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Design of Low Cost Smart Insole for Real Time Measurement of Plantar Pressure

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Abstract

Real time plantar pressure provides information critical to the understanding of gait mechanics and has a wide range of applications. In this study, smart insoles were designed and developed to measure real time foot plantar pressure. Key features of the insoles included cost-effectiveness, good working pressure detection range, wireless data transfer and real-time data analysis. Calibration of the sensing material was done and the resulting accuracy of the insoles was compared to that of a Kistler force plate, achieving an r^2 value of 0.981. Real-time visualization of pressure mapping was incorporated to enable intuitive understanding of relative plantar pressure distribution.

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Keywords: Smart Insole; Real-time; Plantar Pressure; Piezoresistive Sensors; Low-Cost; Wireless Data Transfer; Gait analysis

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1. Introduction

Plantar pressure measurements and analysis has important applications in medical diagnostics [1], rehabilitation [2] and sports related performances [3, 4]. There are two main types of instruments used for this analysis and measurement [5]. They are broadly categorized into platform methods and in-shoe systems. Platform methods usually involve the subject walking over a designated path with pressure sensors embedded. This method limits the study to a confined laboratory or clinical environment. Rigorous tests across varying terrains and surfaces are difficult to conduct and thus do not accurately reflect real world conditions. In-shoe systems have sensors within the base of shoes or in the insoles, and measure the pressure interaction between the foot and the shoe. This portable system enables a wider variety of research to be conducted that is not constrained to laboratory conditions.

Platform systems are generally more accurate than in-shoe systems [6, 7]. However, due to the lack of portability of these platform systems, accurate and economical in-shoe systems are highly sought after. Several commercially available in-shoe systems are designed with embedded pre-fabricated sensors in them. This restrains the density of the sensors in the insole, as they are limited by the size of individual sensors. With the miniaturization of sensors in order to achieve a higher density, the power consumption and cost of the insoles would be severely compromised.

The purpose of this report is to present a low cost plantar pressure measuring insole void of any commercially available sensors but retainig the ability to achieve a high density of sensing nodes. Some factors important to designing a pressure measuring insole such as accuracy, real-time data analysis and pressure range will also be considered [8].

2. Methodology

2.1. Hardware Development

Carbon embedded piezoresistive material (Rmat 3a, RMIT Material code 3a) was sandwiched between two layers of electrodes to form a pressure sensing insole. The horizontal electrodes had a total of 15 elements whereas the vertical electrodes had a total of 5. This formed a total of 75 sensing nodes for each insole. A sensing node was formed at the intersection of the horizontal and vertical electrodes. The assembly of the main sensing components of the insole can be seen in Fig. 1. The electrodes are wired to a microcontroller (TEENSY 3.1, 32 bit ARM Cortex-M4 72 MHz CPU, PJRC, Oregon, USA) with the horizontal electrodes as digital input and the vertical electrodes as analogue inputs. Reference resistors were connected to each analogue input and were used to measure the relative change in resistance of the piezoresistive material. The microcontroller generated a 3.3 V digital output and the change in resistance experienced by the piezoresistive material reflected a change in voltage in the reference resistors. The 2 sets of electrodes were multiplexed and the resistance across each individual sensing node could be calculated. The microcontroller was set to run at 1000 Hz which resulted in approximately 13 Hz per sensing node per insole. In this system, HC-05 Bluetooth modules were used and one was connected to the left insole. This sent the measured data to the right insole, which had 2 Bluetooth modules. On the left insole, one Bluetooth module was synced to the Bluetooth module of the right insole, whereas the other Bluetooth module was synced to a laptop. This allowed the laptop to receive data wirelessly. The hardware components were interfaced in Arduino Software (Arduino v1.0.6 IDE, Teensyduino 1.22).

2.2. Data Analysis

The insoles were placed on a Kistler force plate (Kistler Instruments, Hampshire, UK). A cyclic force with varying peak values (between 30 and 300 N) was applied on one of the sensing nodes and the magnitude of the applied force was measured from the Kistler force plate at a sampling frequency of 1000 Hz. As the force was applied on the insole, changes in the resistance of the piezoresistive material were captured by the microcontroller. The magnitude of the measured force was then plotted against this change in resistance. Their relationship was then