inversion and eversion of the calcaneus and internal and external rotation of the lower limbs during gait, allowing health professionals numerical data for immediate analysis and possible comparison between pre and post-treatment. This study was conducted in two phases: development of a pilot device for initial validation on a table goniometer at the Laboratory of Mechanical Engineering of UFMG and the final validation of the device comparing their data with the video photogrammetry gold standart, the Qualisys Motion Analysis System at the Laboratory of Human Movement Analysis, in Physical Education, Physiotherapy and Occupational Therapy School at the same university. Preliminarily, the pilot device and the data collected by him will be presented in the results of this article. It is expected that the development of this equipment with simple use and low cost, optimizes the evaluation of the human gait bringing more accurate quantitative data and offering to therapists the possibility to compare before and after treatment.*

Keywords*: Gait, Accelerometer, Gyroscope, Video photogrammetry, Motion Analysis System.*

1. INTRODUCTION

The human foot is composed of 26 bones held together by muscles and ligaments forming 33 joints. Are examples of this joints the subtalar, talocrural and tibiofibular joint (Leardini, 2007) The joints of the ankle-foot complex perform movements such as dorsiflexion, plantar flexion, inversion, eversion, supination and pronation, beyond act in the movement of the toes (Leardini, 2007; Rockar, 1995).

Dorsiflexion is the movement to close the top of the foot to the front of the leg. Plantar flexion is the movement opposed to dorsiflexion. Inversion occurs when the medial border of the foot is directed toward the medial part of the leg and eversion motion would be the opposite. Pronation is a triplanar motion and occurs from a combination of movements, composed by calcaneal eversion, abduction and dorsiflexion of the talus. The supination is the opposite of pronation, a reversal occurred calcaneus, adduction and plantar flexion of the talus (Leardini, 2007; Perry, 1992; Rockar, 1995). These movements are present in most of the functional activities of the lower limbs, such as posture, running and walking (Perry, 1992; Winter, 1990).

The gait is the result of a series of cyclical movements that propels the body forward. The gait cycle corresponds to a stride, determined by the initial contact of one leg to the next initial contact of the same limb. The stride cycle is divided into the stance phase and swing phase (Winter, 2004; Zajac, 2002). During the initial phase of the gait occurs the pronation movement in the subtalar joint, which causes the foot to become flexible to allow the absorption of loads, movements and their adaptation to the surface (Moradela, 2011). At the end of that phase of gait, it does the movement of supination of the subtalar joint, which causes the foot to behave rigidly in order to convey strength, allowing the thrust and the anterior transfer of the body (Moradela, 2011; McPoil, 1985).

The movements of pronation and supination not occur in isolation (Daleo, 2004). When performed in closed kinetic chain, due to their triplanar profile, generate compensatory upward movements throughout the lower limb by means of coupling between the talus and the leg in the talocrural joint (Daleo, 2004; Khamis, 2007; Rockar, 1995). The main compensatory movement promoted by pronation is the internal rotation of the lower limbs, as in supination, occurs the movement of external rotation (Khamis, 2007; Pinto, 2007).

Changes of the ideals movements of the foot during activities performed in closed kinetic chain lead to its malfunction and therefore incorrect movements of lower limb joints, pelvis and spine (Duvalab, 2010). These changes are related to modification of load at various musculoskeletal structures and therefore are associated with various disorders, such as medial tibial stress syndrome, patellofemoral pain syndrome and low back pain (Cibulka, 1999; Powers, 1995; Sommer, 1995).

In researches, these movements are evaluated dynamically and quantitatively by video photogrammetry, which consists of triangulate the position of passive markers placed on specific anatomic points, thus generating the relative positions of each segment in the data collection environment (Allard, 1995; Eng, 1995; Winter, 1990; Winter, 2004). These instruments are expensive, which makes them impractical for use in clinical routine (Allard, 1995; Eng, 1995). Clinically, the movements of the ankle-foot complex are evaluated in open kinetic chain and static posture by goniometry, which limit the direct associations between inadequate movements of joints and related orthopedic injuries. When motion is dynamically observed by qualitative assessment of gait, the result is subjective and prone to misinterpretation (Perry, 1992).

In this context, the objective of this study was to develop and validate a low cost device to quantitatively assess the movements of dorsiflexion and plantar flexion, inversion and eversion of the calcaneus and internal and external rotation of the lower limbs during gait. Preliminarily, the pilot device and the data collected by him will be presented in the results of this article. It is expected the development of this equipment optimizes the evaluation of the human gait, bringing more accurate quantitative data and offering to therapists the possibility to compare before and after treatment.

2. METHODS

This study was conducted in two phases: development of a pilot device for initial validation on a table goniometer at the Laboratory of Mechanical Engineering of UFMG and the final validation of the device comparing their data with the video photogrammetry gold standart, the Qualisys Motion Analysis System (Qualisys Medical AB, Gothenburg, Sweden) at the Laboratory of Human Movement Analysis, in Physical Education, Physiotherapy and Occupational Therapy School at the same university.

