Design and implementation of an electrogoniometer system for ankle and knee motion assessment in health care

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***Abstract*– In this paper, the design and implementation of a novel electrogoniometer system called WHITE is presented. First, the specifications of the system were gathered based on interviewing health professionals in public and private health centers. Then, the development was divided into mechanical design, electronics hardware and user interface and detailed explained. Finally, implementation and preliminary test is performed showing that the system has an error lesser than 1%. Further work will be focused on using the system for assessing functional activities and compare results with advanced motion tracking system to test its reliability and robustness.**

***Keywords*—Wearable, hall sensor, electrogoniometer, 3D printing.**

I. INTRODUCTION

Active Range of Motion (AROM) is an indicator of joint functionality [2] and essential parameter to describe normal patterns in diverse human motions [1]. In health, after suffering an injury or neuromuscular diseases, decrease in ROM could diminish autonomy and, therefore, quality of life, thus an acutely assessment is valuable for diagnostics, prevention [4] and progress following-up. In parallel, multiple sensor technologies are already available to precisely quantify joint motion [3]. However, the principal challenges for its use in public and private health center remains in the compromise between cost, precision and practicality.

In this paper, a wireless wearable system, composed of two modules:ankle and knee, is presented. This specialized system is attached to the foot and leg's user to measure independently 2 degree of freedom at ankle and one at knee in order to automate data collection and provide tools for further motion analysis.

II. TARGET SPECIFICATIONS

WHITE is a system that accurately measure independently ankle and knee joint rotation motion and aims to be a tool for health professionals to measure principally AROM and its quality in functional activities such as gait, climbing stairs, among others. For this reason, health professionals of public and private institutions had been consulted in order to gather all requirements of the system. Thus, the specifications for the electrogoniometer were the following:

- Practicality: Anatomically design, simple to use and wear.
- Digitalize information: Obtain and store motion information in a central computer for recording and following-up.
- Kinematics analysis: Assessment of quality of motion e.g. for gait: Comparison between data obtained by the system and literature reported.

In addition, for design purpose these characteristics are subdivided into three categories: Mechanical design, electronics hardware and user interface. In the next parts of the paper, each of these will be explained.

III. DESIGN

A. *Mechanical design:*

- *Attachment and structure*

The design includes one and two degree of freedom joints: knee and ankle. Based on literature, principal motion at knee is performed at sagittal plane, and its ROM varies from 5° in extension to 150° in flexion. On the other hand, ankle joint complex has two degree of freedom, one properly called ankle joint or talocrural joint with axis mainly located in the sagittal plane and, subtalar joint (STJ) which has a triplanar axis. STJ's axis widely varies through subjects, and even during motion [5], thus its interpretation could be misunderstood. Therefore, WHITE will measure pronation/supination motion, which occurs only in frontal plane and has a clinical relevance in physiological evaluations [6].

The mechanical structure is composed by two modules: ankle and knee. The ankle module is composed by three bodies: lower, middle and upper support. Lower support is attached to footwear, upper support to calf and middle to connect both. Rotation sensors are placed in parallel to each joint and unite the bodies. In addition, a package that contains the electronics hardware is attached behind the upper support, as it seem in Fig 1a.

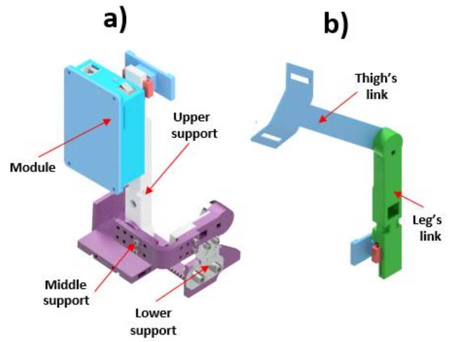

Fig. 1: Module of a) the ankle and b) the knee

The knee module is composed by two bodies: the thigh's link and the leg's link. The thigh's link was designed in order to adapt to the shape of the user's thigh, so it is made it a bit elastic.

