An Embedded Tactile and Force Sensor for Robotic Manipulation and Grasping

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1. INTRODUCTION

A fully embedded tactile/force sensor system is presented. The sensor has been designed to be installed on a dexterous robotic gripper (MAC-HAND). It consists of:
- A matrix of 64 electrodes for each phalange, etched on a flexible PCB covered by a conductive rubber layer;
- A three-axis force sensor, available off-the-shelf, for each phalange;
- Analog and digital electronics fully embedded with the sensor forming a self-standing module mounted on each finger phalange.

2. THE MAC-HAND ROBOT

MAC-HAND is a four-fingered anthropomorphic robot hand. Each finger has three degrees of freedom (DOFs), and is actuated by four independent tendons driven by DC motors. The four fingers are identical, and consist of two phalanges. The scheme below shows the modularity of the MAC-HAND system. Each finger is independently actuated by four motors. The control is performed by four microcontrollers, one for each finger. Finally, the coordinated control of the hand is performed by a supervision computer connected through a CAN bus link.

![Diagram of MAC-HAND robot](image)

3. FORCE/TACTILE SENSOR DESIGN

At system level the goal is to develop an integrated tactile/force sensor with embedded electronics that is placed on the phalanges of MAC-HAND. The relevant problems considered have been:
- Choice of appropriate force transducers;
- Pressure transducers for contact measurements;
- Integrated electronic design.

4. FORCE SENSOR

As a force sensor, we have used the integrated micro joystick (from CTS Corp.). This device has good linearity, Furthermore, its 5-MHz package makes its mechanical integration with other electronics very simple.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output linearity</td>
<td>1.0 %</td>
</tr>
<tr>
<td>X/Y Axis Output</td>
<td>0.85 pV/μV</td>
</tr>
<tr>
<td>Z Axis Output</td>
<td>0.123 pV/μV</td>
</tr>
<tr>
<td>Maximum Overload Force</td>
<td>40 N</td>
</tr>
<tr>
<td>Dimensions</td>
<td>10 x 7.5 x 5.5 mm</td>
</tr>
</tbody>
</table>

The device consists of a strain-sensitive thick-film resistors. A force applied to the interface stick produces a change of resistance. Proper arrangement of the resistors in three Wheatstone bridges, and a simple decoupling amplifier, allow to obtain three voltages proportional to the applied force components.

5. TACTILE SENSOR

The tactile transducer is a matrix of 64 electrodes covered by a pressure sensitive conductive rubber (PCR Co. Ltd.). The electrodes are etched on a flexible PCB substrate, in order to conform to a cylindrical surface.

A thin elastic sheet covers the whole sensor and provides a mild preload useful to reduce noise.

All the components needed for the signal conditioning have been placed on the flexible PCB, in order to limit cabling. A miniature connector interfaces the transducer with a local microcontroller (MCU).

6. INTEGRATION

In order to simplify the design, the same mechanical structure for all the sensors (i.e., for the first and the second phalange of each finger), has been used. Each sensor is composed by three modules:

- Microcontroller Module;
- Force Sensor Module;
- Tactile Sensor Module

6.1. MICROCONTROLLER MODULE

This module contains:
- a microcontroller (PIC18F4525 operating at 40 MHz);
- 3 digital potentiometers (needed for force sensor calibration);
- a CAN Transceiver for the communication with a supervisor computer.

The figure below shows the entire phalange assembly procedure. It is important to note that the force sensor supports the finger cover where is placed the tactile matrix. In this way, force measurements can be obtained for contacts arising around the whole phalange, while tactile information is restricted to the lower part of the cover.

![Assembly procedure](image)

6.2. FORCE SENSOR MODULE

The module contains:
- a three-axis force sensor;
- three instrumentation amplifiers;
- a decoupling low noise amplifier

A technique to compute the contact centroid and a quadratic approximation of the pressure distribution during contact has been implemented. This technique allows to reduce the transmission overhead due to the limited bandwidth of the CAN bus data link implemented.

C is the computed contact centroid, $x_i$ is the coordinate of the i-th sensor, and $P_{ij}$ its sensed pressure, and E is a symmetric matrix associated with the ellipsoid.

![Diagram of force sensor module](image)

7. CONCLUSIONS

The proposed sensor consists of three components commercial force sensor and of a custom matrix tactile sensor based pressure sensitive conductive rubber. The sensor is modular and mounted in eight identical replicates on the phalanges of the anthropomorphic MAC-HAND.

The joint use of both tactile and force information allows the direct solution of the point contact problems.

The tactile-force sensor system has been so far integrated and functional tests have been performed on the various modules separately. Ongoing work is focusing on detailed aspects of calibration and detailed performance analysis.

Future work will involve the redesign of the palm of the MAC-HAND to host a tactile sensor based on the same principle of the sensor described here.

![Diagram of tactile-force sensor system](image)