Electronic Footwear for orthopedic patients

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Abstract- Partial weight-bearing instructions are given to orthopedic patients suffering from a leg-injury for proper healing and to avoid failure of the construct. This paper presents an abstract model of a real time Embedded Electronic Footwear (Electrowear) that constantly monitors the weight on injured leg of an orthopedic patient and is capable of accurately and efficiently measuring foot pressure. In order to stay compliant with the dual desired instructions, the patient needs a fully portable system capable of measuring pressure of many steps over extended periods. This paper presents an inexpensive, reliable, portable plantar pressure acquisition system which is developed to operate on real time basis. It allows the recording of pressure applied on the injured leg from 6 insole pressure sensors. The portable, battery-powered, microcontroller based data acquisition system provides a convenient and user-friendly device. It also provides a means to store the acquired data for future analysis. The design and development of this portable insole plantar pressure measurement system is described in the following paper.

I. INTRODUCTION

Orthopedic patients with leg injuries/fractures often suffer in staying compliant with the instructions given to them by the physiotherapists. They are instructed to bear certain nominal pressure on the injured leg. For e.g. instructions such as applying certain weight (e.g. 70% or 50%) of the total weight on the injured leg. Common instructions include partial weight bearing or weight bearing as tolerated.

These instructions are given to the patient under the fear that excessive pressure seen by the injured leg might lead to implant failure (either deformation or breakage). On the other hand, patient is advised to increment his weight bearing capacity which would stimulate osteoblastic activity in fracture patterns and help in its fixation. Hence there exists a dual desire to attain two contrasting situations.

Here emerges a need to develop an aiding device for the patient to comply with the partial weight bearing instructions that are bestowed.

This project focuses on developing embedded electronic footwear that would keep on informing the patient on the pressure he/she is applying on the injured leg on REAL TIME basis.

II. LITERATURE SURVEY

Over the past two years there has been increasing interest in developing in-shoe foot plantar pressure systems and recently there have been applications to plantar pressure using both wired and wireless systems. Nearly all use off-the-shelf sensors, microprocessors and wireless transmitters, so the end product is bulky and not comfortable to wear by the patients.

Literature studies described dynamic plantar pressure for human identification using a FlexiForce® (Tekscan, USA) in-sole pressure sensor [10]. They compared the pressure at different positions of key points then identified and classified them using a support vector machine (SVM) running on a PC. The system uses wire to transfer data from the sensor to a data acquisition card on a PC and it is reported that the system has 96% identification accuracy. The system is named 'WalkinSense' (Aoife Healy, Philip Burgess-Walker, Roozbeh Naemi) and consists of a data acquisition and processing unit and eight individual sensors. It appears that only the sensor part is their own development, the rest of the system is similar to FlexiForce® (Tekscan, USA) hardware and software. Benocci and Lin Shu used Bluetooth modules to attach to the ankle. In 2009, Benocci et al. [11] from University of Bologna, Italy developed a wireless system for gait and posture analysis. The wearable system utilized 24 hydrocells (by Paromed) to measure the plantar pressure and inertial measurement unit (IMU) in each shoe insole. The IMU integrated a 3-axes accelerometer and a digital 3-axes gyroscope. To control the system, Texas Instrument MPS430 microcontroller was implemented and Bluetooth acted as the transceiver. The collected data from the sensor allowed the user to recognize walking phases such as swing and stance, step and stride duration, double support and single duration. Bamberg [12] has developed the in-shoe gait analysis system but the system is not wearable for daily activities monitoring. The digital textile sensors by Chang-Ming are small and really flexible but it is wired to a Bluetooth based transmitter device at the belt. Yamakawa [13] also proposed their own biometric identification in-shoe system based on both feet pressure change and reported that the system could recognize over 90% of the test subjects. The system used F-scan (Nitta Corp, Japan) as the pressure sensor

III. DESIGN METHODOLOGY

An overall view of the project can be briefly classified broadly into two phases viz. Software framework and the hardware implementation (including configuration mechanism). The block diagram is as shown in figure1 below:

