Device, Continuous Passive Motion-CPM, for the rehabilitation of motor skills of the forearm and wrist using a mobile application and Arduino

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Abstract – The objective is to support with this intelligent device to patients with injuries in the upper extremity. **HS1 Forearm and wrist, Pronation/Supination CPM (HS1-CPM)**; is an intelligent device of rehabilitation therapeutic with Bluetooth technology, where, the Range of Motion (ROM) is controlled and monitored by means of short-range radio signal technology that uses radio frequency fields to transmit signals over short distances between devices. The mobile application used, also called a mobile app, is a type of application designed to run on a smart mobile phone using App Inventor to control the **Hand Smart device (HS1-CPM)**. Besides, through data collection and analysis, the therapist will rely in this case on the joint movement of the patient's upper extremity after having performed the rehabilitation therapy with the intelligent device HS1-CPM, the analysis of data obtained by the Leap Motion Controller (LMC) sensor, which captures the position of the joint movement of the affected upper extremity, this data obtained will help therapists to quantify the patient's improvement and/or identify the problem areas of the patient's upper extremity injury.

Keywords— Rehabilitation, ROM, Movile app, Arduino, LMC, HS1 – CPM, upper extremity.

I. INTRODUCTION

CPM rehabilitation is a main key to regenerate the performance of the hand to achieve enough performance [1]. The LMC certainly represents a revolutionary input device for gesture-based human-computer interaction [2]. The elbow is prone to stiffness after trauma, to regain this functional movement the physiotherapist under his supervision will apply rehabilitation using a CPM device immediately [3]. Patients after joint surgery require CPM devices that are carried out continuously, the movement is applied to reduce the stiffness that occurs in the joints after joint surgery [4]. CPM device therapy is a common procedure in postoperative rehabilitation [5]. Kinematic analysis of the upper extremities provides information on the control of the movements of the central nervous system, the LMC is a portable and inexpensive tracking device that allows recording the position of hands and fingers in 3D [6]. The LMC is a motion capture device that tracks hand, wrist, and forearm position [7].

II. MATERIAL AND METHODS

A. CPM device design and development (HS1-CPM).

HS1 Forearm and wrist, Pronation / Supination CPM (HS1-CPM); is a device Intelligent of rehabilitation therapeutic with Bluetooth technology. Fig 1.

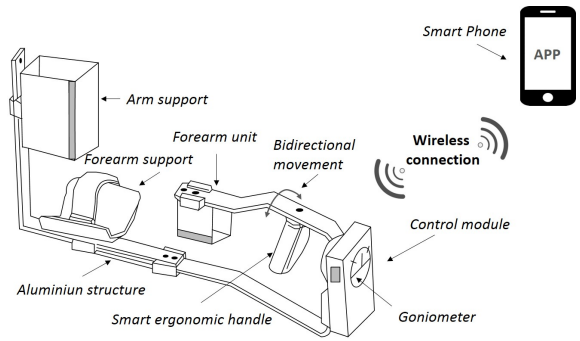

Fig. 1. HS1-CPM / CINVESTAV IPN

The schematic in Fig. 2, shows the major parts of the developed CPM device. These include the main controller board (Arduino UNO), stepper motor to provide rotational motion, stepper motor driver board, Bluetooth module chip to make connectivity between the main controller and the mobile phone, limit switches to provide feedback on the limits of Range of Motion (ROM), and an electrical power supply for the whole device.

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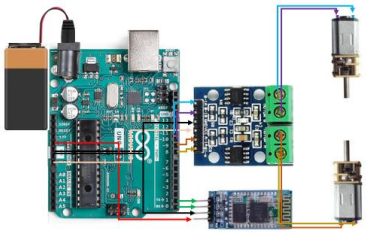

Fig. 2. Schematic of the Developed CPM device. (HS1-CPM)

B. Mechanical System Design and Development

Operation is from the bi-directional gear driven drive of the two electric stepper motors, this rotational motion will rotate the main gear which in turn will move the forearm unit and ergonomic handgrip of the smart device to degrees of Range of Motion (ROM). Fig. 3

