HSOA Journal of
Physical Medicine, Rehabilitation & Disabilities

Research Article

# Design and Fabrication of a Pressure Sensing Device to Aid with Fitting Lower Limb Prostheses

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## Abstract

A near real time pressure measurement system for the limb-socket interface for a lower limb prosthetic was developed. A matrix of thin and flexible force sensitive resistors coupled with multiplexing circuitry allows for pressure readings to be taken in the form of a voltage differential. The readings are sampled by a programmed microcontroller that translates the average of a sequence of voltages into the corresponding pressure value in kilopascals (kPa). The microcontroller then transmits the values as a stream of characters to a PC running a MATLAB Graphic User Interface (GUI). Near real time plotting was demonstrated with a 250ms refresh rate for pressures up to 350kPa with a sensitivity of 1kPa.

**Keywords:** Amputations; Design; Lower limb prosthesis; Pressure sensor

## Introduction

A common method for fabricating lower limb prostheses for persons with lower limb amputation at tertiary care rehabilitation centres involves an iterative process that uses subjective tests to determine the pressure distribution on a residual limb caused by a prosthetic socket. This is an imperfect and time consuming process. Up to 25% of patients experience wounds related to their prosthesis[1]. These manifest primarily as blisters or abrasions from friction with the prosthetic socket. In patients with reduced sensation or a diminished capacity to heal, small wounds such as these can easily become infected and be the cause of significant complications. Improperly distributed pressure within a prosthetic socket can cause pain, skin irritation and tissue breakdown[2]. Consequences range from discomfort, extended hospital stays, delays in prosthesis fitting and gait training, or even a revision of the amputation of the limb to a more proximal site [3].

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**Citation:** Ed Hanada, Benstead T, Keeble R, Brown J (2015) Design and Fabrication of a Pressure Sensing Device to Aid with Fitting Lower Limb Prostheses. J Phys Med Rehabil Disabil 1: 006.

**Received:** August 07, 2015; **Accepted:** September 15, 2015; **Published:** September 30, 2015

Previous methods of measuring skin-socket interface pressures include use of electrical strain-gauge transducers, which were accurate and sensitive but required that the socket be significantly modified to accommodate the bulk of the transducers [4]. More recent use of fiber bragg grating sensors demonstrated that it was accurate in measuring pressures at the patellar tendon bearing area in a model transtibial amputee, but there was significant work to fabricate the sensors [4]. Furthermore, the sensors needed protection and were not tested in the dynamic setting with a suitable data acquisition system [4,5].

For this reason, a quantitative method for measuring pressure at the socket interface was developed to help determine areas of excessive pressure in the skin-socket interface to prevent potential complications during prosthesis fitting.

## Objectives

The objective of this project was to build an economical proof of concept system that was:

- Easy to use
- Robust and portable
- Insensitive to heat within the socket
- Thin enough to fit unnoticeably between the limb and the socket, without requiring significant alterations to the socket.

## Methods

An array of 16 thin and flexible Force Sensitive Resistors (FSR) coupled with a buffer amplifier and multiplexing circuitry (MUX 16:1) allowed for pressure readings to be taken in the form of a voltage differential. The signal then passed through a Low-pass Filter (LPF) to produce a smoother output. The readings were sampled by a programmed microcontroller that translated the average of a sequence of voltages into the corresponding pressure value in kilopascals (kPa). The data was passed from the microcontroller to a PC via USB, where it was displayed on the User Interface (GUI).The final system architecture is displayed in figure 1. Sensor device is designed to be worn by a patient while in use. Straps can be fastened around the leg above the socket, or around the socket itself. Wires to the sensor array are formed into ribbons to reduce their profile inside the socket, ensuring a better fit. The set up of the pressure sensing system is displayed in figure 2.

