Design of IoT Solution for Velostat Footprint Pressure Sensor System

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Abstract. The paper describes design of a footprint pressure sensor system using 3M Velostat. The proposed design is intended for on-shoe implant for foot plantar pressure measurement. The system comprises Velostat based foot pressure sensors and IMUduino sensor node with Bluetooth communication towards mobile device running pressure monitoring application. The system prototype was implemented and used to test Velostat sensor performance. The proposed design has met all main requirements while providing fully functional and low cost solution.

Keywords: Velostat · Foot plantar pressure · In-shoe monitoring

1 Introduction

The objective of the paper is to describe a design of an IoT solution for in-shoe footprint pressure monitoring system using Velostat as a pressure sensor. Advantages of using shoe implants for pressure monitoring when compared to analysis performed using pressure platforms and walkways were recognized in the past [1]. There are developed systems using shoe implants that were customized for a specific research [2] or were based on commercially available implants [3]. Review of recent research in gait analysis shows that only 22.5% of research is performed using wearable sensors, stating that the portable systems based on body sensors are offering promising approach [4].

The structure of the paper is as follows: Sect. 2 describes application domain of the system and its requirements, with subsequent design of the system. The Sect. 3 presents Velostat and volume conductivity as a feature enabling its usage as a pressure sensor. Section 4 describes application for monitoring pressure changes and shows measurement results testing Velostat performance. Finally, obtained results are discussed and conclusions and recommendations for the future work are presented.

2 Footprint Pressure System

Feet provide the primary surface of interaction with the environment during locomotion. Thus, it is important to diagnose foot problems at an early stage for injury prevention, risk management and general wellbeing. One approach to measuring foot

M.U. Ahmed et al. (Eds.): HealthyIoT 2016, LNICST 187, pp. 171–176, 2016.
DOI: 10.1007/978-3-319-51234-1_30

health, widely used in various applications, is examining foot plantar pressure characteristics. It is, therefore, important that accurate and reliable foot plantar pressure measurement systems are developed.

Pedobarography is the study of pressure distribution across the plantar surface, measured dynamically force fields acting between the foot and a supporting surface [5]. The differences in pressure across the plantar surface are the result of the distribution of the weight on the foot, showing the activity of muscles. In order to analyze the pressure distribution and foot biomechanics, the foot is divided in sub-segments, and frequently used sub-segment schematic is described in [6]. Sensor positions are defined to cover sub-segments of interest, depending on the application domain.

2.1 Application Domain

Typical applications for foot pressure analysis include injury prevention, improvement in balance control, diagnosing disease, sports performance analysis and also footwear design [6–10].

Improvement in balance is considered important both in sports and biomedical applications. Notable applications in sport are soccer balance training and forefoot loading during running [7]. With respect to healthcare, pressure distributions can be related to gait instability in the elderly and other balance impaired individuals, and foot plantar pressure information can be used for improving balance in the elderly [8]. Foot pressure monitoring can be used also for monitoring physical activities as weight loads while working [5].

2.2 Requirements for the System

Main requirements for foot wearable pressure monitoring sensor system are: light weight and small overall size of the sensor, limited cabling, flexible and light shoe implant, divided in areas for detection of pressure and distribution of weight. Another important requirement is also a low power supply.

Methods based on wearable sensors indicate importance of features such as precision, conformability, usability and transportability [4]. Majority of research in pedobarography is performed using non-wearable sensor solutions, what could be linked to cost of commercial implant pressure monitoring systems. This leads to conclusion that an additional important requirement is a low cost of the implemented system.

2.3 Footprint Pressure System Architecture

The architecture of the footprint pressure system is in compliance with common remote IoT health monitoring systems architecture. The proposed solution is a subset of the full architecture including: (1) sensor node: shoe implant made of Velostat and silicone with IMUduino device for acquisition and communication, and (2) co-ordination node: smart phone or other portable device with Bluetooth communication capability and application for monitoring foot pressure. The system is presented in Fig. 1. The proposed solution can be easily integrated with remote server unit for data storage and further processing.

Sensor node utilize IMUduino BTLE (r1.0.6) device with the following characteristics: Bluetooth low energy, Atmel MCU with 5 ADC channels, gyroscope and accelerometer, Arduino programming environment and small dimensions: 41.5 mm × 15.7 mm [11]. The IMUduino sensor node can be easily mounted on the shoe to acquire foot plantar pressure and movement data.

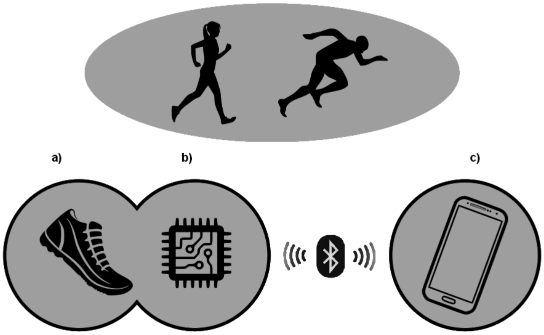

Fig. 1. Footprint pressure system: *shoe implant* with Velostat sensor (*a*); *IMUduino sensor node* (*b*); and *mobile phone* with application for pressure monitoring (*c*).