- *User adaptability*

In order to be fully wearable, considerations at each joint has been taken. Since knee joint present not only rotation but translation due to it not a pure rotative joint [7], a Self-Alignment Mechanism (SAM) has been implemented to account possible misalignments, this is shown in Fig. 2

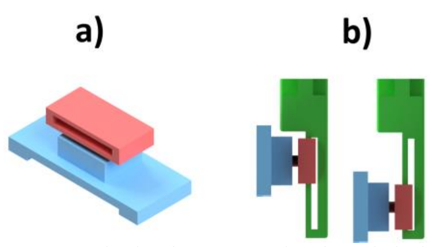

Fig. 2: a) SAM mechanism b) SAM moving through the leg's link

Similar approach has been taken at ankle. As it is possible to see at Fig. 3, a SAM interfaces upper structure to the calf.

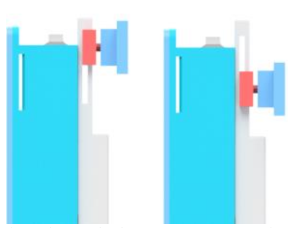

Fig. 3: SAM moving through the upper support in the ankle module

Although, upper support for knee is connected through straps to the leg, a different approach were taken for lower support to ensure comfort and robustness. It presents a mechanism that attaches it to footwear's sole. This solution is secure and quickly wearable, as it is seem in Fig. 4.

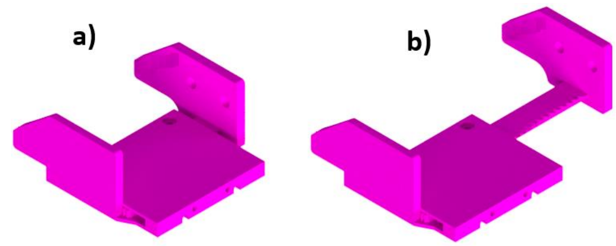

Fig. 4: Mechanism attachable to footwear's sole. a) Mechanism open and b) closed.

B. *Hardware electronics*

For the electronic solution, the block diagram showed at Fig. 5 was proposed.

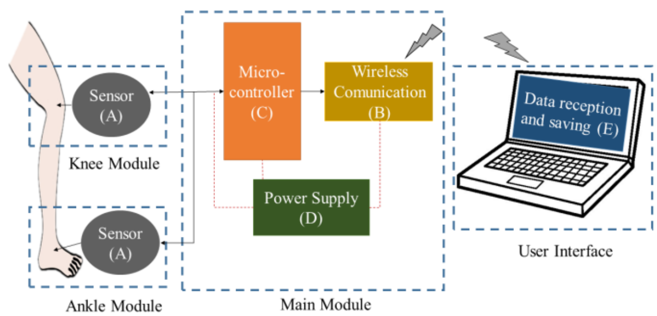

Fig. 5: Block diagram of electronic hardware

In order to obtain precisely the range of motion of the ankle and knee, the electronic specifications were that the sensor would provide less than 1 degree of error and smaller than 5 cm to not interfere with the movement of joints. For that reason, four sensor technologies were analyzed (potentiometers, IMU's, Optic elements and Hall - Effect elements), choosing the Hall Effect sensors due to the noise filtering capacity, small size (TSSOP package) and a longer life-time due to the lack of friction for the sensing method.

In addition, the selection of Hall sensors were done by comparing principal package, and it is summarized on Table I. AS5048B (2 cm including board) were selected for the possibility to have a sensor network without adding more elements (other sensors did not have the possibility to change the address register on Fast I2C), and to use only four cables for a smaller size.

TABLE I
HALL EFFECT SENSOR COMPARISON

Name	Size	Supply voltage	Communica-tion	Resolution
AS5048B	5 x 6.4	5V	Fast I2C - SPI	14 bits
AS5050	4 x 4 x 0.85	3-3.6V	SPI (serial)	10 bits
MLX 90316	4.9 x4.3 x 1.1	5V	SPI - PWM - DAC	12 Bits
AS5601	5 x 4 x 1.25	3.6 V, 5.5 V	Fast I2C – I2C	12 bits

For the wireless communication, three technologies were considered: Bluetooth, Wi-Fi and ZigBee. Bluetooth was chosen because it did not require real-time connection to the web with an access point like Wi-Fi, and had bigger data rate than ZigBee [8]. Further, for the data reception, an USB dongle could be necessary if the computer does not have a receptor incorporated. With an arduino mini pro module, the acquisition and transmission of the data was covered.