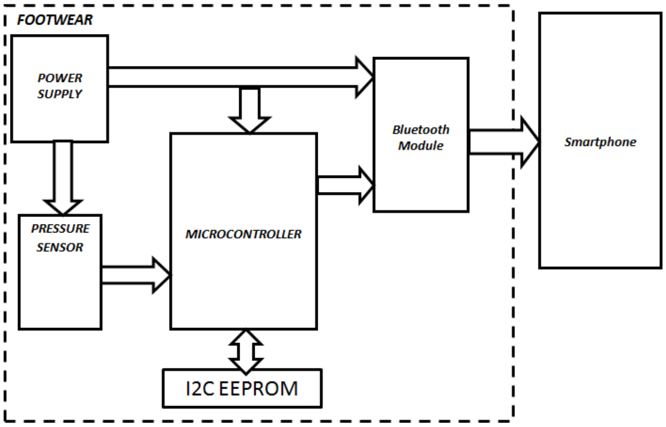


Figure3. Block Diagram of Electronic footwear system

The components impregnated in the sole will only comprise of weight sensors. The remaining hardware will be resting on a strap wound on the ankle of the patient. That will comprise of a microcontroller, signaling circuit, Bluetooth module and battery.

Following are the steps followed for designing the software:

The basic idea of the software framework is that the analog values as read by the sensor are converted into digital format and then analyzed. Initially we consider eight virtual variable analog inputs (analogous to eight pressure sensors) that are considered as sensor readings. These are converted into digital format using the microcontroller's 10 bit ADC module. 10 bit resolution provides a précised converted digital output represented in terms of binary numbers 0 and 1. The resolution in terms of voltage can be calculated as:

$$\text{Resolution (in Volts)} = \frac{\text{Analog voltage}}{1024} \quad \text{....\{Since } 2^{10}=1024\text{\}}$$

The decimal numbers are extracted from this binary representation and this gives a Numeric representation of the sensed signal.

For e.g. an analog input voltage of 3.65V will be represented as 1011101100 i.e. equivalent to 748 decimal number. The analog to digital conversion can be mapped as shown in figure2 below [9]:

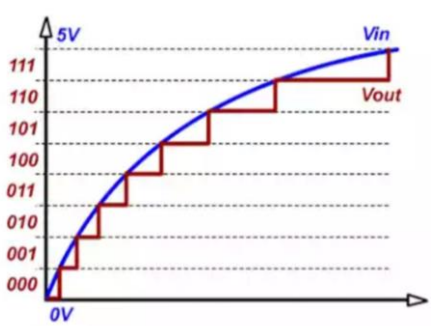


Figure2. Quantization of analog values into digital format

This number is stored into memory as the 'Reference' value so that the later sensed values are compared to this reference value and a percentage of pressure (or weight) applied can be calculated as:

$$\frac{\text{Sensed weight}}{\text{Reference}} \times 100 = \text{Percentage of applied weight}$$

Hence the patient has to first apply a full scale pressure on the footwear so that a reference value signifying full weight can be stored for analysis. Another important aspect required for calculation the 'Threshold' value. This signifies the minimal pressure (in percentage) the injured leg has to exceed so that the readings can be captured for processing. This is the hard coded value in the software itself. The footwear continuously monitors the pressure exerted by the patient on the injured leg and once it exceeds the threshold percentage, after 1sec all the analog values of the sensors are passed on for processing. One final requirement of the footwear is the value of 'Limit' (in percentage) that should not be crossed by the patient to avoid post-operative injury. Therefore the patient must follow the following condition for smooth operation:

$$\text{Threshold value} \leq \text{Applied pressure} \leq \text{Limit}$$

In case the patient exceeds the limit value, a buzzer occurs to alert the patient. The complete transaction with the patient occurs via Bluetooth module (HC-05) and an android Smartphone. The applied weight (in terms of percentage) is displayed on the Bluetooth terminal on the Smartphone on real time basis.

The second phase consists of write and read cycles from the EEPROM and configuring the Bluetooth module (HC-05). HC-05 is configured as the slave module which serves as the transponder for the microcontroller. The patient gives the input readings to the system via the Smartphone which are collected by the Bluetooth module and transferred to the microcontroller and on the other hand it also provides real time assistance for the patient. The major consideration on hardware phase is the proper placement of the weight sensors. Real-time measurement of natural gait parameters requires that sensors should be mobile, light weighed, untethered, can be placed in the shoe sole, and can sample effectively in the target environment. There are certain suitable positions for placing weighing sensors in the sole as shown in figure3.

