# An Anthropomorphic Tactile Sensor System for Dexterous Manipulations

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***Abstract*— We present an anthropomorphic fingertip system that can detect force and vibrational modalities through force sensors and accelerometers. This fingertip was used in grasping, manipulating and environment perception tasks. We present systems and methods that could be used to detect the presence or absence of contact, incipient slip detection, and contour tracking. Analysing simultaneously spatio-temporal data obtained by sensors provides sufficient information for object manipulation and environment perception.**

## I. Introduction

Tactile data obtained from mechanoreceptors in fingertips [1] coupled with previous experiences allow humans to manipulate objects and evaluate surfaces with high accuracy. This was a compelling reason to mimic human tactile system when developing artificial tactile systems. A state of the art survey on tactile sensing [2], and [3] explains the requirements for tactile sensors and it introduces technologies available to develop these sensors. Resistive, capacitative, piezoelectric, optical, and photoelastic technologies were utilized in the development of large area tactile sensors [4]-[7]. We focus our studies into developing robotic fingers with force sensors and accelerometers. The two specific tasks that the artificial fingertips were used were material or texture recognition [8], and object manipulation [9].

Here, we present a tactile fingertip system that was reported in [10]. Additionally, we evaluate the ability of this fingertips to perform various activities: contact detection and localization, contour identification, and detection of incipient slippage that are required by a robot. Experiments showed that the tactile system we developed was capable of performing tasks similar to those performed by human tactile systems.

## II. Anthropomorphic Tactile Sensor and its Evaluation

The anthropomorphic tactile sensor (ATS) mimics a human distal phalanx in shape and functionality. It can sense vibrations and pressure using accelerometers (Analogue Devices$^{TM}$ADXL327) and force sensors (FlexiForce$^{TM}$A201) embedded in the sensor. Design aspects of the fingertip sensor is presented in [10]. The fingertip was fabricated of two layers of soft material with different stiffness, similar to the epidermis and dermis of glabrous skin. The fingertip accelerometers were sensitive to vibrations above 500 Hz, and force sensors were sensitive to loads of frequency under 100 Hz. These numbers were similar to the tactile sensitivity of a human fingertip [11].

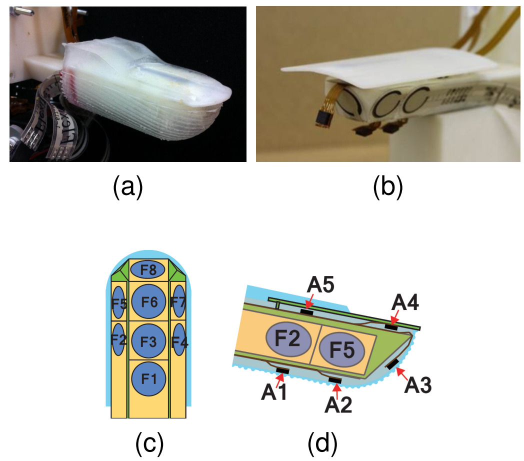


Fig. 1. Fingertip sensor. (a) Fingertip. (b) Inside fingertip with five accelerometers and eight force sensors. (c) Force sensor designations. (d) Accelerometer designations.

### A. Detection of the making and breaking of contact

In controlling the robot hand during object manipulation, it is necessary for the fingertip to make contact with the object. This transient event is a cue for the hand to shift from position control to force control. By analysing the force sensor and accelerometer signal together, it was possible to identify the instant of contact. The derivatives of the force and accelerometer signals were calculated (Fig. 2). If, within a given period of time $T$ (250 ms), the derivatives of the accelerometer and force sensor signals increased above a threshold, it was assumed that the fingertip had made contact with an object. After contact was detected, the system moved to the grip phase, in which a predefined force was applied to the fingertip to pinch the object (phase (ii) of Fig. 2). In Fig. 2, the portion $(ii)$ was considered $T$. At the moment contact was broken, the force sensor value was gradually reduced to zero while the accelerometer signal showed a large deviation.