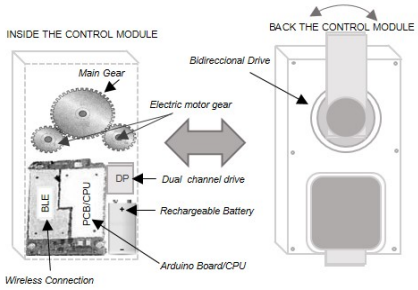

Fig. 3. Mechanical and Electric System Design

The ergonomic handle will present a torque when the electric actuator produces a bidirectional rotational movement in the control module. The movement of the radiocarpal joint in which Pronation and Supination are performed involves two joints mechanically linked proximal radio-ulnar and distal radio-ulnar. The Range of Motion (ROM) for rehabilitation therapy in joint movement in the forearm and wrist will be: (Pronation = 0° to 85° / Supination = 0° to 90°).

This bidirectional rotation movement or Range of Motion (ROM), causes two movements in the joint of the forearm and wrist reflected in a number of degrees in the Goniometer, which is the instrument used to read the angle of flexion between joints and his movement. Fig 4.

Fig. 4. Control module: Goniometer / HS1-CPM Prototype

The two joint movements of the forearm and wrist to be carried out by the patient in his upper extremity are Pronation and Supination. Both joint movements occur between the bones of the forearm, at the trochoid joint between the ulna and radius at the level of the elbow. Fig 5.

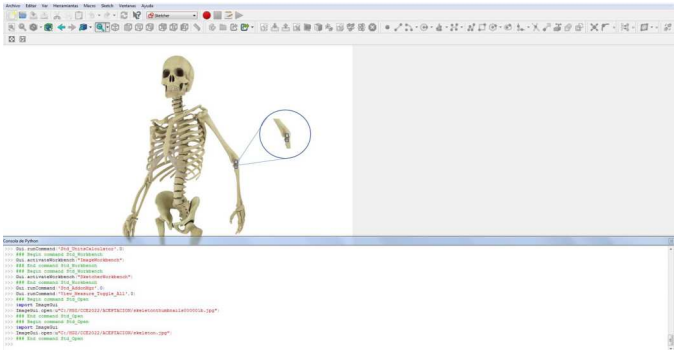

Fig. 5. Range of Motion ROM / Forearm and Wrist Pronation and Supination

C. Electrical and Electronic System Design

The Arduino UNO board (with Atmega 328P-PU processor) was used as the main controller of the CPM device. This board is an easy solution for controlling the rotation amounts, direction and speed of stepper motors. Fig 6.

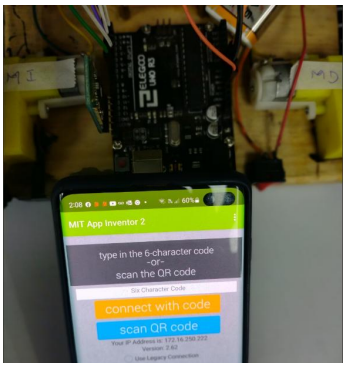

Fig. 6. Electrical and Electronic System Design (HS1-CPM)

The Arduino board was connected to the mobile phone via the Bluetooth module (hc-05), and to the stepper motor via the motor driver and position limit switches used form Range of Motion (ROM) limits. Therefore, the Arduino UNO board has full control of electrical and electronic system components. The Arduino UNO board contained a control code developed using C++ language in Arduino IDE software. The Range of Motion (ROM), is controlled and monitored using short-range radio signal technology that uses radio frequency fields to transmit signals over short distances between devices.

D. Mobile application Development.

Mobile application, also called Mobile App is a type of application designed to run on a smart mobile phone using App Inventor 2 to control the HS1-CPM device. Fig. 7.

