GRAPHICAL USER INFERFACE FOR AMBULATORY MONITORING OF MOTION AND PRESSURE USING EMBEDDED PRESSURE SENSORS AND IMU IN A PORTABLE MULTISENSORY DATA-LOGGER, PROCESSOR, AND TRANSMITTER

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INTRODUCTION

Home health care is a constructive component of patient care. Continuous monitoring of patients outside of a clinical setting: at home, in the community, and in a person's regular daily routine, can provide a more comprehensive integration between clinical information and data collected of real-life scenarios and activities in real-time. Remote monitoring devices can play a key role in early intervention. If a clinician could watch the patient's walking patterns in daily living – foot pressure and orientation – more accurate assessments could be made. In this paper, a Graphical User Interface (GUI), which enables such monitoring, is presented.

OVERVIEW

Monitoring of physical parameters is a very important topic, and many researchers have developed systems for continuous monitoring of patients for different purposes. Works of interest include an in-shoe multisensory data acquisition system [1] and a project called "GaitShoe" at MIT, where a number of sensors were used to retrofit a special shoe for quantitative gait analysis [2]. Continuous monitoring for fall detection using a body-worn sensor has been explored and is also of interest [3]. Gait analysis has even been explored in terms of human recognition [4].

DATA COLLECTION TOOLS

In previous work, we discussed the Arduino-derived JeeNode board and how a Bluetooth radio or low-power HopeRF radio can be used for monitoring and how it is possible to include a variety of sensors, especially given the open-source nature of the electronics, the algorithm, and the code. The small device unites home monitoring and remote monitoring. It is quite easily integrated into daily living. This device collects information from an accelerometer, gyroscope, and pressure sensors, and then the information collected is corroborated in a basic GUI. In previous work, merits of such a device have been discussed. The hardware that collects the data used by the GUI described in this paper is the device discussed in [5].

GAIT PARAMETER CALCULATION

In other previous work, the system discussed in [5] was used in [6] to create a novel algorithm that determines stride time based on readings from a single accelerometer and gyroscope. The pressure sensor was not used in [6].

VIEW PATIENT'S GAIT IN REALTIME

Figure 1: Microcontroller, accelerometer, and gyro mounted on the outside of a hightop basketball shoe. Pressure sensors are secured inside the shoe. Note that the electronic components are exposed for the picture, but can be masked, inserted, or camouflaged, without loss of positioning, and patients retain choice of slipper or shoe style preference [6].

The system features Flexiforce resistive pressure sensors, an accelerometer, and a gyroscope in conjunction with a low-cost, low-power microcontroller board. This experimental setup, shown in Figure 1, can be utilized with the person's regular shoes and slippers. It is not cumbersome. The experiment was set up in a similar way to [6], as shown in Figure 1. In those papers, the hardware and algorithms were discussed extensively; however, the Graphical User Interface for use by a clinician or patient was not discussed.

In this paper we discuss a Graphical User Interface (GUI) that was created to visually display patient information to a clinician or to the patient. The GUI is a 3D visualization of a patient's walking motion or movements and some gait parameters in real-time.

Increased use of personal devices such as these for different conditions and afflictions would add much data. A collection of supplementary information regarding many types of afflictions could therefore vastly increase the database for mining data in numerous areas of research: more detailed data, more knowledge.

Use of these visualizations could facilitate self-observation by a patient, or family member, to detect changes in physical motion patterns. Family members who may not be so highly trained, or home-healthcare team workers, could perhaps notice abnormalities in the visual system and alert to potential changes in movement of a routine nature, thus having the potential for early detection of a mobility problem.

This system can be used for monitoring a patient's adherence to a recommended therapeutic treatment. Also, it can be a visual to assist with assessments of post-surgical patients upon discharge from hospital and/or rehabilitation centre.