Finally, to assure the portability of the system, the evaluation of the energy consumption was made according to the worst case scenario. In this case, the energy consumption is 17.8 mA and, therefore, using a battery of 550 mAh, the total time energized is about 30 hours or equivalent to 1080 evaluation of 10 minutes each one.

C. User interface

The interface contains three windows that are shown in Fig. 6. The first window, shown in Fig. 6a, displays the personal information spaces that need to be filled out with the patient information and the language selection. The second window, shown in Fig 6b, shows the data collection, in other words, the degrees captured by the electrogoniometer. To start the test, the user should press “start communication” button, and “stop and save” to end and save the information captured.

These charts show the signals of the real-time. The third window, shown in Fig. 6c, it displays, at the top, a summary of the patient's main data, at the center, there is a chart where the specialist doctor can enter the treatment to follow and at the bottom are options for saving and printing.

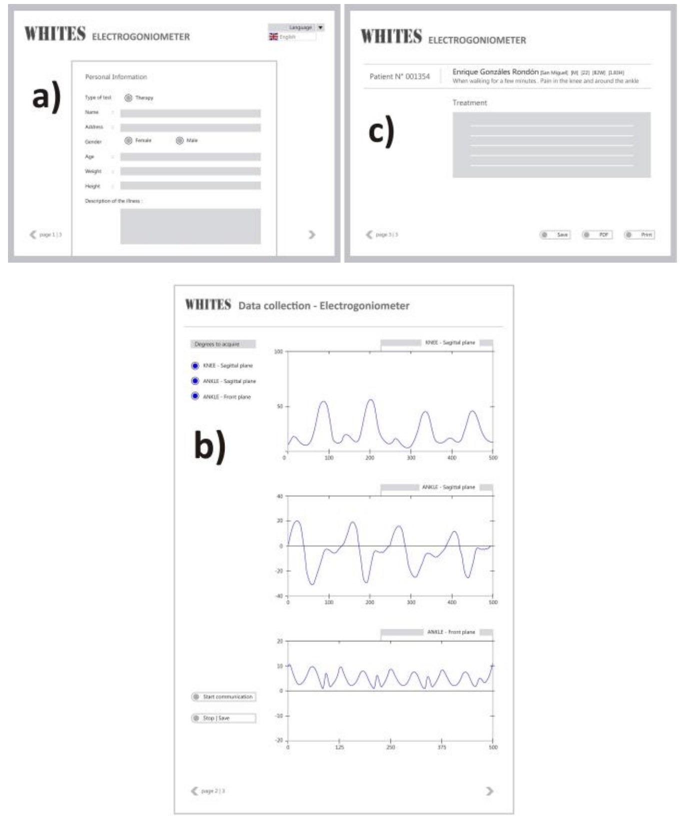

Fig. 6: a) Personal Information b) Data Collection c) Treatment
“Graphs use as reference”

III. IMPLEMENTATION AND PRELIMINARY TEST

Mechanical structure is fabricated using 3D printer “Ultimaker Extended 2 Plus” with ABS plastic. In Fig. 7, the system integrated for ankle and knee is shown.

Fig. 7: Electrogoniometer system implemented using 3D printing

In addition the precision of the sensor was tested. In TABLE II, the relations between angle measure by a protractor and the sensor are shown for different angles.

Fig. 8: Use of protractor for measuring sensor signal

TABLE II
HALL EFFECT SENSOR ACCURACY TEST

Test	Protractor [º]	Sensor [º]	Error (%)
1	360	360.18	0.05
2	45	45.35	0.8
3	90	90.62	0.7
4	135	135.09	0.1
5	180	180.00	0
6	225	225.26	0.1
7	270	270.35	0.1
8	315	315.40	0.1

IV. Conclusions and Future Work

In the present paper a design and implementation of an electrogoniometer system is presented. Based on the tests performed, its error is lesser than 1% (or 1º). Finally, in further development, tests in functional activities such as walking and climbing stairs will be performed to ensure its reliability and robustness of the system.

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