Detection of slip from multiple sites in an artificial finger



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# Detection of slip from multiple sites in an artificial finger

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**Abstract**. A Piezoelectric thick-film sensor is a good candidate for the extraction of information from object slip in hand prosthesis. Five slip sensors were fabricated on different linkages of an artificial hand. The signals from each sensor were compared to the output from the sensor mounted on the fingertip. An analysis of the output signals from all the sensors indicates that the linkage sensors also produce similar output signals to the fingertip sensor. In the next phase of the research, velocity and acceleration of the slipped object will be considered in the analysis.

## 1. Introduction

A prosthesis is a device that is intended to replace a missing natural body part such as arms or legs. Artificial limbs may be needed for a variety of reasons, including disease, accidents, war and congenital defects [1]. The device should be designed so that it can perform the same or limited prehensile tasks similar to the natural hand with minimal side effects to the user. The Southampton Hand is a prototype system intended for the use as a prosthesis. At present, the research is very active, covers a wide area of technology such as the control system, mechanical functionality and the integration of sensors.

The Southampton Hand has four fingers and a thumb with one electrical motor for each of the fingers and two for the thumb. In the human hand, the three middle fingers are similar in size and movement, so for our prosthesis they were made identical [2]. The little finger is a smaller version of these fingers. Each finger is made up from six bar linkages. Of the six bar linkages, five have a lead zirconate titanate (PZT) thick film sensor fabricated on them. A sensor is also fabricated on the fingertip. The thumb is more complicated than the fingers with respect to the number of movements it can make. Therefore the thumb of the Southampton Hand has two electrical motors to allow it to rotate and also to flex. The mass of the Southampton Hand is about 400g, which is considered to be light and comparable to the mass of a natural human hand.

The Southampton Hand is controlled using the Southampton Adaptive Manipulation Scheme [3]. The controller uses information provided by sensors in the hand to control the force applied to an object. The fingers of the hand have been designed using a worm-wheel combination to drive their movement. Since a wheel cannot be back-driven, when using high gear ratio, individual fingers retain their grip on an object should the power be removed from the electric motors. Hence, a range of activities of daily living can be performed by the user.

## 2. Experiments

Using the PZT sensors and a purpose built test rig, several experiments were performed to collect output signals. The test rig comprises an aluminium sliding block, aluminium angle base with a pulley attached to it, a metal cable from which to hang weights and a three channel rotary encoder [4]. Figure 1 shows the test rig and equipment for the characterization of the PZT slip sensors. It consists of the six finger sensors, a power supply, an instrumentation amplifier for each of the sensors, and two Tektronix DPO 3014 oscilloscopes. Each oscilloscope has four channels with eight bit channel resolution, sampling rate at 2.5 GS/s, 5 x $10^6$ points record length on all channels and USB available for quick and easy storage.

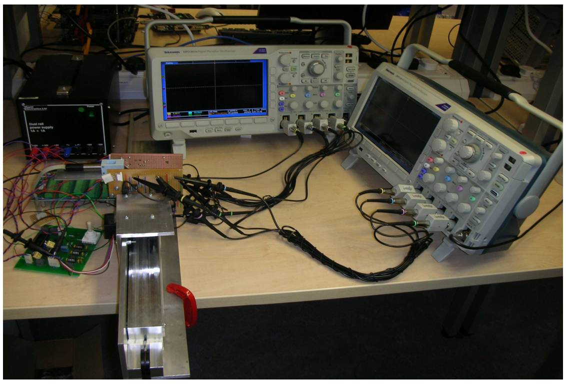


**Figure 1**: Photograph of experimental apparatus.

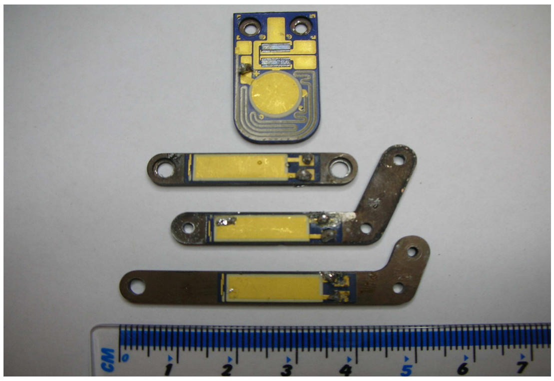



**Figure 2:** Photograph of the three types of finger linkages and a fingertip. From top: sensor T, sensor L2, sensor C and sensor L1.

