Embedded Distributed Capacitive Tactile Sensor

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ABSTRACT

A novel embedded distributed capacitive tactile sensor system designed to be installed on humanoid robots is presented. It provides pressure and shape information about the contacts with objects and the environment. The system is based on conformable mesh of sensors having triangular shape, interconnected in order to form a networked structure. Each triangle is a flexible substrate allowing the sensor to be conformed to smooth curved surfaces. It provides 12 capacitive measurements and it has three communications ports placed along its sides: one for the input from an adjacent triangle, and the others as outputs toward adjacent triangles. Each triangle is therefore a single sensor module implementing 12 taxels. The measurements are sent to microcontroller boards using serial bus communication links. A microcontroller board set-up and reads the data coming from a group of modules. Every microcontroller board has a CAN-bus link. The spatial resolution of the skin is one sensor every 5mm. The aim of the project is to install the artificial skin on the humanoid robot iCub, for studying control strategy using tactile feedback coming from the whole body, but it can be used for many other different mechatronic applications where distributed pressure information along a surface are required.

1. INTRODUCTION

The control of interaction between a robot and its surrounding environment (e.g. objects, humans, or other robots), appears to be highly relevant to the development of humanoids robots, as shown by the wide scientific literature published on this topic. As a matter of fact, transducers and sensors designed to provide contact measurements and appropriate feedback play a fundamental role in order to implement safe interaction control. Tactile sensing in robotics has been studied deeply, mainly for application on robotic hands [1-5]; in this field many types of transducers has been adopted [6]. Recently, with the new generations of humanoid robots, the *robotics community* started to investigate more complex task such as walking, interaction with humans, body manipulation [7], which require contact of the robot with the environment, not only with the hand, but using the whole body. Furthermore, for the safety of people around the robot and the robot itself, it is needed to have touch information from the whole humanoid body, in order to implement control strategy, for reacting to external stimuli (contact whit object or with the environment). The design requirements for such a tactile sensor system are: conformability, power consumption, installation space, toughness and manufacturability

Shinoda, made study on the possibility of the realization of small sensors, with wireless connection and power supply, to be embedded in a silicone rubber cured around the limb [8], in order to spread sensors randomically in the arm of a robot. This idea is very difficult to be make, due to the high noise level in the environment (motors, electronic boards, etc.), and due to the limitation of the bandwidth of a radio communication.

In the 2006 Ohmura and Kuniyoshi [9] designed a sensor suitable for covering a robot, based on optical sensor. However the spatial resolution of the system is very low: 0.14 sensors every centimetre square. Furthermore the power consumption is high, due to fact that every sensor has a led. They try to limit the power required switching on only few lads per time, but it reduce the frame rate of the sensor.

Ishiguro, [10] presented an artificial skin for a robot based on PVDF. The skin has low spatial resolution as the previous, and it has the possibility of measuring stimuli with frequency higher then 5-10Hz (no constant load detection), due to the characteristic of the transducer.

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In this project it has been designed and realized a novel artificial skin for covering the whole body of a humanoid robot (except for the fingers). It provides pressure and shape information about the surface of the robot in contact with object or the environment. It is made in such a way it is conformable and can cover complex surfaces. It has low power consumption, it has been calculated that for 2 square meter of the skin (human-size) the power required is about 10 watts. All the electronic is embedded, the transducer and the signal conditioning part is on the cover of the robot, while only the microcontroller board are installed inside the cover, for having a skin as less *invasive* as possible. The toughness is guaranteed by a thick layer of silicone foam (3-5mm) wrapping the entire skin, used as part of the transducer but also good for protecting the robot. The skin is based on a capacitive sensor technology, and it has a resolution of 2.6 sensors every square centimetre. Furthermore the spatial resolution can be reduced on the fly; increasing the temporal resolution (the system can provide an average of many measurement points very fast, instead of reading each point separately). This feature is very useful for detecting the *first contact* rapidly reducing the spatial resolution and when the point is detected it is possible to increase the spatial resolution in the area around the *first contact* in order to reconstruct contact surface shape which more accuracy, (the drawback in this procedure is the slowing down of the temporal resolution).

