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IntelliCane: A Cane System for Individuals with Lower-Limb Mobility and Functional Impairments

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***Abstract*—**The purpose of this research paper is to study and develop a system that is able to help identify problems and improve human rehabilitation after traumatic injuries. Traumatic injuries in human's lower limbs can occur over a life time and can have serious side effects if they are not treated correctly. In this paper, we developed an intelligent cane (IntelliCane) so as to help individuals in their rehabilitation process and provide feedback to the users. The first stage of the paper involves an analysis of the existing systems on the market and what can be improved. The second stage presents the design of the system. The third part, which is still under development is the validation of the system in real world setups with people in need. This paper presents mainly stages one and two.

***Keywords*—**IntelliCane, 3D printing, microprocessor, weight measurement, rehabilitation tool.

I. Introduction

IT is very well known that the shortage and expenses associated with human physical therapists are a real problem and these two factors diminish the time that patients spend in therapy. In this context, our paper deals with intelligent microcontroller devices and Android application system for IntelliCane, a cane system for individuals with physical impairments for self-assisted rehabilitation and home usage. The use of these applications in concordance with the cane system helps and guides individuals with physical lower limb mobility and functional disabilities in the rehabilitation process. The system that we developed can be extended and also help the user to understand the environment by using a LIDAR sensor and translate this into sound, in the case of users with visual impairments. It can also be used to conduct a recovery program for individuals that have suffered physical accidents such as fractures and other medical issues that require an external support for walking. Because of the electronics and microprocessor market, it is growing very fast nowadays, and all the microprocessors are becoming more performant in a matter of computing power, the use of this kind of components is facilitated in daily use products for every kind of applications. For example, back in the 80s when the first microcontrollers were emerging, they were quite large in size and very slow in computing performance, they were very similar to a pocket calculator with very limited applications.

There are many types of functional rehabilitation systems at research level used to restore or improve lower limb functionality. "One of them is the Hybrid Assistive Leg (HAL), developed by Prof. Sankai at the Cybernics Laboratory of the University of Tsukuba in Japan [4] and the Berkeley Lower Extremity Exoskeleton (BLEEX), developed by Prof. Kazerooni at the University of Berkeley in the USA."[12]. The HAL device is a walking aid [9] system used for people with walking disorders or in rehabilitation programs. The HAL device was successfully used for gait training patients with lower extremity paresis [10]. The researchers from HAL device are using control method based on biological and motion information.

Another example is BLEEX, which is a robotic exoskeleton for human performance augmentation capable of carrying its own weight plus an external payload [11]. The average speed it is around 1.3 m/s with a payload weight of 34 Kg. The human-machine interface on this system it is based on sole pressure measurements and no direct measurements so the issues associated with interaction for or muscle activity are not present. It has 7 degrees of freedom driven by hydraulic cylinders organized like this: 3 on hip, one at knee and 3 for the ankle. Furthermore, another lower limb rehabilitation system that is more closely related to this paper is the one done by Dr. Patric Aubin at University of Washington [3]. This system is based on a metallic cane, a force sensor was added for providing information about the applied force and microcontroller for algorithm integration and communication.

Over 33% of people around the world older [1] than 45 suffer from osteoarthritis, and this can cause, loss of motor functions and pain while moving [7], [8]. In order to reduce these side effects, we proposed using the IntelliCane. The authors in [5] show that real-time biofeedback has been shown to be effective in reducing the knee adduction [2] moment, and to reduce knee pain after a few weeks of testing and one-month post-training in individuals with knee osteoarthritis [6]. Also, this system can be used on patients that have suffered fractures and muscular damage from accidents. Moreover, if two of our IntelliCane systems will be used, it can also be used for rehabilitation therapy for individuals with traumatic brain injuries (TBI) that suffered motoric function degradation.

The system is designed to be easy and fast manufactured using 3D printing manufacturing technology, lightweight, easy to use and remotely accessible by the medical personnel. It has wi-fi communication, ultra-low power for long battery life,

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and can be connected to the internet.

The paper is structured as follows: Section II presents the System architecture, Section III presents the results, Section IV describes the medical analysis, Section V illustrates the Mechanics, Section VI presents the Experimental results and Section VII concludes our paper

II. System Architecture

A. High-Level Design

The central part of the system is the microcontroller itself; it is the main component that makes all the calculations and decides if the forces applied to the cane are following a specific path or not. The information about the force it is gathered by MCP3914 sigma-delta ADC made by Microchip Technologies, it is a special ADC with a very high resolution, 24 Bits, and a high gain and low noise amplifier. The communication with these parts it is done through an SPI interface, which it is very fast and the data can be acquired and processed in real time. By using the sigma-delta ADC, we can read the analog output of the load sensor, a sensor that is made of four resistors. The load sensor it is a resistive bridge sensor, which converts the force load into an analog signal, the sensor has a nonlinearity of 0.03%, and a good temperature drifts over the 0 -- +50 degree Celsius.