The IMUduino sensor node is equipped with the five AD channels enabling simultaneous measurement from five anatomic regions, as: heel, medial forefoot, central forefoot, lateral forefoot and toes.

3 3M Velostat

3M^{TM} Velostat^{TM} is made of an opaque polyolefin, from the class of polymers, and it is impregnated with particles of carbon. Its chemical structure shows the current leading features, due to carbon particles. Physical properties are not dependent on age and humidity. Due to its polymer characteristics that change electrical resistance when a mechanical bending, elongation or pressure is applied, opens up the possibility of using this material in the pressure sensors.

The total resistance of piece of Velostat depends on its size, so it is possible, by changing the geometry, to modify a total resistance between two points. Increase or decrease in length, contributes to the increase or decrease of the total resistance, which directly connects the influence of pressure or stress on the measured resistance or voltage. Technical and electrical characteristics of the material depend on the thickness and the total area of which is used as a conductor, which provides the ability to create tape with different conductivity and thus sensitivity to mechanical changes.

For a successful detection and analysis of the distribution of pressure on the foot, when using a Velostat, it is necessary to make a segmentation of the feet, or divide the surface of Velostat in several regions, in order to have independent measurements.

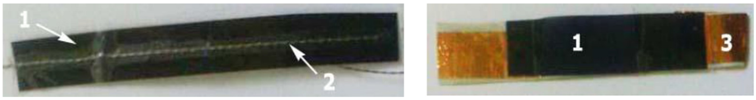

Fig. 2. Velostat based sensor prototypes: *Velostat track (1)* with *steel thread (2) (left)* and *Velostat track (1)* with *copper ribbon (3) (right).*

Velostat should be coated with medical silicone, which will provide insulation to Velostat and allow deformation that will be mapped to Velostat, and therefore react to changes in pressure in the form of voltage changes.

For the prototype system testing we have used 4 mils thick Velostat (1 mils = 0.0254 mm). We have tested prototype using steel threads and copper ribbons as conductive pads, and both solutions provided identical results. The sensor prototypes shown in Fig. 2 that were used for testing Velostat linearity and accuracy, have following geometric features: steel thread: 250 mm with Velostat track 70 mm × 10 mm, thickness 0.127 mm, and copper ribbon: 65 mm × 8 mm, thickness 0.127 mm with Velostat track 40 mm x 10 mm, thickness 0.127 mm. Connection to the AD pins of the IMUduino device were made of steel threads length 200 mm, with negligible resistance.

4 Pressure Monitoring Application

Application for foot pressure monitoring is implemented for use on Android mobile device with objective for effortless data acquisition and measurement display. In addition to communication with IMUduino sensor node via Bluetooth channel, the application is responsible for communicating data for further usage via Internet.

The graphs in Fig. 3 present measurement results obtained during the system testing. The monitoring application is used to test linearity and accuracy of the 3M Velostat based sensors, and change in its performance depending on the wrapper material. The later tests were aimed to evaluate 3M Velostat performance when coated with different silicon types. The graphs are presented to illustrate different scenarios that were used during testing. The analyses included measurements using wrapper materials of different softness. The graphs in Fig. 3 correspond with the tests using softer wrapper material resulting in a less smooth pressure measurement curve. The tests indicated that change in measured value was proportional to change in the true value.

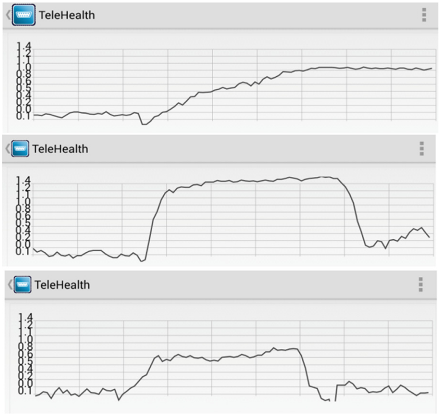

Fig. 3. Pressure monitoring graphs illustrating Velostat sensor testing: (*control mass - top)*; (*50% increase - middle*) and (*50% decrease - bottom).*

5 Conclusion

This paper presents design proposal for a foot pressure monitoring system using Velostat sensors. Implemented solution includes: 3M Velostat pressure sensor prototypes, IMUduino sensor node programmed to collect data from the 3M Velostat pressure sensors and from an inertial measurement unit with accelerometer and gyroscope, and mobile phone with Android application for pressure monitoring. The application is used to test linearity and accuracy of prototype sensors. Achieved results are demonstrating that the proposed solution is worth further development.

The proposed design has met the requirements related to the dimensions of the sensors and sensor node, while providing fully functional and low cost solution.

The solution is suitable for several other pressure monitoring health applications, and in addition to foot plantar pressure we are extending our interest in hand physiotherapy assessment and Kegel exercises. The later application requires only one measurement point. Different applications will influence sensor design and its wrapping. The future work demands custom development of the sensor node because the reduced number of measurement points enables more simple design and decreased dimensions.

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