For the first phase of the study was used a table goniometer of a combination square C435ME-600 (Starrett®, Athol, Massachusetts) to impose known angles to the pilot device and evaluate their resourcefulness to offer measurement free of uncertainties. The table goniometer was calibrated in the horizontal plane by a alcohol level and the developed equipment was coupled to the ruler of the square. Then, the angles from 0 to 180 degrees were applied following a metric scale of the one degree in the table goniometer illustrated in Fig. 1. During the total period of testing the pilot device captured and stored the angular data in a computer for later analysis.

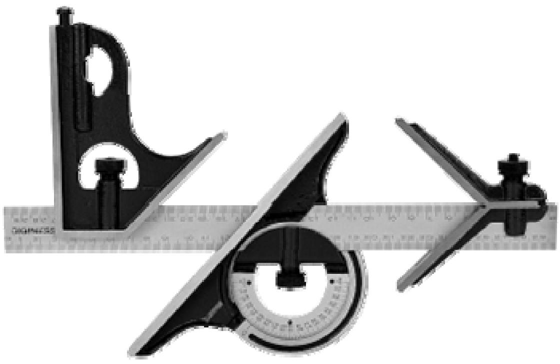

Figure 1. Combination square C435ME-600

After the initial validation, the equipment developed will be validated in relation to the gold standard for human motion analysis. In this phase, 20 volunteers will be invited to participate in the study using the following criteria: age between 18 and 35 years old and be able to walk without mechanical or human help. Had no history of injuries or leg surgery, has no limitations of range of motion of the ankle, knee or hip and do not have hearing or visual impairment not corrected. Participants included will be instructed about the research objectives and if they agree, sign a Consent Form.

Then, gait kinematic of participants will evaluated by developed instrument and the computerized video photogrammetry Qualisys ProReflex at the same time, thus ensuring comparable data. After fixing the prototype in the articular segment in question, passive reflective markers are positioned in specific anatomical landmarks of the lower limbs and pelvis of the participant. There will be a static collection of data with the individual relaxed on standing position. In this collection the participant will be with tracking and anatomical markers. The marks will be fixed in anatomic bony protrusions that specify the boundaries and alignments of the lower limb segments for the subsequent creation of appropriate biomechanical model. The tracking markers, set in clusters, will be firmly affixed to the segments pelvis, thigh, leg and heel. The participant will be asked to walk on his natural speed on a ten-meter walkway. Will be considered for analysis 10 strides that the system can capture all markers.

The processing of video data collected by the system of motion analysis is performed using the software Visual 3D (C-Motion, Germantown, USA). The kinematic data are filtered with a lowpass filter with a cutoff frequency of 6 Hz Dependent variables obtained from the kinematic data are: (a) maximum angle of internal rotation, (b) maximum angle of hip external rotation (c) maximum angle of inversion of the calcaneus, (d) maximum angle of calcaneal eversion (e) maximum angle of ankle dorsiflexion, (f) maximum angle of plantar flexion of the ankle. The average of each variable will be considered at the 10 strides.

Data analysis of all phases of the study will be conducted through the statistical package SPSS version 11.0 (IBM, New York, USA). Initially will apply tests of normality (Shapiro-Wilk) and tests of equal variance (Levene) for the angles variables. The Pearson correlation test will be used to verify the correlation of the measure provided by the developed device and the system of movement analysis. For all the analysis will be considered a significance level (α) of 0.05.

3. PRELIMINARY RESULTS

The pilot device developed consists of two triaxial accelerometers and a gyroscope. Triaxial accelerometers are small sensors able to get the value of the acceleration in X, Y and Z, detect motion, shock, descent and ascent of a slope. Its sensitivity can be selected in 1.5 g, 2g, 4g and 6g, consuming low current. For this pilot device was used only the function of detecting motion in the X and Y planes, where the tilt of sensor in one of these plans are stored variables voltage values related to the angles later. The Plan Z can not be used because the sensor records altitude and not informing the rotation.

Two accelerometers are needed to generate angles for the planes of movement in the frontal and sagittal ankle joint. One of these sensors will be positioned on the side of the leg and another sensor on the side of the foot. Crossing the absolute angle of each sensor at each stage of the gait will be calculated relative angles of interest.

The gyroscopes are angular rate sensors for assessing the instantaneous rotation of objects. These sensors such as accelerometers have small size and low power consumption. In this device only one sensor was used for reading the internal and external rotation of the lower limb in the Z plane of motion.

For the proper functioning of the sensors were built printed circuit boards with a flat cable connector illustrated in Fig. 2. This type of connection and cabling was chosen for easily replacing in case of break and by not disturbing the mobility of volunteers. After the final assembly will be developed a compartment for each sensor separately and facilitate the adherence of the same to the skin of volunteers.

