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Shoe-integrated sensors in physical rehabilitation

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Abstract. This paper presents a shoe-integrated sensor device which collects objective information concerning the gait quality in patients' physical rehabilitation. It involves four pressure sensors, two bending sensors, an ultrasonic sensor and a 9dof IMU, an Inertial Measurement Unit with three accelerometers, three gyroscopes and three magnetometers. The device includes a SDRAMPS with the aim of storing the information for long periods of time. The collected data can be sent to the server for later visualization by the specialist and the patient on a web platform. An interface shows the data in real time, allowing it to verify the connections and to check different movements.

Keywords: Gait, sensor, wireless

1. Introduction

Gait analysis used as a rehabilitation tool due to a series of parameters related to factors including bone structure, posture, and shape of the foot. Each of these factors is unique to individuals and thus gives each person a distinct gait. An increasing number of specialists demand objective results regarding the gait, as it is also related to neurodegenerative diseases such as Parkinson's or Multiple Sclerosis (MS). A consultant collects the information and analyzes it, using their experience and a subjective analysis.

Since specialists do not always have objective information, it is often difficult to study the way that a person's gait changes throughout the day. Some factors, like fatigue, can affect the way of walking during the day, meaning that the gait may differ between morning and afternoon Thus, specialists require a tool that can collect objective information during different stages of the day.

The device that specialists use consists of a shoe with different sensors, such as pressure, bending, ultrasound and inertial, which send information to an Arduino mini, a single-board microcontroller whose programming is simple and open-source [2]. A Bluetooth module sends data to a PC or mobile phone, as well as an SDRAMPS, a module which allows connecting a micro SD via Serial Peripheral Interface (SPI The hard wiring allows data to be stored for long periods of time and guards the server against interferences. The information is sent to a server shows the data to specialists and patients on a web platform, so both can see the evolution and the abnormalities in the gait pattern. Analysis of the data provides specialists information to help them decide a prognosis and possible treatments.

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The paper is organized as follows: firstly, the State of the Art section details previous and related work. The System Design section describes the technological solution. The findings of the study are then presented in an experiment results section, followed by an outline of the various conclusions drawn.

2. State of the art

There are numerous studies that analyze gait. Bae J. et al previously designed a wireless network of inertial sensors which estimates the orientation [3] and the same system was applied in [4]. The authors in [5] combine different sensors (accelerometers and gyroscopes) to capture movement, comparing different parameters with a camera-based system. The study in [6] presents a shoe with different pressure, bending and inertial sensors, transmitting via RF and GPRS to a receptor connected to a PC. The use of data as feedback was carried out in studies throughout [7], which showed the footprint of users, including additional information. This way, users can test whether they step properly. Also [8] discussing a shoe-based device that includes an application presenting information for the rehabilitation of stroke patients.

Most of the devices that capture movements are based on inertial sensors, but other systems use fiber optics. A computer program using this system was developed in [9] in order to help an athlete with rehabilitation exercises using ten inertial sensors. The system used was Xsens, one of the most widely-used devices in capturing movement. It has been used in numerous studies aside from rehabilitation, such as tracking [10], movements of a dancer [11], and sports [12]. In [13], authors present a rehabilitation system based in a robot which can detect patient's intention revealing that robots are able to assist patients in treatment.

3. System design

In this section, the different modules integrated into the shoe are presented. Fig. 1 shows the general scheme of the device.

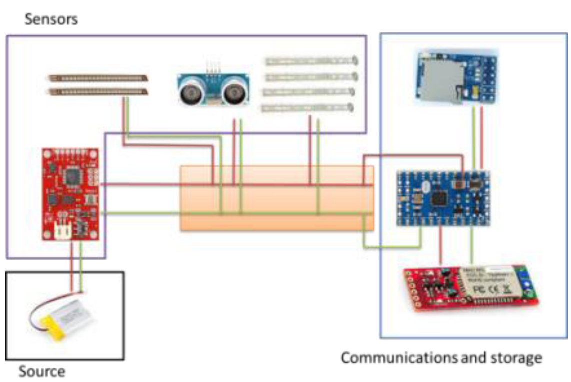

Fig. 1. General diagram.

The main modules of the device are the following:

- **Arduino mini**: This is the processor which controls the shoe, acquiring the different signals from the sensors and enabling communication. The sample frequency selected was 20 Hz.
- **Source**: A rechargeable polymer lithium ion battery of 2000 mAh is placed in the tongue of the shoe and is connected to the accelerometer with a JST connector. The rest of the components are powered by the Vcc and GND pins
- **SDRAMPS**: A module where a micro SD is inserted to store the data for several hours. This module was incorporated due to Bluetooth's rapid consumption of battery power. It is connected to the microprocessor via SPI.
- **Ultrasound**: Placed in the tongue of the shoe, it measures the distance between the two legs, called the stride length. It is combined with the pressure sensors to ensure a higher accuracy of the value measured and connected to one of the processor's digital pins.
- **9 Degrees of Freedom Razor IMU**: This incorporates a triple axis accelerometer, a triple axis gyroscope and a triple axis magnetometer. The IMU is used for detecting whether the user makes any characteristic movement of the foot. The connection to the Arduino is made via Serial Port (RX and TX).
- **Pressure sensors**: Four sensors, placed in the insole, acquire the force generated in the heel, the hallux and the first and fifth metatarsal.
- **Bending sensors**: One sensor is placed on the insole and a second one near the Achilles tendon. They detect the angles of the bent foot and ankle. Both pressure and bending sensors are connected to the analog inputs through a resistor that forms a voltage divider.