Capacitive sensor technology it has been used, thanks to the commercial available capacitance to digital converter integrated circuits (CDC), used in the last generation of cell phones. These sensors detects variation of the capacitance due to the presence of a human finger over a copper plate, the closer the finger, the higher the variation. In this project the structure of the *capacitor* has been modified in order to be able to recognize not only human touch but also objects, by using a deformable substrate (a thick layer of silicone rubber foam, 3-5 mm) covered by a thin layer of conductive silicone rubber connect to ground. In this way, when any object is pressing the silicone rubber, in fact, the ground plane become closer to the copper plate, changing the capacitance value read from the sensor. The ground plane forming the outer layer of the sensor has also the benefit of reducing noise coming from the environment.

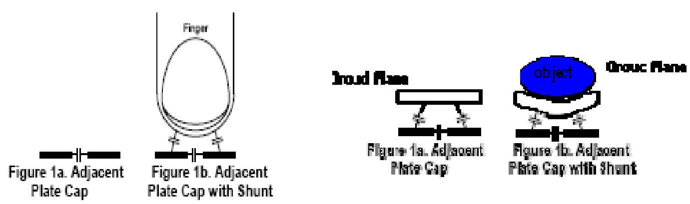


Figure 1: Sketch describing the structure of the sensor

The system described is thought to be installed on a humanoid robot, but it can be used in many other mechatronic application, where there are needed distribute pressure measurements.

In Section 2 will be described the artificial skin system. In Section 3 will be presented the first prototype. Conclusions in Section 4

2. Artificial Skin System

The system is based on conformable mesh of sensors having triangular shape and interconnected in order to form a networked structure. Each triangle is a flexible substrate allowing the sensor to conform to smooth curved surfaces, and it provides 12 capacitive measurements and three communications ports placed along its sides: one for the input from an adjacent triangle, and the others as outputs toward adjacent triangles. Each triangle is therefore a single sensor module implementing 12 taxels. The measurements are sent to a microcontroller using serial bus communication links. A microcontroller board is required to set-up and read the data coming from a group of modules (16 triangles are attached to a microcontroller). Furthermore, every microcontroller board has a CAN-bus link, so that the boards can communicate between them and/or the PC.

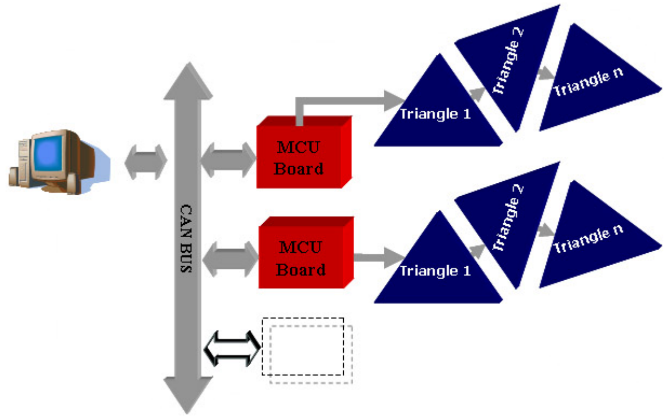
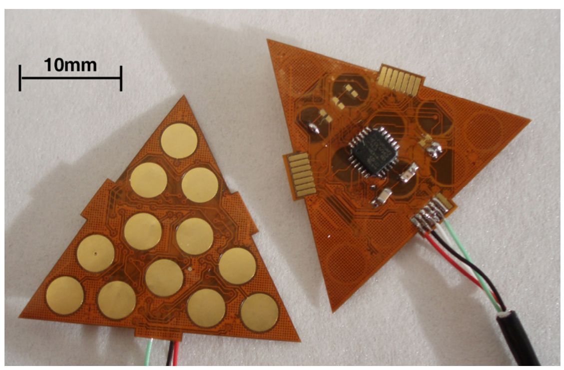