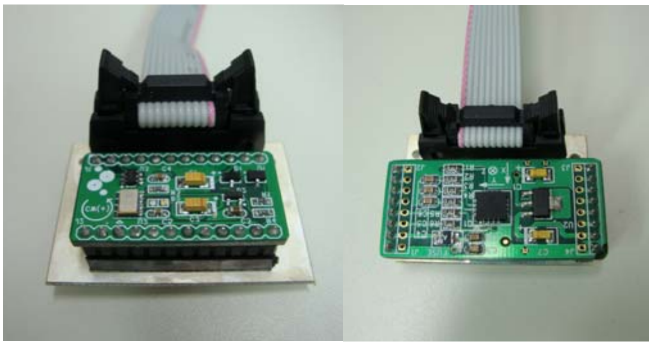

Figure 2. Gyroscope and triaxial accelerometer assembled in circuit board with cables connector

The three sensors are connected to a central board responsible for controlling and supplying each one of them, process and store the collected data as showed in Fig. 3. The data storage will be done in a flash type memory with SD format, thereby facilitating the transfer of data to a microcomputer. The system power is held by a rechargeable battery which will promote freedom for testing in clinical settings and in field.

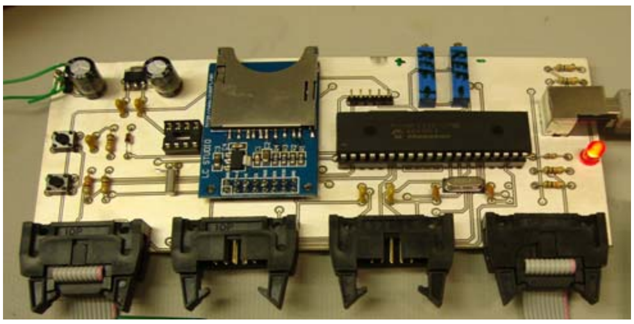

Figure 3. Central board components

After the final assembly of all boards and sensors, a preliminary data collection was conducted aimed at regulating the system and compare the data given by the prototype to the angular data indicated by the combination square. Initially, an accelerometer was fixed on top of the rule of combination square, allowing when tilting this rule, the sensor read data according to the angle indicated by the square. Then, the goniometer of square was positioned in nine random angles indicated in Fig 4. These angles were the recorded and expressed in graph. To continue the research, will be assembled over three sensors, two accelerometers and a gyroscope. The new sensors will be tested in the same way described above and validated in humans by comparing their data with video photogrammetry Qualisys ProReflex. The positioning of equipment in humans can be seen in Fig. 5.

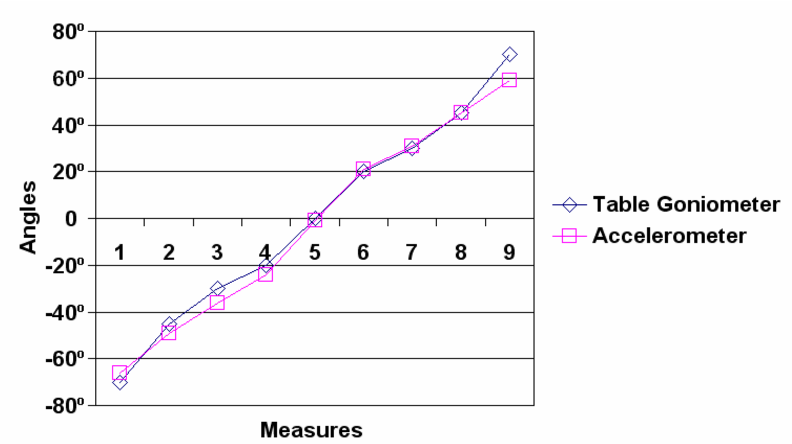

Figure 4. Angles indicated by the table goniometer in relation to the angles measured by the accelerometer

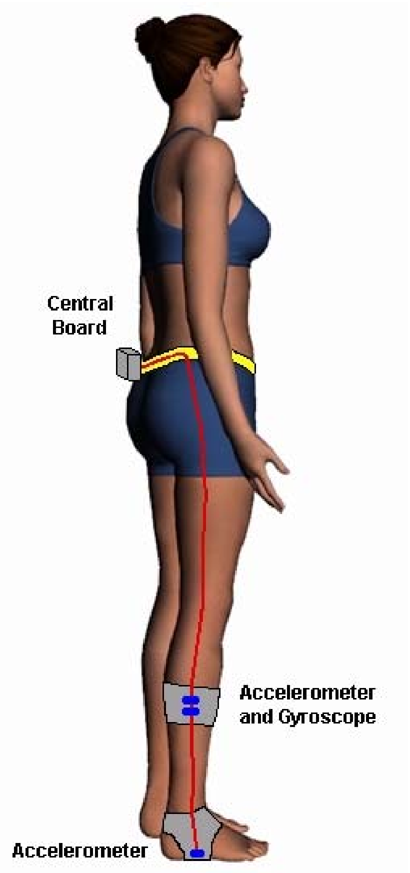

Figure 5: Positioning of equipment in human body

4. CONCLUSION

After completion of the preliminary tests may be concluded that the sensors regulation is necessary for more accurate measurements and perform the tests with the gyro for the construction of the final device to be applied in humans. The developed device will offer reduced cost when compared to computerized systems of video photogrammetry, small size and portability. It is also hoped that their use is simplified and that its use is not restricted only to joints of ankle-foot complex.

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