### B. Contour identification and surface identification

Humans follow contours on an object to determine its size and shape. Edges and corners constitute the boundaries of an object. Thus, by identifying edges, a robot should be able to estimate the size of an object. The ATS could be slid over the object to find the edge, an exploratory motion similar

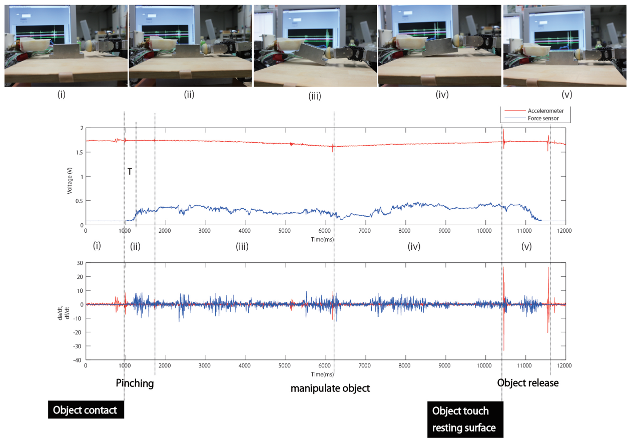


Fig. 2. Accelerometer and force sensor data obtained while gripping, manipulating and releasing an object. In this figure only the accelerometer and force sensors closest to the contact are presented. The object was placed on a surface and the two fingers were moved closer until the fingertips touched the object. The object was pinched by the two fingers and lifted. The object was rotated clockwise and counter-clockwise for a few degrees each and rotated back to its initial position. The object was subsequently lowered until it touched the horizontal surface and was finally released by the fingers.

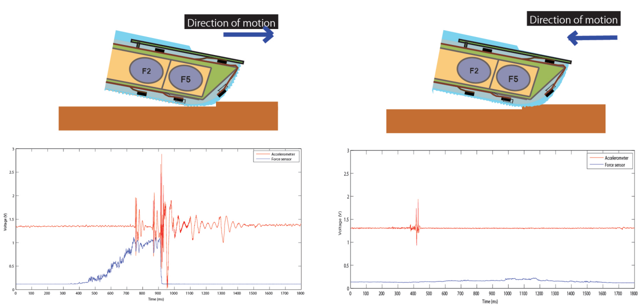


Fig. 3. Accelerometer and force sensor signals when a fingertip encounters a step-up edge and a step-down edge

to that of a human fingertip. Upon encountering a step-up edge (Fig. 3), the force on the fingertip increased because the edge resisted the motion of the fingertip. To overcome the edge, the fingertip must be deformed, such that the area of the fingertip in contact with the edge decreases. A larger vibration could be detected at this point. Thus, by comparing the force sensor values before and after the large vibration, the edge could be detected. Upon encountering a step-down edge, the force signal of the fingertip did not increase suddenly. Rather, only the accelerometer experienced a sudden change.

### *C. Detection of incipient slippage*

It was difficult to identify incipient slippage by analysing raw accelerometer signals from ATS. This was likely due to the combined damping of the soft tissue layers and skin layers, making these sensors less sensitive to vibrations. This drawback was overcome by using the Discrete Wavelet Transform (DWT) to separate the high frequency components of the accelerometer signal. Careful examination of fig. 4 showed that, just prior to gross slippage, the first decomposition signal changed markedly. By introducing a threshold value, the states of slippage and non-slippage were determined. These two states were used to control the pinch grip force when manipulating the object (phases (iii) and (iv) of Fig. 2). If slippage was detected, the controller shifted from position control back to force control. The force was increased by 5% of its initial value and position control reinstituted. Similarly, the fingertip controller changed from position control to force control and back to position control. These changes among control algorithms were not smooth, although they were ignored in this study.

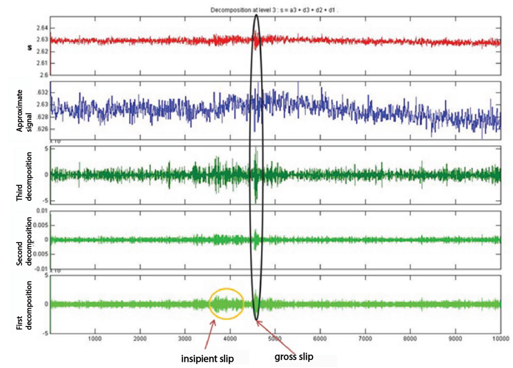


Fig. 4. DWT signal of accelerometers at incipient and gross slippage

## III. Conclusion

The fingertip system detects both low frequency signal with force sensors and high frequency signal with accelerometers, mimicking the function of humans fingertips. Experiments were conducted to detect making and breaking of contact while in manipulation, identification of object contour and surface, and detection of incipient slippage. The ATS described in this work performed sufficiently well in dexterous manipulation tasks. The control cues are understood by monitoring accelerometer and force sensor signals. The fusion of force and vibration modalities in generating control cues is an advantage compared with using either vibration or force sensor signals alone.

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