A Wireless Pressure-sensitive Insole for Gait Analysis

S. M. M. De Rossi, M. Donati, N. Vitiello, T. Lenzi, F. Giovacchini, M. C. Carrozza
The Biorobotics Institute, Scuola Superiore Sant'Anna, viale Rinaldo Piaggio 34, Pontedera (PI), Italy

Abstract— **We present the development of an in-shoe device to monitor plantar pressure distribution for gait analysis. The device consists in a matrix of 64 sensitive elements, integrated with in-shoe electronics and battery which provide an high-frequency data acquisition, wireless transmission and an average autonomy of 7 hours in continuous working mode. The device can fit in any sport shoe in place of the regular insole, and provides remotely the pressure distribution on the plantar area.**

***Keywords*—Gait Analysis, Instrumented Shoe, Pressure sensor, pressure sensitive insole, wearable sensor**

I. INTRODUCTION

Measurement of plantar pressure distribution is widely recognized as a key tool in clinical gait analysis [7]. Two types of devices are commonly used for plantar pressure monitoring: force platforms and pressure-sensitive foot insoles. Force platforms are high-resolution, high-frequency floor-mounted matrices of pressure sensors, which can capture three-axial pressure data of the barefoot. These platforms are very valuable for clinical studies but are not suitable when measurements of pressure at the shoe-foot interface are required, or when a high-portability is desired. Pressure-sensitive foot insoles have been developed through several sensing technologies, ranging from force-sensing resistors, as in the F-Scan® system to capacitive sensors, as in the Pedar® system. Most of these systems require electrical wires to connect to wireless communication modules that are strapped around the waist or the ankle of the user, causing discomfort and making long-time monitoring and recordings during daily life or sport activities difficult to obtain.

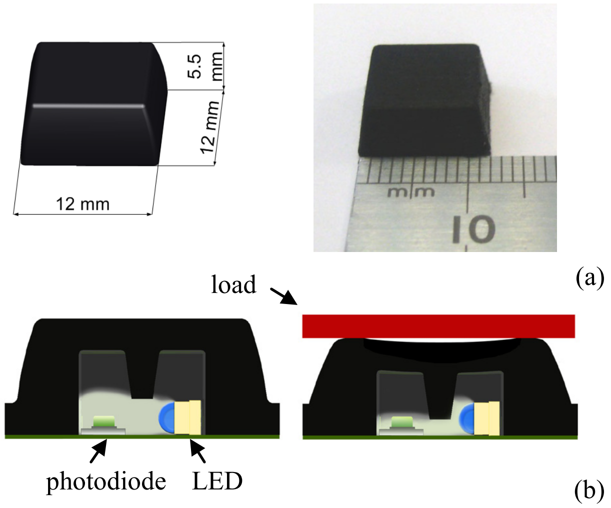


Figure 2. Base sensitive element of the pressure-sensitive insole. (a) Silicone cover of the sensitive element. (b) Representation of the transduction principle. When a load is applied (on the right), the consequent deformation of the structure occludes the light path, and results in a diminished output from the photodiode.

In this work, we present a new in-shoe device to monitor plantar pressure, consisting in a matrix of 64 sensitive elements, integrated with in-shoe conditioning electronics and battery. The device provides high-frequency data acquisition, on-board computation of center of pressure and ground reaction force, and wireless communication, with an autonomy of about 7 hours in continuous working mode. The device can replace the insole of commercially available shoes, without interfering with the normal gait. The system is presented along with an experimental characterization and a preliminary validation on a healthy subject.

II. HARDWARE COMPONENTS

Our in-shoe device comprises two hardware parts: an array of pressure sensors, and an in-shoe electronic board for signal conditioning and wireless data transmission.

1) *Sensitive Element*

This sensitive element, presented in [1][2][3][4] is made of a LED light emitter facing a photodiode as light receiver. These optical components are covered by a shell made of opaque silicone, which deforms under the effect of external force. The sensitive element is shown in Figure 1(a). It can be seen that the sensor cover has the shape of a square pyramidal frustum, with the base having a side of 12 mm, and the top face of 10mm. This contact surface provides a $1 cm^2$ resolution to the estimation of pressure distribution and center of pressure. The cover is made of a black-dyed opaque