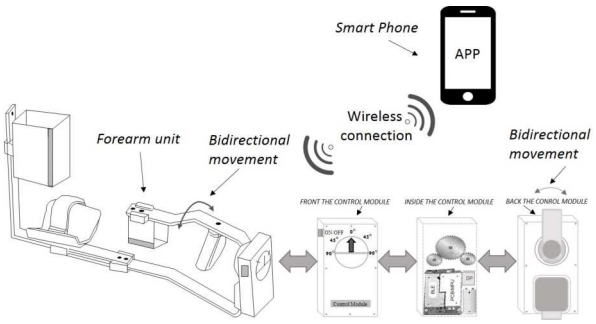

Fig. 7. HS1-CPM device with Mobile application and Arduino

A mobile application or mobile app was developed to control and monitor the HS1-CPM device, the mobile application used is App Inventor for smartphones that work with Android.

The smart mobile phone connects with the HS1-CPM device through the wireless connection module, then access is given to the control software installed in the microcontroller-CPU of the device's Arduino card, with the control parameters it begins to operate the HS1-CPM until the trajectories of the joint established in the patient's forearm and wrist motor rehabilitation therapy are completed.

E. *Data Input Module*. The data captured by the LMC sensor generates 3D spatial and temporal information of movements in real time. It uses three infrared LEDs and two monochrome IR cameras to capture joint movements of the patient's upper extremity in a 150° field of view with a range of approximately 25 to 600 mm within a hemispherical field.

The LEDs produce the infrared light for the cameras to generate approximately 200-frame images of the patient's upper extremity.

F. *Data Analysis Module*. A program coded in C# processes the stream of frames from the sensor and extracts data from the movement of the patient's upper extremity, then forms a data structure based on the 3D spatial and temporal information. Fig. 8

$$\rho = \phi\,(x, y, z), t \quad (1)$$

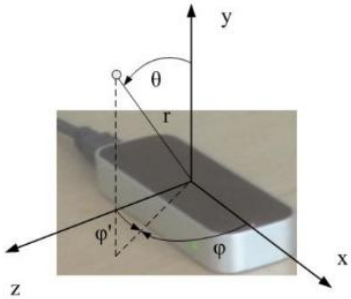

Fig. 8. The cartesian and spherical coordinate systems used to describe positions in the controller´s sensory space.

III. RESULTS

The analysis of the data obtained during the capture of the movement from images using the LMC, the patient performs the movement of the radiocarpal joint pronation and supination, where 2 joints mechanically linked proximal radio-ulnar and distal radio-ulnar of his upper extremity intervene this without the help of the HS1-CPM. Fig. 9

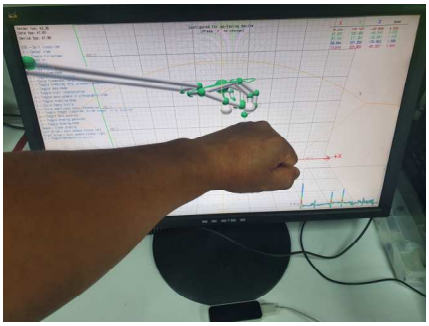

Fig. 9 Radiocarpal joint movement using LMC without help of HS1-CPM / Pronation and Supination.

LMC captures the movement of the patient's upper extremity with a sampling frequency of 60Hz. The patients performed the pronation and supination radiocarpal joint movement on their own after completing and undergoing rehabilitation therapy with the HS1-CPM device for 30 minutes. The data obtained using the LMC without the aid of the HS1-CPM are plotted on the Fig. 10 and Fig. 11. Pronation and supination of the upper extremity are easily visible when the elbow is flexed to 90°.

