

Tri-axial force sensor unit for smart prosthetics

Guido Sordo¹, Alvise Bagolini¹, Daniele Perenzoni¹ and Leandro Lorenzelli¹

¹*Fondazione Bruno Kessler, Trento. 38123, Italy*

Summary

This work reports the results of the design and fabrication of a tri-axial force sensor designed to be implemented in a master socket. The scope was to provide a smart sensing unit as building block for investigating automatic and less handcraft procedures for tailoring the prosthesis shape to the anatomical profile of the residual limb. In order to achieve this task, the continuous monitoring of parameters as the shear stress and normal pressure interaction between the leg and the socket plays an important role [1]. In the proposed approach the aim is the integration of a wireless system based on several force microsensors in a master socket for providing the biomechanical data for a fast customization of prosthetic socket for lower limb.

Motivation and results

The function of a lower prosthetic is highly dependent upon the characteristics and anatomical profile of the residual limb. A poorly fitting socket can cause significant trauma so it is important to consider how to optimise the fit to maximize the amputee's comfort while wearing the prosthetic limb in gait tasks. Current practice in designing a prosthetic socket is time-consuming, and is highly dependent on the handcraft experience of the prosthetists [2]. One of the most important parameters in determining the comfort of the socket is the pressure distribution generated between socket and residual limb during different activities [3-4]. For this reason, we have proposed a system architecture aimed to integrate several micro pressure sensors within a master socket which can help the prosthesis to achieve a fast customised design and manufacturing of prosthetic socket for lower limb amputees. We report a novel 3-axis force sensor based on a pressure sensor technology, which shows several desired features, e.g. good linearity, compatibility with VLSI fabrication process and high integration capability. The sensor unit consists of a MEMS piezo-resistive force sensor array with five silicon thin membranes as sensitive areas on a single chip (Figure 1). The device fabrication is based on a dedicated process sequence, which allows the membranes to be circular, unlike standard mems pressure sensors that have square membranes (Figure 2). This provides a better structure, with 33% higher resistance to pressure as the stress is not concentrated on small spots over the membrane area, but evenly distributed on it. The chip size is of 10 x 10 mm², and it includes five pressure sensors with circular membrane with a diameter of 1100 μm and thickness of 20μm (Figure 3). In order to measure both the normal and shear stress we have integrated a PDMS polymeric dome for the distribution of the (normal/shear) stresses on the surface of the sensor. The dome acts as a medium, transferring the orthogonal component of the applied force, and converting the shear component into an unbalanced load on the pressure transducers laying underneath it. The sensor is assembled on a two-side printed circuit board (Figure 4), with a microcontroller for data management through an I²C communication standard. This activity was supported by the H2020 project SocketMaster, coordinated by TWI Ltd.

Word count: 500

References

- [1] K Sundara-Rajan et al., An interfacial stress sensor for biomechanical applications Meas. Sci. Technol. 23 (2012) 085701.
- [2] Arthur F.T. Mak, et al., State-of-the-art research in lower-limb prosthetic biomechanics socket interface: A review, J. of Rehab. Res. and Develop. 38, 2, 2001, 161–174.
- [3] J.E. Sanders, S.G. Zachariah, A.K. Jacobsen, J.R. Ferguson, Changes in interface pressures and shear stresses over time on trans-tibial amputee subjects ambulating with prosthetic limbs: comparison of diurnal and six-month differences, J. of Biomech. 38, 2005 1566–1573
- [4] Tucker et al. Control strategies for active lower extremity prosthetics and orthotics: a review, J. of NeuroEng. and Rehab., 2015, 12:1.

Corresponding author

Leandro Lorenzelli - FBK-CMM Via Sommarive 18, 38123 Trento, Italy;
Phone: +390461314455; e-mail: lorenzelli@fbk.eu .