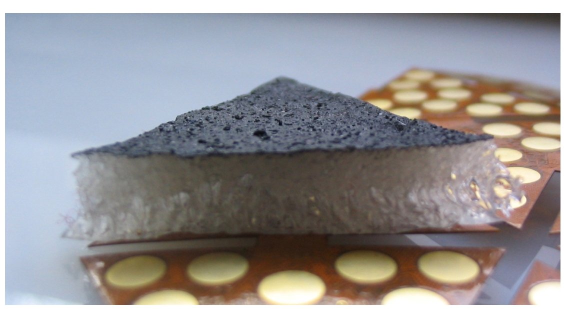
Figure 2: System Architecture

2.1. TRIANGLE MODULE

The idea of using a mesh of triangles for covering three-dimensional surface is inspired by the triangulation technique, widely used in computer graphics. Using triangles in fact, it is possible to approximate complex surfaces such as the ones presented on a humanoid robot, for example, in the arms, legs and thorax. The triangle is the base unit of the tactile sensor. It consists of an off-the-shelf *capacitive to digital converter* (CDC - AD7147 from Analog Device) that provides twelve 16bits measurements of capacitance and three communications ports placed along its sides: one for the input from an adjacent triangle, and the others as outputs toward adjacent triangles. It is etched on a flexible printed circuit, with in one side 12 circular pads (taxels), having the function of a plate of the capacitor, covered by a thick layer of silicone rubber foam, sprayed on the top with a thin layer of conductive silicone rubber. In the other side is mounted the CDC chip and are etched the three port, as shown in figure 1.



a)



b)

Figure 3: The triangle module, both sides (a), and the thick layer of silicone rubber foam sprayed on the top with conductive silicone rubber (b).

2.1. MICROCONTROLLER MODULE

The microcontroller board is based on a dsPic30F4011 microcontroller from Microchip, and two connectors, one for the CAN bus and the power supply and the other for the four I2C busses connected to the triangular mesh. The microcontroller unit is used for programming the CDC chips of the triangles and for reading the measurements coming from them. The microcontroller can also be used to switch to different behaviour of the triangle modules, as mentioned in Section 1. In fact, it can program the CDC in order to get one average measurements of the 12 taxels with a high frequency (about 500 Hz), or reading the 12 measurements reducing the frequency up to 50 Hz. Furthermore *data compression* techniques can be implemented on the microcontroller.

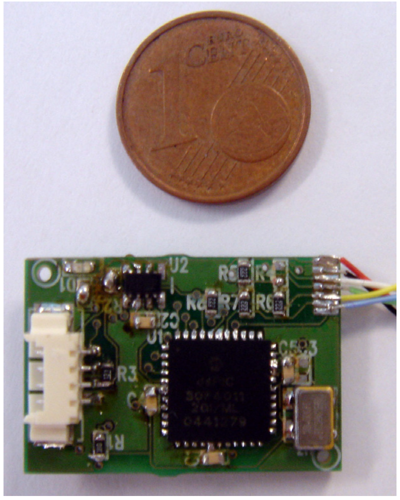


Figure 4: The microcontroller board. It is small in order to be installed inside of the robot.

3. THE HEXAGONE PROTOTYPE

For testing the entire system it has been realized a sheet with 6 modules connected to form a hexagon. Have been made qualitative tests and the entire system works, mechanically, the hexagon can be conformed to curved surface, and electrically, the modules response to a single point or multipoint of contact.