RESULTS [7],[8],[9]

A graphical user interface (GUI) was developed that displays two rectangular objects in 3D space. The object "deeper" into the screen is the plantar region of the foot, and the object that is "closer" is the heel region. To mimic the motions of the patient, the tilt of the objects on the screen relative to a centre point shifts the tilt in 3D based on the data received from a single shoe mounted accelerometer and gyroscope. In the results presented here, two pressure sensors were installed unobtrusively inside the patient's regular shoe. In testing, the Flexiforce pressure sensors were placed in many locations, including the hallux, metatarsals (esp. 3rd metatarsal), heel (medial and lateral), and under different conditions including dorsiflexion and plantarflexion. One sensor was placed under the forefoot plantar region, and the other was placed under the heel. Additional sensors can be added to increase resolution if needed, including under each metatarsal.

In Figures 2 through 8, screenshots are taken from the GUI showing the various phases of gait. Software allows us to compensate for the placement of the accelerometer and gyroscope. Note that a pressure value of 1.0 means no load, and the visualization of the foot would be white, and 0.0 is maximum load, and the visualization is black. Intermediate pressures are visualized with each foot component changing its colour in shades of gray ranging from white (minimum pressure, 1.0) to black (maximum pressure, 0.0). During clinical use, the time counter would count up from 0 to allow timing comparisons.

The experiment involved the test subject walking and thus going through the standard phases of gait. The subject was asked to pause at certain instances corresponding to a certain gait phase. A screenshot of the GUI was taken, and then the patient resumed movement and continued walking.

The gait cycle encompasses a stance phase followed by a swing phase. Within the stance phase, the first observation made was of *Initial Contact* (Fig 2). In this phase, the 3D visualization of the foot is rotated and the colour of the heel component visualizes the magnitude of Heel Pressure.

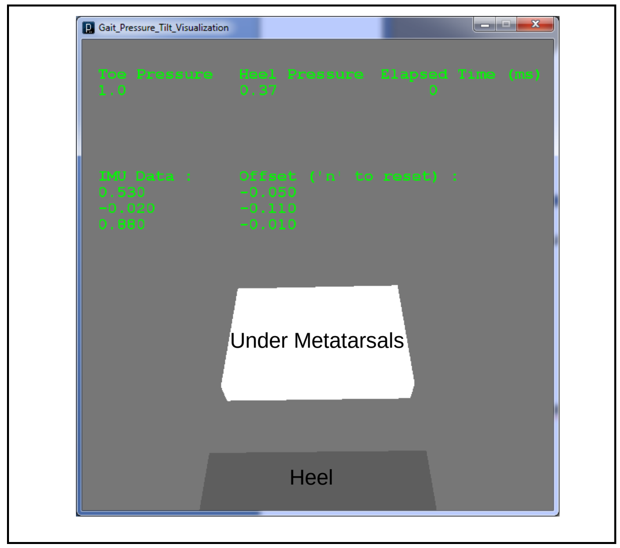

Figure 2: Initial Contact

After *Initial Contact*, the *Loading Response* can also be observed. The repositioning foot is shown, and the heel pressure magnitude is greater; however, pressure is not yet distributed to the plantar region.

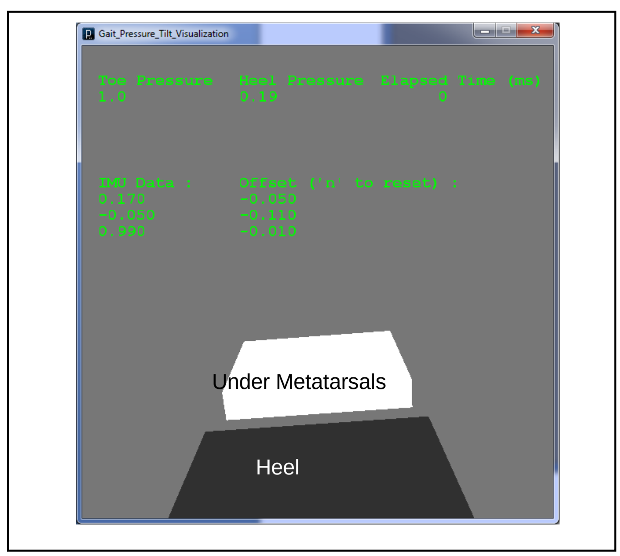

Figure 3: Loading Response

Mid-stance can also be observed in Figure 4, as the foot again assumes a relatively flat orientation, and the pressure is seen to be applied in both the heel region and the plantar region in relatively equal amounts.