Figure 2 shows a photograph of the stainless steel finger linkages and fingertip with the PZT thick film sensors fabricated on them. The fabricated PZT thick-film structure is polarized initially to develop the piezoelectric properties. This process (referred to as poling) involves applying an electric field of $3MVmm^{-1}$ using a high voltage supply whilst they are heated to a temperature above their Curie temperature (200°C). The poling voltage was applied for between eight to ten minutes and then the film was allowed to cool down to room temperature. In the next step, all the sensors were assembled to form a finger. In Figure 3, sensor link L1 is paired with R1 and sensor link L2 is paired with R2. Each pair is of identical size and dimensions. Figure 4 shows the finger attached to the rig and also the electronic components. A piece of silicone glove from a cosmesis was located between the fingertip surface and a mechanical grating attached to the sliding block. Figure 5 shows a diagram of the test rig where the grip force of the finger tip is normal to the direction of motion of the sliding block.

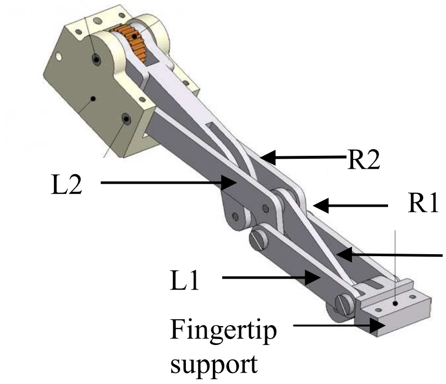



**Figure 3**: The finger link system [3].

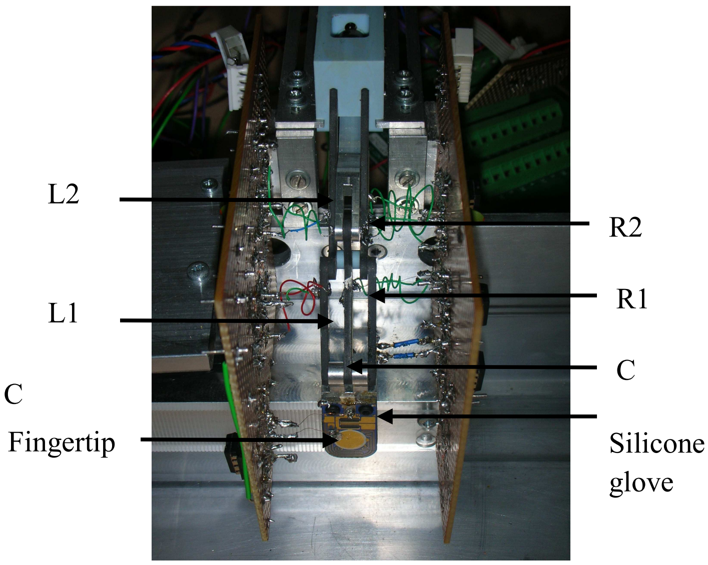



**Figure 4**: Electronic components on the circuit boards placed near to the PZT slip sensor.

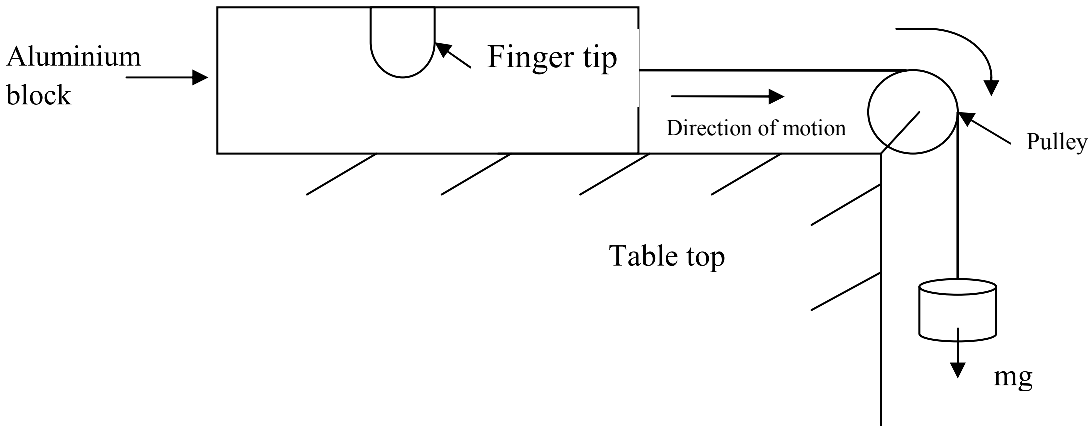



**Figure 5**: Diagramatic presentation of the test rig.

## 3. Result and discussion

There are eight output signals obtained which are encoder 1 signal, encoder 2 signal, T signal, C signal, L2 signal, R2 signal, L1 signal and R1 signal, examples of which are shown in figure 6 (a) to (h). The output signal waveforms from the four side-links and the central-link, as in figure 6 (d), (e), (f), (g) and (h) are similar to the finger tip sensor waveform in figure 6 (c) which is in contact with the object. All the signals have significant peaks at the same starting and ending time.