4. Experiment results

An interface developed in Matlab shows whether the shoe is connected properly and captures the movements in real time. The main interface allows users to see the principal data of all the integrated sensors, without any extra information. It is also possible to select the desired sensor and access another interface that presents more detailed information. Every person has a unique gait, which means that patients have to establish a database of foot positions that can be compared to previous samples.

The shoe was tested with different movements to check whether the sensors could collect the different parameters. Fig. 2 shows the prototype with the different sensors.

Fig. 2. Prototype.

The gyroscope and the pressure sensors indicate difference between both tests. In Fig. 3, the difference between the foot completely resting on the ground and the foot tilted can be seen.

The same module shows any anomalous movement when the user steps forward. Fig. 4 shows three different graphs in which the user made three different actions.

In the first one, the user is stationary with both feet resting on the floor. The second one shows a normal step. Only movements on the Y and Z axis can be seen. Finally, the third graph represents an abnormal step: the user did not step directly forward, but made a horizontal movement prior to stepping forward. The third graph then shows acceleration on the X axis, as well.

Fig. 3. Comparison between foot on the ground and tilted.

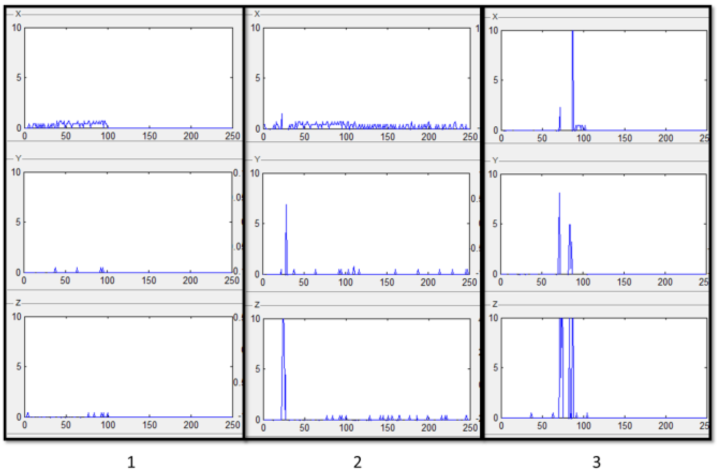

Fig. 4. Acceleration for three different moments: stationary (1), normal step (2), step with displacement (3).

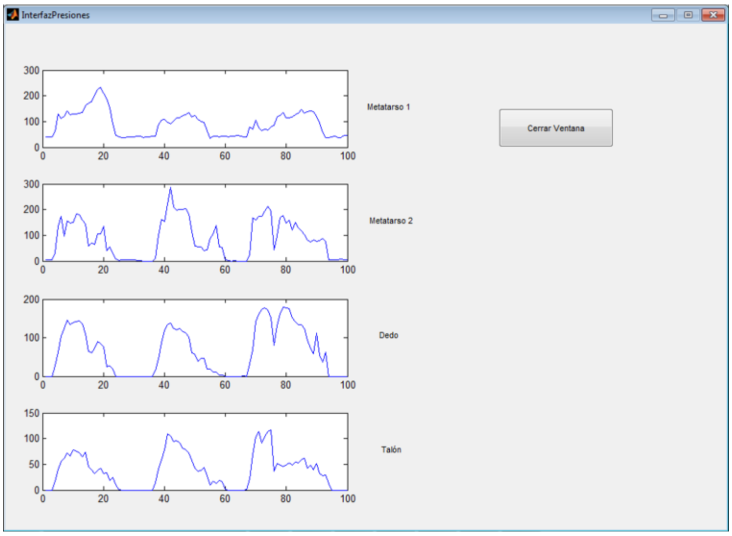

Fig. 5. Pressure sensors signals: first metatarsal, fifth metatarsal, hallux and heel.

In terms of pressure sensors, the main interface only shows values that are indicators of pressure. The user, however, can select another interface from the main one to show the four signals in real time, Fig. 5. In the case shown in the example, the graphs show three steps.

A later analysis shows the specialist whether the step was done correctly, indicating the different phases (stance and swing), order of the zones of the foot in the stance phase, and force applied at each point.

The pressure and bending sensors used in this device were initially tested in [14], differentiating between a normal walk and dragging. Through using Bluetooth to show the different data in real time, the interface can be considered a rehabilitation tool.

5. Conclusion

A shoe with different integrated devices was developed to give rehabilitation specialists a tool that shows objective information and can store large amounts of data for the long periods of time. The different data is sent to a server for later analysis and is shown on a web platform to both specialists and patients. A Bluetooth connection serves to verify the different module elements with the help of an interface. The system is very useful for doctors because it allows them to make the necessary modifications to the patients' rehabilitation or treatment.

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