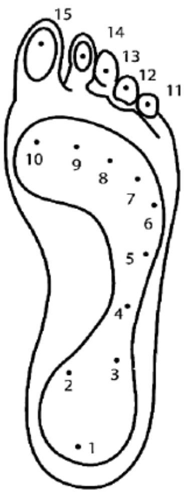


Figure3. Foot anatomical areas

Resistive Sensors provide electrical signal output (either voltage or current) that is proportional to the measured pressure. When pressure is applied, the sensor measures the resistance of conductive foam between two electrodes. The current through the resistive sensor increases as the conductive layer changes (i.e., decreases resistance) under pressure. The strain gage changes resistance with strain, increasing under tensile strains and decreasing when in compression. This weight sensor (load cell half bridge 50KG [15]) is a strain gauge type suitable for electronic balance and other high accuracy electronic weighing devices as shown in the figure4. When measuring, the correct force is applied to the outer side of the strain E-shaped beam portion of the sensor and the outside edges to form a shear force in the opposite direction. The supply wires are shown by Red and Black which represent Vcc and ground respectively in figure5. Output from the sensor is obtained as a differential signal (i.e. Green wire represents positive signal and White wire represents negative signal)

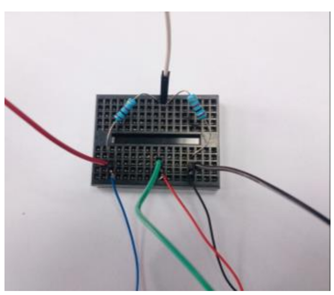


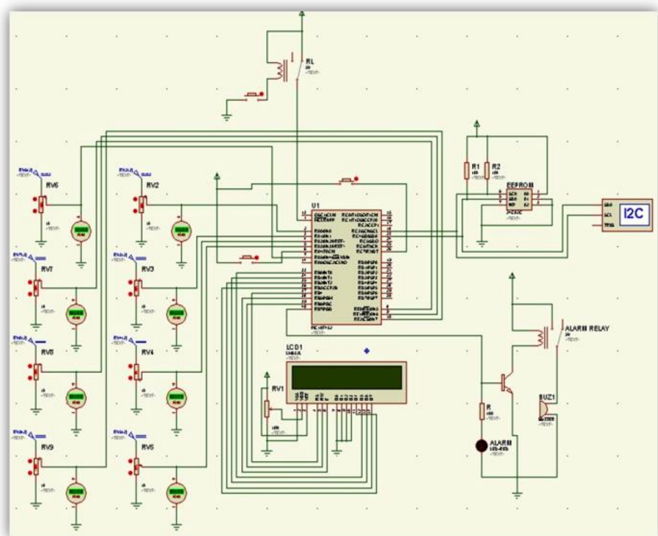
Figure4. 50KG Load cell Figure5. Half cell circuitry

The algorithm for the entire project can be written as follows:

1. Once the footwear is powered on, the user has to establish connection with the Bluetooth module and the android Smartphone.
2. On successful connection, the user has to enter the prescribed limit to be maintained on the injured leg in terms of percentage on the android Smartphone and send this data to the microcontroller.
3. After this, the patient has to initially apply a full scale pressure on the footwear until a 3sec buzzer occurs which symbolizes a successful capture of the full scale pressure. This value is stored as the 'Reference' value in the system for comparison.
4. At this stage, the footwear is ready to use. Now on application of pressure on the injured leg (i.e. by walking) the user is guided by displaying the partial weight on his/her injured leg each time a step is taken.
5. On exceeding the limit, a 1sec buzzer alerts the patient to reduce the pressure for next step thereby aiding him to stay in compliance with the partial weight bearing instructions.

V. Simulation Results

In the simulation figure shown below, LCD is used just for the debugging purpose. It is not involved in the actual footwear circuitry. Eight analog inputs symbolize the amplified version of the sensed signal obtained from the weight sensor.