Figure 6 (i) to (p) show the output signals for the initial 100ms of data from each of the sensors in the corresponding figures (a) to (h) as the sliding block first begins to move. The first pulse of the encoder 2 signal, shown in the figure, occurs when the block starts to move after about 40ms. A large signal is observed in the data from each of the individual sensors about 40ms later corresponding to a movement of the block of about 0.552mm as shown by the vertical dashed line in the figure.

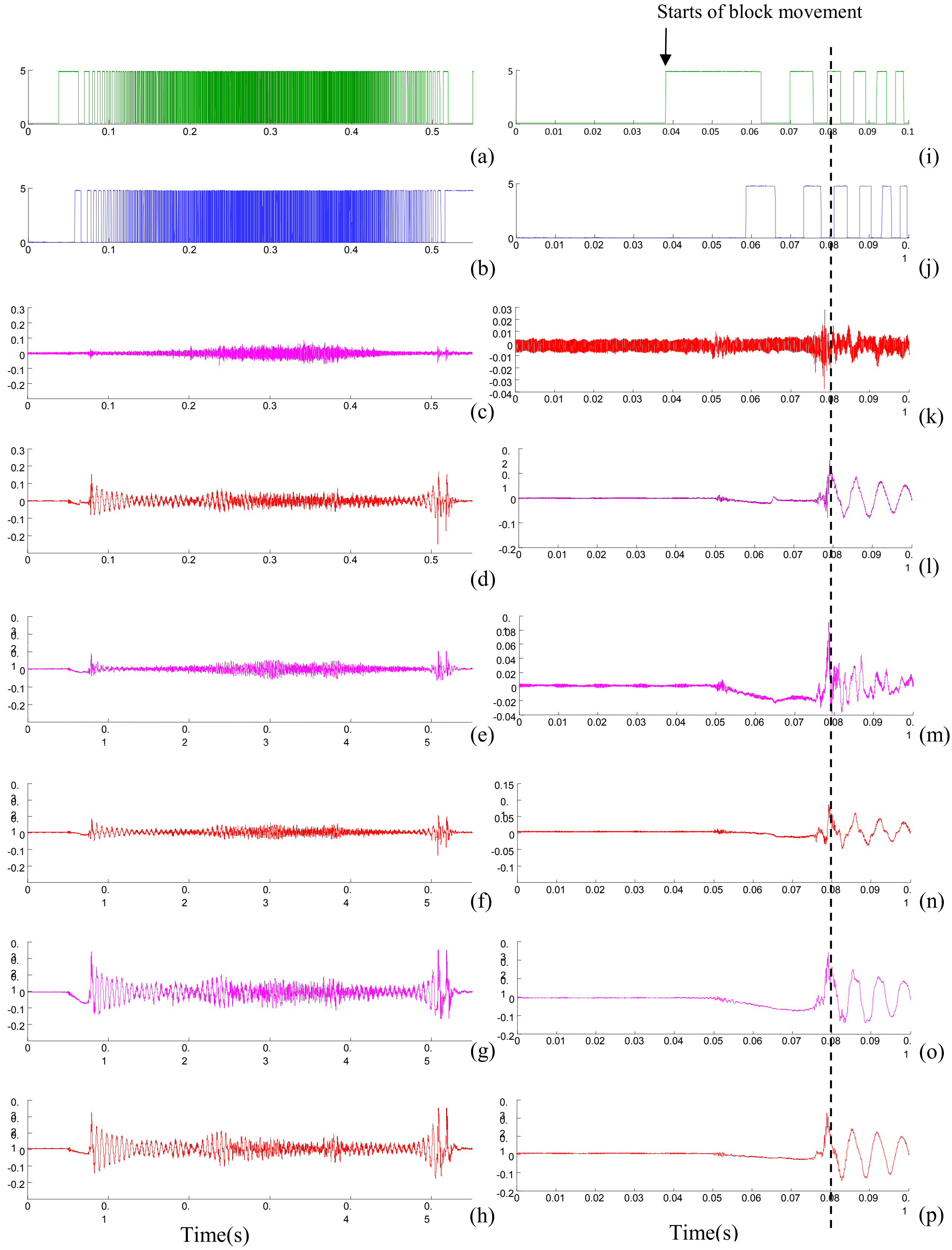
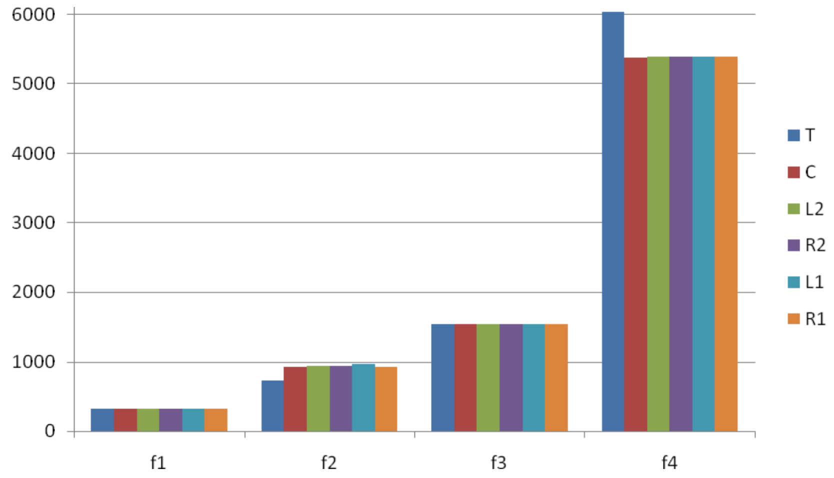
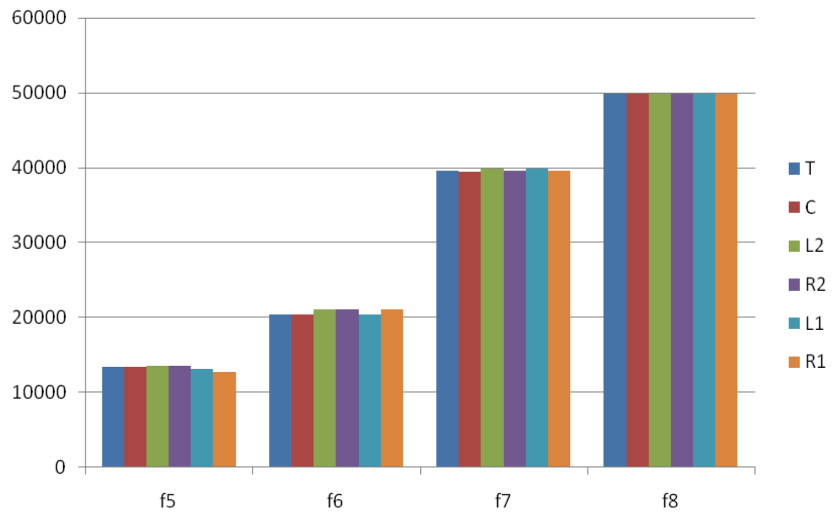