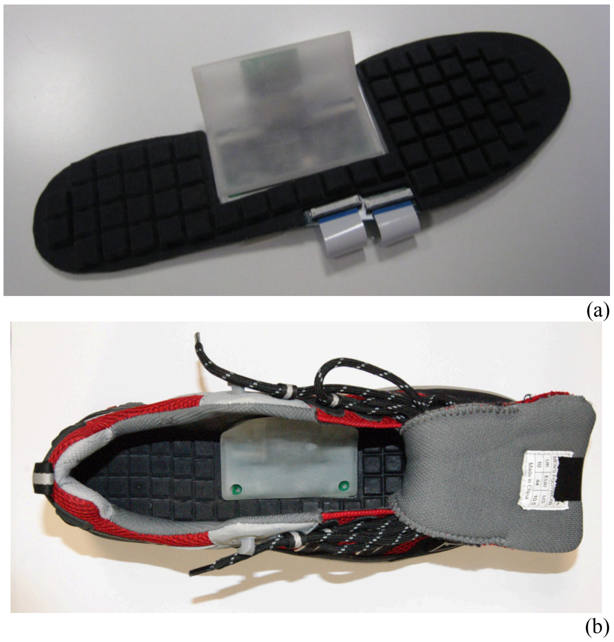


Figure 1. Overview of the device. (a) outside of the shoe and (b) inside the shoe.

silicone. Figure 1(b) represents the transduction principle of the sensitive element: Figure 2(a) and (b) show the characterization curve of the sensor and its structural behavior, respectively. It can be seen that each sensor can bear up to 500kPa, in line with plantar pressure values [5][6]

2) *Sensor Board*

The sensor board comprises 64 sensitive, placed as in Figure 3(a). The sensitive area covers about 80% of the foot-insole contact region, leaving the Medial Arch area free from sensors, and available for the integration of the electronics.

The sensor board is based on a thin PCB, housing, for each sensor, a power and ground wire, and a signal wire. The 64 signal channels, and the two common power and ground channels are routed through two flat cable connectors, placed in the Lateral Arch area. The cable connectors are not in contact with the foot, being positioned at a height lower than the sensors. Figure 3 (b) shows the final appearance of the sensor board, complete with silicone cover for the 64 sensitive elements.

B. *In-Shoe Electronics*

The board comprises analog-digital converters (ADCs), and a microcontroller to perform signal processing. The board is connected to a Bluetooth receiver/transmitter (RoboTech s.r.l., Pisa, Italy) on a UART socket. Power to the board and to the sensors is supplied by a Li-poly 700mAh battery operating at 3.6V (25x25x10mm).

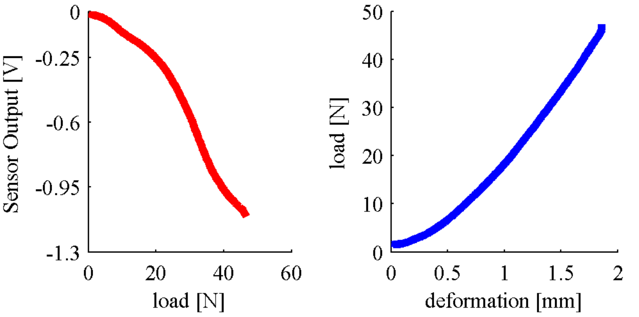
The board acquires the 64 signals at a 1.8kHz frequency through four 16-channels 14-bit ADCs. Signals are low-pass filtered and de-sampled to 100Hz.

The power consumption of the device (sensors and electronics) is about 100 mA at 3.6-3.7V. The on-board battery can power the unit for up to 7 hours in continuous working mode. The in-shoe electronics is protected by a rigid plastic cover, providing protection from impacts, sweating and humidity.

III. SOFTWARE COMPONENTS

The data from the pressure-sensitive insole can be received by any remote device (PC, tablet or smarphone) equipped with a Bluetooth receiver. A 921.6Kbit/s connection is required to sustain a 100Hz communication rate. Each data packet sent from the insole includes a timestamp to verify transmission reliability on the remote host.

The remote host can command the device to initiate (or stop) a data acquisition and communication sequence. Commands can be sent to require force de-offsetting, battery level as well as for debugging information.



(a) (b)

Figure 3. Characterization of the sensitive element. (a) Shows the force vs. Voltage output characterization, while (b) shows the structural characterization of the sensor.

A. *Software Modules*

We developed a graphical user interface (GUI) to allow for data monitoring and logging, as well as to remotely command the device. The interface was written using National Instruments^{TM} Labview® 2010 and gives a real-time monitoring of the foot pressure map, of the ground reaction force trend, and of the position of the center of pressure. Taking into account that no computation is required from the remote host side (all calculations are done on-board), similar interfaces could be developed for less powerful architectures like tablets or smartphones.

IV. CONCLUSIONS

We developed a new in-shoe device to monitor plantar pressure consisting in a matrix of 64 pressure-sensitive elements, integrated with in-shoe conditioning electronics and battery. The device can replace the insole of commercially available shoes, without interfering with the normal gait, and allowing the user to wear his/her own shoe.

These features, along with its long-time autonomy, make the proposed device very useful to monitor the gait and for the assessment of quality of the walk in healthy subjects. Most importantly, this device can used for long-term monitoring of gait (all-day monitoring), thanks to its simplicity of use and to its versatility.

ACKNOWLEDGMENTS

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