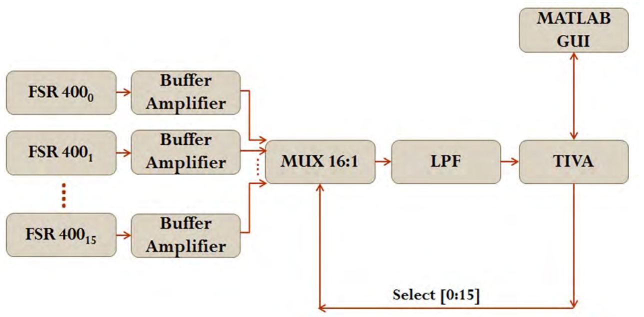


**Figure 1:** System architecture.

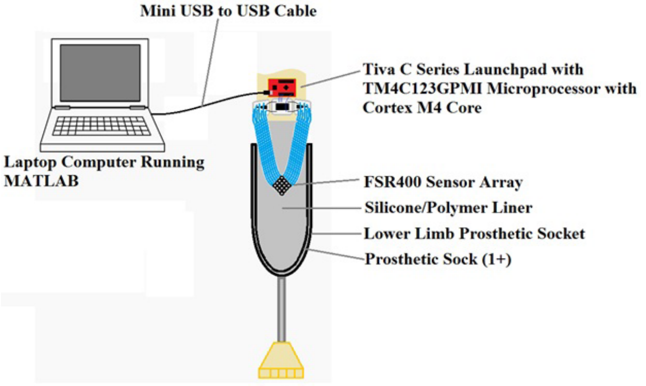


**Figure 2:** Diagram of components of pressure sensing device.

## Results

Many trials of pressure values from able bodied persons were detected by the sensing layer and successfully sent from the controller and mapped with little delay. Near real time plotting was demonstrated with a 250ms refresh rate for pressures up to 350kPa with a sensitivity of 1kPa. To test the accuracy of the sensors, an object of known mass (275g) was isolated on sensor 15 to compare the expected pressure reading to observed readings.

The expected pressure was calculated as follows:

$$Pressure = \frac{mg}{A} = \frac{(0.275\ kg)(9.8\ {}^{m}/{}_{s^2})}{2.83 \times 10^{-5}\ m^2}$$

$$Pressure = 95.3\ kPa$$

As an example, one sensor showed a reading of 89kPa to 96kPa (maximum error = 6.3%) after at least ten trials.

High pressure areas were color coded and mapped to location as in figure 3.

The sensor array fit inside the prosthetic socket without impeding the fit when it is worn by a subject. Pressure readings were sampled then transmitted at a rate that could accurately reflect changes in pressure as the patient moved. Pressure was displayed in an intuitive manner that could be interpreted easily by a prosthetist or clinician [4]. However, the sensor array requires further development and needs to be expanded to cover the entire residual limb at the socket-skin interface. Its efficacyandsafety also have to be assessed to a greater extent and tested.

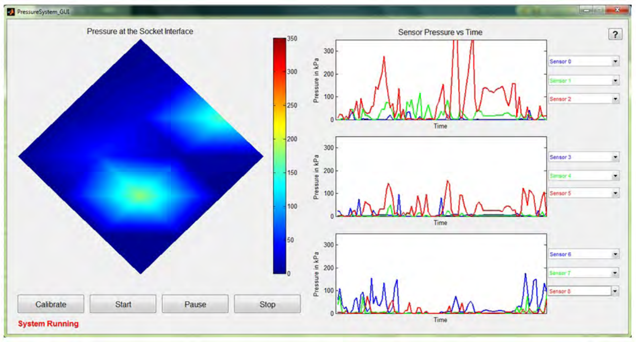


**Figure 3:** Colour-coded pressure mapping system (left) with blue pixels denoting low pressure areas and red pixels high pressure areas with pressure measurements in real time displayed (right).

## Conclusion

An economical (<$500) pressure sensing and mapping prototype system was successfully designed and built, and has high potential for providing a means for preventing pressure ulcers in persons with major lower limb amputations. Fully developed, such a system could facilitate the rehabilitation process, prevent complications from ill-fitting prostheses, and potentially decrease inpatient length of stay. Future studies are required to test the sensor array's efficacy and safety to a greater extent.

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