The whole system is driven by a Li-ion battery that gives the system autonomy of 48 hours or more.

In order to log data from the system, a PC or Android application can be used. Moreover, the data can be logged to a local SD card with an FAT32 file system, the information it is then stored in a .csv or. excel file. To communicate with the graphical user interface, either it is an android/iOS system or a Windows computer; we use a Wi-Fi interface, that can offer us a distance freedom up to 100 meters or more.

Another vital component of the system it is the feedback part, which can be a speaker that provides audio feedback, or a vibrating motor that offers a haptic effect, both can be combined to create the best feedback for the user. Please see Fig. 1 for an overview of the system.

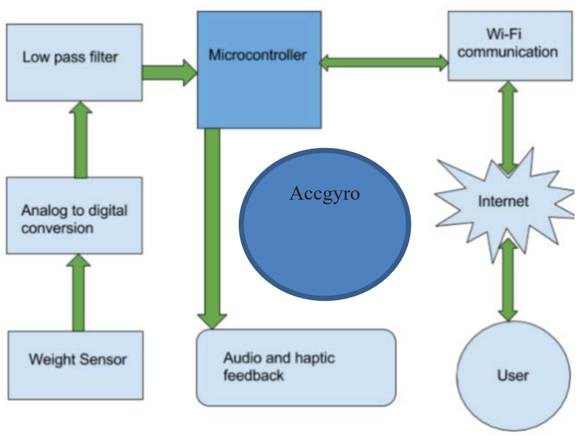

Fig. 1 System block diagram

B. Graphical User Interface

Because we want to be able to also monitor the information from the cane remotely, we designed an Android application capable of connecting to the internet to the IntelliCane. This app shows you the real time value of the force applied to the sensor and logs all the values during the operation, and upon closing, all the values are exported to an excel file.
Fig. 2 illustrates the Android application.

Fig. 2 Android Graphical User Interface

C. Mechanical Design

In order to measure the force, we used an aluminum standard medical cane. The sensor that translates the force to analogical signal it is an FC22 analog amplified output sensor from TE Connectivity.

A high-resolution 3D printer was used for testing and building the prototype parts such as enclosure, weight sensor supports clips, holders, etc. The final prototype it is fully made with 3D printed parts, and it is robust and fully functional. Fig. 4 can be seen for more details on the mechanical design.

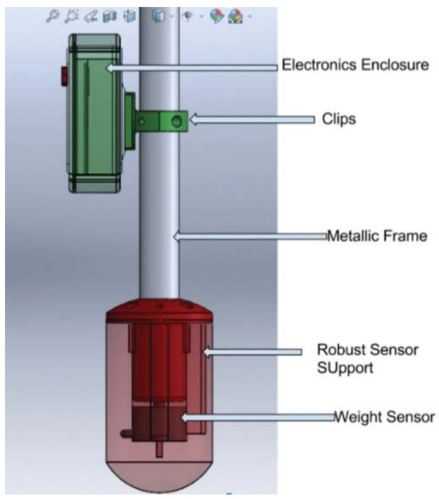

Fig. 3 Side wireframe view of the system

D. Experimental Data

The data was taken during the validation phase of the system. The graph depicted in Fig. 4 the characteristics of the load cell during a small force press and a slow release are shown. This is later used in the system calibration equation.

Because the load cell it has a linear output pattern we were able to use excel to generate the calibration equation using a 3-points calibration method. Figs. 5 and 6 show two examples.