**Figure 6**: (a) Encoder 1 signal, (b) encoder 2 signal, PZT output signals for sensor (c) T, (d) C, (e) L2, (f) L1 (g) R2 ,(h) R1, initial movement signal for sensor (k) T, (l) C, (m) L2, (n) L1 (o) R2 and (p) R1. (The block starts to move at about 0.04s).

An FFT analysis of the signals showed that they have similar frequency spectra. Figure 7 shows a histogram of dominant frequencies for eight selected peaks. These peaks f1, f3 and f8 for all the sensors have the same frequency values that are 323Hz, 1,539Hz and 49,860Hz, respectively. There are a range of slightly different frequencies for peaks f2, f5, f6 and f7. For peak f4, the fingertip sensors have larger frequency value compared to the other sensors.




(a)




(b)

**Figure 7**: Histogram of frequencies from PZT sensors T, C, L2, R2, L1 and R1 for eight selected peaks. (a) First four amplitude, f1, f2, f3 and f4. (b) Last four amplitude f5, f6, f7 and f8.

## 4. Conclusions and future developments

The study carried out demonstrates clearly that sensors on the four side-links and a central-link can produce output signal waveforms that are similar to the finger tip sensor waveform which is in contact with the object.

The central-link sensor appears to have all the frequency components of the slip signal and this is similar to the components of the sensor on a fingertip. The frequency content of the central-link sensor is between 250Hz to 2.5 kHz. For the four side-link sensors, the amplitude for each of the frequency components is lower than the finger-tip and central-link sensors. L2 and R2 side-link sensors have frequency content between 1 to 2.5kHz, meanwhile for L1 and R1 side-link sensors, their frequency content is lower than 1kHz. It has been confirmed that the signal received by a side-link sensor is smaller the further it is away from the fingertip sensor. Nevertheless, all the side-link and central-link sensors are found to be able to receive microvibration from the slip activity at the fingertip.

The next phase of this research is to include an analysis for the velocity and acceleration of the object while it moves in the test rig for the side-link and the central-link sensors. It is expected that more information will be retrieved by adding these parameters. The effect of object movement direction, whether it is perpendicular or normal to the sensors will also be studied.

## References

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