An experimental study dictates successful working of ADC as well as writing and reading to and from the EEPROM (24C02). EEPROM is configured via I2C interface. Each time the data is written the data pointer is incremented and this happens similar to reading cycle. This is clearly verified by using the I2C Debugger in proteus. The writing cycle is indicated by the following display on the I2C debugger:

47.469 s| 47.470 s| S| Sr| A2| A| 01| 19| A| P|

This statement implies the start of writing and end of writing time as given by 1st two time interval respectively in seconds.

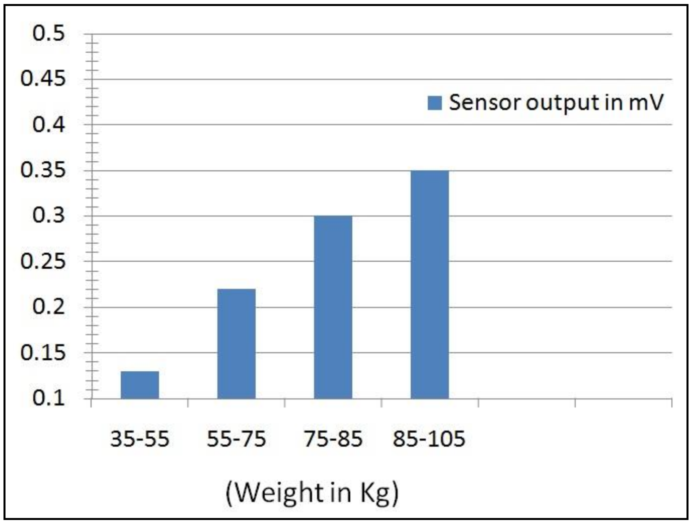
‘A2’ is the command for writing at location ‘01’ and the data to be written is ‘19’ which is the ASCII value of number to be stored in the memory (in this case the number to be stored is ‘25’). Similarly the writing cycle is described as :

91.992 s| 93.768 s |S | A2| A| 01| A| Sr| A3| A| 19| N| P|

Here, the ‘19’ value is read from the memory location ‘01’ with a positive acknowledgement. This verifies the successful simulation of the project.

V. Practical Results

The 50kg load cell on pressurizing gives a double ended output voltage ranging in milivolts. This voltage has to be amplified to a volts scale so as to apply it to the microcontroller. This is done using differential amplifier LM324 which is a 14 pin, high frequency compensated quad Op-amp IC with an offset of 5mV (approx.) and giving a single ended output. Sensor output has to be amplified 1000 times in order to convert the signal to a conventional use. However the offset also get amplified to about 2.5 volt which makes the calculations critical. The system is now designed to make calculations considering 2.5 volts as the base value (which corresponds to a zero percent). For example, if a full scale pressure corresponds to a voltage of 4V then system is designed to display an output of 100% corresponding to 4V and 0% corresponding to 2.5V. Thus the values are mapped as 2.5V-4V with respect to 0%-100%. The sensor however has its own nominal output at rest. The system does not get affected to these offsets as it scans the whole system once before starting the manipulations and sets all there offsets to a base value corresponding to 0%. The sensor gives different output for varying pressures or weight applied. A graph of sensor output voltage corresponding to different weights applied is as shown in figure (6).



VI. Conclusion and Future Scope

The project has reviewed some major foot plantar pressure measurement systems reported in the current literature and available in the market. Firstly, it discussed the available pressure and weighing sensors such as Strain Gauge and load cell. Then, reviewed the latest research on wearable hardwired and wireless sensor systems for gait analysis and discussed their limitations which mainly comprised of size incompatibility and unfavourable wearable structures. The project includes Bluetooth module for wireless transmission and attain user friendliness. Finally it represents a solution for wearable wireless pressure sensor systems for sensing weight and pressure. Initial IC design results show potential for some good results by the proposed in-shoe foot plantar pressure measurement system. A power consumption of 570mW was achieved using rechargeable battery. Although the design managed to minimize the dimension, among other significant considerations is power consumption.

The project is being worked to have additional features such as time-aided readings by using GPS synchronization. Further miniaturization of whole system can be done by using SMD packages of hardware components. Usage of DSP processors can give exceptional enhanced analysis of gait monitoring by displaying various graphs and spectrum by the means of Fourier analysis.

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