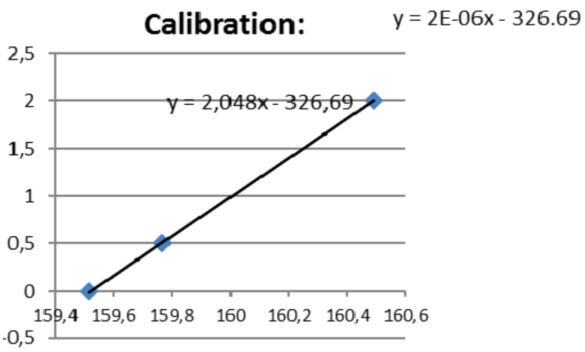

Fig. 4 Calibration equation

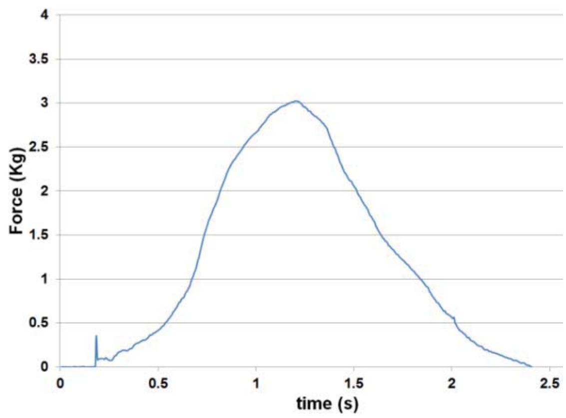

Fig. 5 Small force press

III. Results

A. Intention Detection

We developed an algorithm that it is able to estimate how much force it is necessary to load the cane in a different type of situations, like slow walking, climb stairs, fast to walk.

Moreover; the system is equipped with two inertial sensors, one gyroscope and one accelerometer, which can indicate if the patient has a correct straight position or it handles the cane in a wrong manner, helping the physical therapist understand better the movements executed.

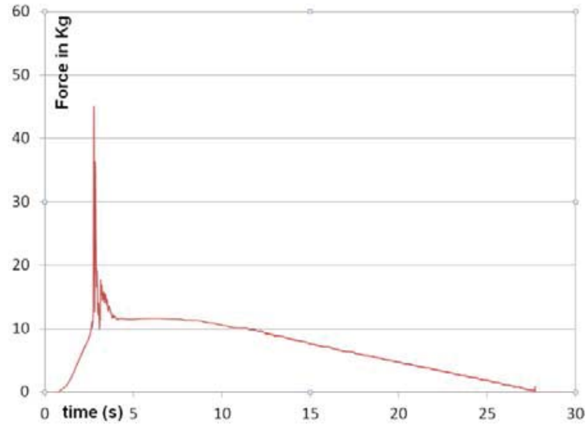

Fig. 6 High force press

B. Data Collection

We validated the system ourselves, walking with the cane and observing the force on the smartphone. There are 3 test methods used to validate our design, and the walking distance is 100 meters.

Method 1. With the feedback system disabled. Walk the whole distance in the same way as with a classical cane.

Method 2. With the feedback system enabled. The system vibrates if the force applied on the cane it is below or greater than a certain level, for example, you will have to put a force of 20% of your weight, let’s say at 80 Kg will result in an interval between 15 >= 16Kg <= 17.

Method 3. With the feedback system disabled. Trying to put the same 20% force on the cane, but no feedback will be used. The system will still continue to track all the information in the onboard logger; as shown in Fig. 7.

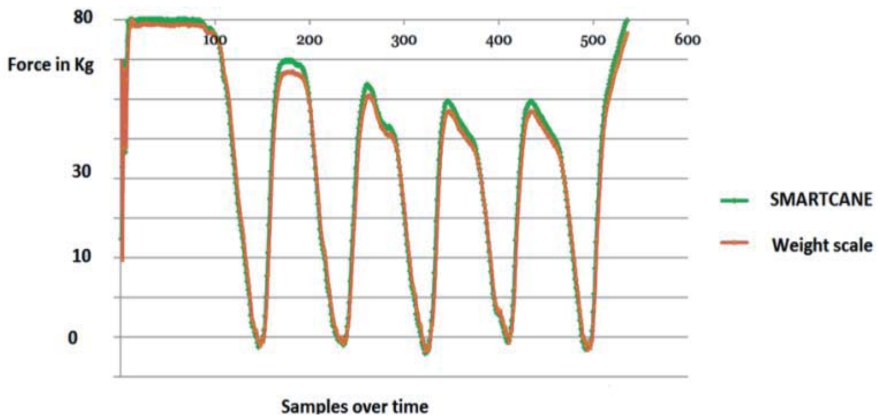

Fig. 7 Multiple forces during walking with a cane

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IV. Conclusion and Further Work

We have developed a system that it is battery powered, which means that it can be daily used without being restricted by cables and other heavy equipment. The device can store data up to 48 hours, and storing data means storing ADC values from the weight sensor in Kg force, gyroscope, and accelerometer , height, it can store information about tilt and rotation, and also it has a real-time clock that can be used to log at specific time/event every information. The haptic and audio feedback makes it very easy to be used by anyone, and it can withstand to force up to 700N.

For the improvements that will follow, we plan to add features for some other type of use. Adding one LIDAR sensor could allow us to map the environment in a simplified 3D model, in real time by using a DSP Digital Signal Processor. With this simplified 3D model we can translate the visual sense to some other human senses, like sound or event taste. “Tasting the light” it is a new way of translating the visual sense for blind people to taste. There are some studies regarding this topic proving that it is feasible, but all of them are still at a seminal stage .

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