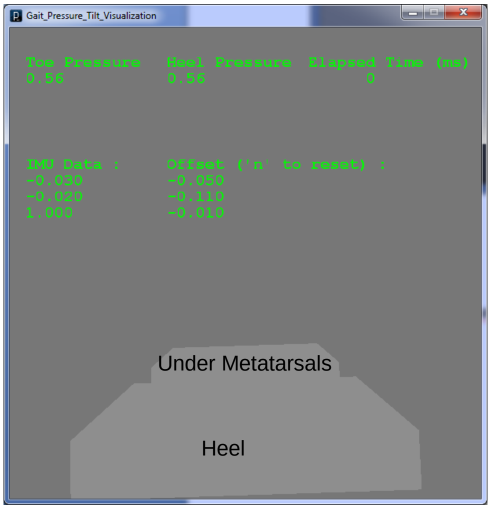

Figure 4: Mid-Stance

In Figure 5, after mid stance, *Terminal Stance* can be observed as the heel rises. The amount of pressure can be seen to increase in the plantar region, and is meanwhile removed from the heel region.

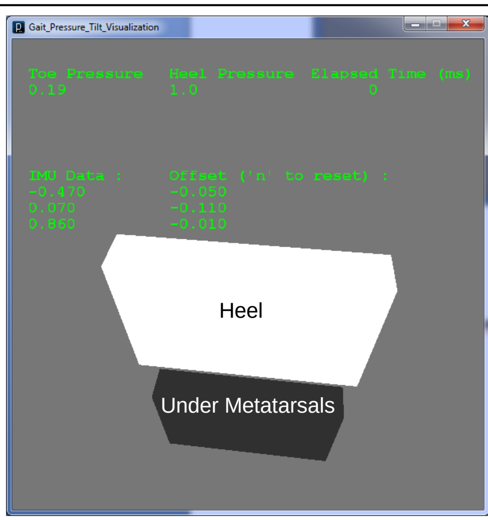

Figure 5: Terminal Stance

In gait, after the Stance phase, follows the Swing phase. In all Stance phases, some of the foot is making contact with the ground, and Figures 2 through 5 all indicate the presence of pressure. In Swing, the foot is in the air, so all these images indicate that no pressure is applied.

There are three captured images from the Swing phase. We begin during the initial swing, and the tilt and lack of pressure, as expected, can be seen in Figure 6.

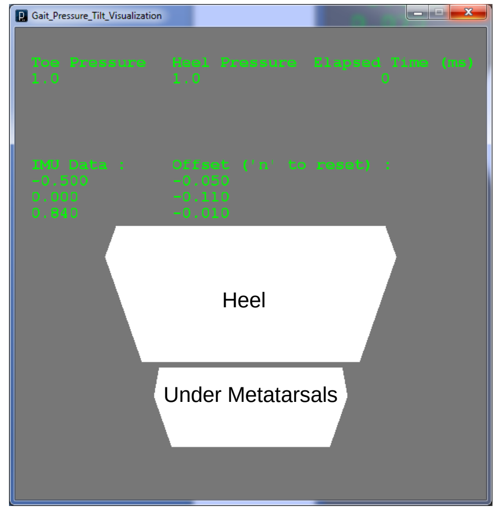

Figure 6: Initial Swing

After the initial swing, as the leg moves forward, the *Mid Swing* can be observed in Figure 7.