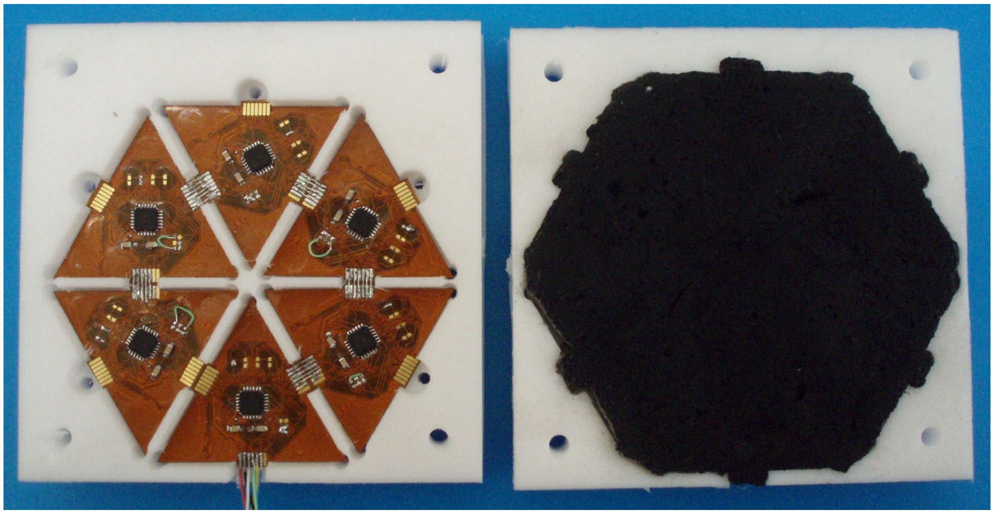


Figure 5: The hexagon inside the mold used to shape the silicone rubber substrate.

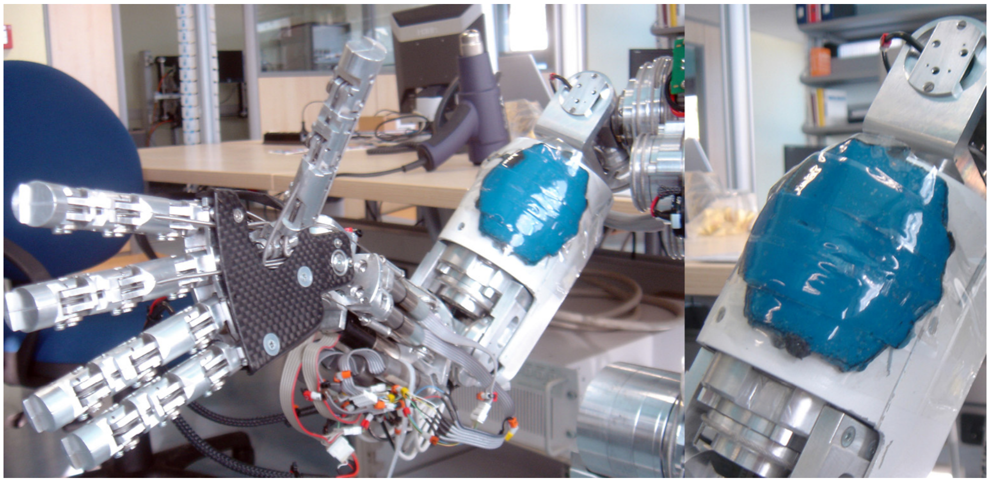


Figure 6: A very preliminar test for covering the upper arm of the humanoid robot iCub [11].

6. CONCLUSION

This document provides the description of an embedded and distributed tactile sensor system for a humanoid robot. The system is based on mesh of triangle modules covering the robot body. Capacitive sensor technology is adopted for measuring the external forces applied to the robot. The sensor network is designed to acquire the tactile image of the whole body, giving shape and pressure information. A first prototype with six triangle modules has been realized and quantitative experiments are ongoing. Next step will be the integration of the skin on iCub, a humanoid robot which size of a 3 years old child [11].Future work, regarding the study of control strategy using tactile feedback coming from the whole body, for crawling and to interact with humans. Furthermore the system described can be used in many other different fields because it is self standing and it is modular, and then easily adaptable to other applications.

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