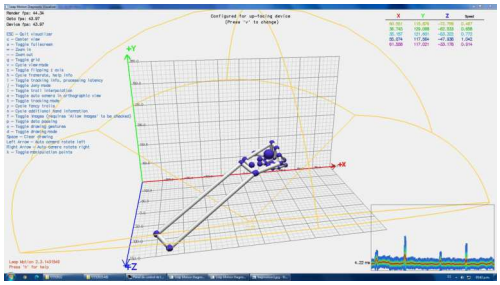

Fig. 10 Rotation of the forearm in which the palm faces down Pronation

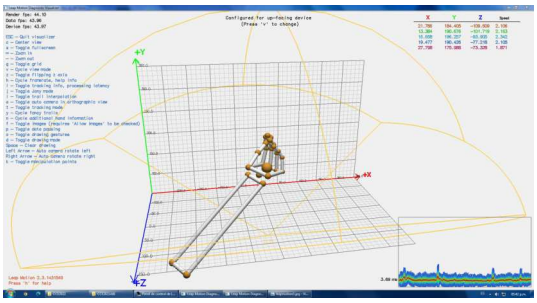

Fig. 11 Rotation of the forearm in which the palm faces up Supination

Another important piece of information obtained was the Angle that the upper extremity of the patient keeps using LMC. Limits of agreement (LOA) is defined as the mean difference ±1.96 standard deviation (SD) of the difference (red lines). Fig.12.

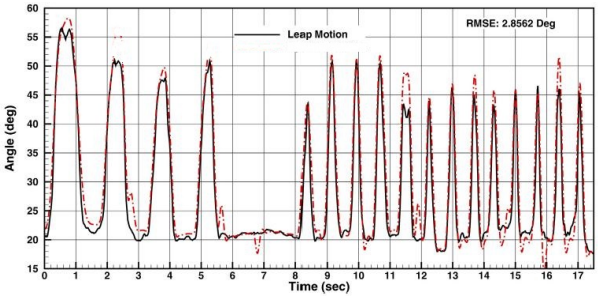

Fig. 12 Upper limb angle using Leap Motion Controller

IV. DISCUSSION

Wrist recovery using CPM devices are one of the most common rehabilitation treatments. The estimation of ROM is an important medical evaluation. Physio- therapists often utilize inclinometers and goniometers to quan- tify the angular distance of hand joints, however this approach is time consuming for determining ROM. The HS1-CPM assistive device was used to exercise the patient's upper extremity ROM. During rehabilitation therapies, patients with different injuries in their upper extremity usually follow the therapist's instructions to recover the full ROM of the wrist. The LMC sensor provides an effective tool to measure active joint ROM of the patient's upper extremity injury. By comparing the measured ROM to the normal ROM of a healthy joint, patients can assess their joint movements. Active ROM of the patient's upper extremity joint can be accurately tracked, recorded and displayed in the developed framework.

V. CONCLUSIONS

The study carried out was to examine the movement of the radiocarpal joint in patients with injuries in their upper limb after having undergone their rehabilitation therapy with the HS1-CPM device. The device HS1 Forearm and wrist, Pronation/Supination CPM (HS1-CPM); Its purpose is to achieve routine physical movements in the joint of the affected upper extremity of the patient within a predetermined Range of Motion (ROM). The study carried out verified the therapeutic effectiveness of the HS1-CPM device, in the therapeutic process by the treating medical area, this is due to the feedback of an external observation resulting from the adjustment of the actions and the repetition in the rehabilitation of the upper extremity of the patient. Through the evaluation of real-time data, the movements of the upper extremity are evaluated to guide the rehabilitation process or Range of Motion (ROM), in the joint movement of the forearm and wrist using the HS1-CPM device under the control and monitoring of the mobile app. The HS1-CPM device can be used as a means of forearm and wrist rehabilitation in hospitals or at home. By assessing real-time data with LMC, forearm and wrist movements can be evaluated to guide the exercising process with device HS1-CPM. The therapists measured the Range of Motion (ROM) of the forearm and wrist, with the help of the analysis of data obtained by the LMC sensor, which captures the position or degrees of joint movement after having used the HS1-CPM device in therapy. The Leap Motion sensor provides an effective tool to measure the active ROM of forearm and wrist. In the rehabilitation, the data obtained with LMC helps therapists to quantify the patient's improvement and/or identify problem areas of the injury. The system LMC uses data processing methods to analyze, record, and display movement data from the affected joint. The HS1-CPM device is recommended for patients with injuries to the distal radius, radius and ulna, radial head, humerus and ulna, carpal-radius-ulna joints, radial ulnar synostosis and carpometacarpal joints. The next phase of work may to enhance the robustness and ergonomics mechanical.

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