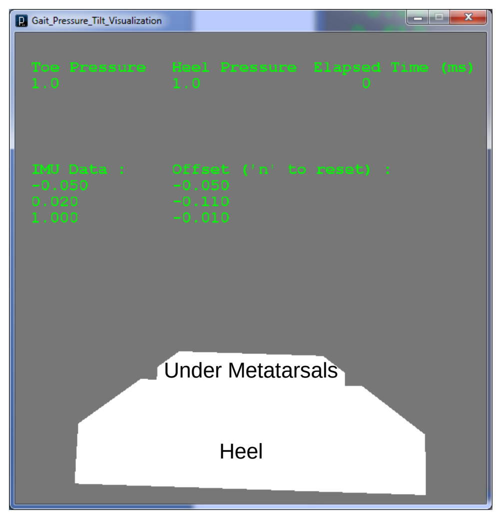

Figure 7: Mid Swing

Finally, at the end of the swing cycle, we can observe the *Terminal Swing* in Figure 8, where the foot is almost in the initial contact orientation, but pressure has not yet been exerted.

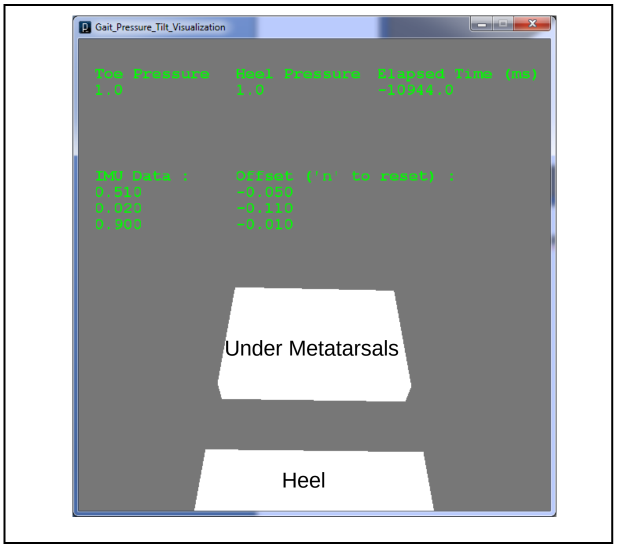

Figure 8: Terminal

Literature has confirmed that determination of activity using similar sensors can occur with post-processing [6]. This system can display other information that is extracted on the microcontroller such as components of gait phase, like stride time, as calculated in [6].

Long term monitoring could give doctors a better assessment of effectiveness in a particular therapeutic technique for a given individual. The visualizations could be beneficial for medical professionals to monitor locomotion of a patient, detect abnormalities and other medically important changes, and to predict potential dangers and assist in a decision as to whether or not intervention should occur. Physiotherapists could evaluate whether a particular exercise program is of small or large benefit to a patient's improvement during a recovery period.

Today's well-informed health consumer may strive to understand the particular medical circumstances and scenarios in which they find themselves, but unless they are trained as medical professionals, a large gap remains. Such small increments of their increased knowledge and understanding can help to increase patient compliance. This visual dynamic can be of some help. An illustration can be an informative addition to simplify a point and increase their grasp of understanding. The patient's direct interest in being actively involved with their own wellness regiment could in turn be a useful tool for serving to increase patient compliance.

FUTURE WORK AND CONCLUSION

The images shown were from the system as implemented on a PC; however, when paired with a tablet or smartphone, can further transmit data, when necessary, to show medical professionals the readings during routine daily activities of the patient. In conjunction with a smartphone, pressure and other collected information can be transmitted to cloud storage, or if there is cause for concern, the relevant information can be transmitted directly to the patient's healthcare provider or doctor. Regardless of a patient's ailment, age, or condition, their interest in such direct, active involvement with their own individualized home data collection might empower him or her to better manage their health conditions.

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