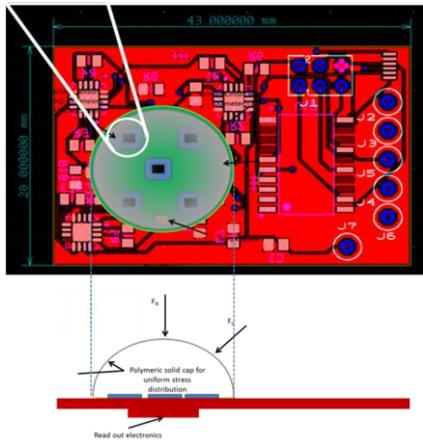


Figure 1: Schematic representing the integration of the sensor in the master socket. Top view of the PCB and cross section of the sensor unit.

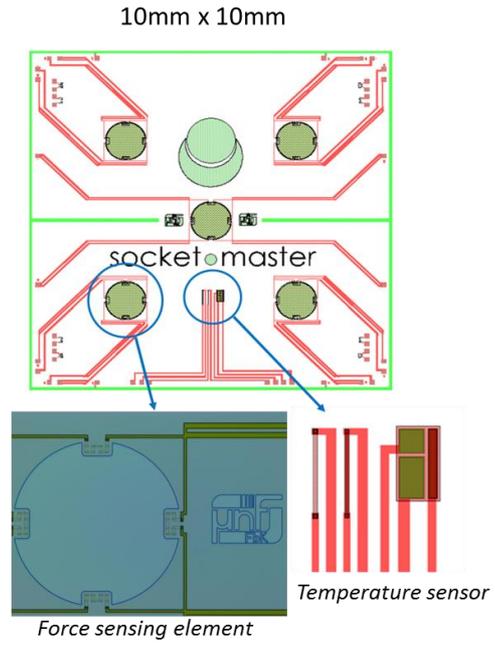


Figure 3: The fabricated device includes all 5 pressure transducers integrated in a single chip, a temperature readout set of resistors and diodes, a set of test resistors in the proximity of each pressure sensor.

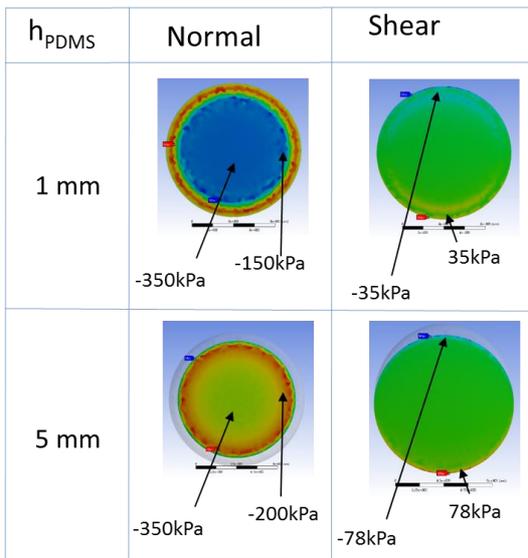


Figure 2: Stress distribution within the PDMS dome. The dome was simulated with different heights (1 and 5mm), preserving the semi-elliptic cross section. Normal stimulus presents similar stress distribution in the two cases. Shear stimulus responsiveness increases drastically using a more spherical dome.

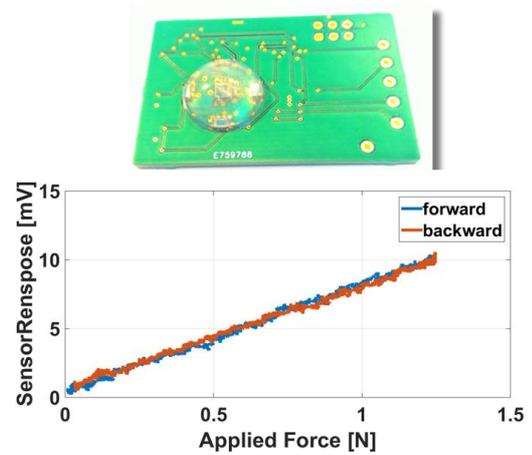


Figure 4: (Top) Final sensor unit assembled with the PDMS dome. Example of electrical response of a single membrane to an applied force. (Tests have been performed in dynamic mode by means of a TIRA shaker setup).