Improvement of tactile capacitive sensors of the humanoid robot iCub's fingertips

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***Abstract*—Humanoid robots use tactile fingertips to perform object manipulation. In this paper, an improved prototype of a tactile capacitive fingertip for the hands of the humanoid robot iCub is presented. In particular, a conductive silicone based material has been used to improve the characteristics of the capacitive sensor and an additional silicone foam layer has been also introduced in the sensor architecture to prevent behavior variation due to fingertip deterioration (e.g., caused by object manipulation). A characterization of the fingertip sensing behavior is presented. This work is funded by the European Commission as part of the project ICT-FP7-231500 RoboSKIN.**

I. Introduction *(Heading 1)*

Tactile and kinesthetic systems provide important information to humans about their interaction with the world [1]. Shape, roughness, first impact contact and position are some examples of physical parameters. For the same reasons, the development of reliable and stable tactile sensors endows humanoid robots with the ability of interacting with the external world. The use of sensors placed on robotic systems capable of measuring variable contact forces and pressures therefore becomes important both in research and real world applications. Active object exploration by humanoid robots leads to the development of tactile sensors which gives the opportunity for object grasping and manipulation by the use of robotic hand

In literature are already presents survey on the state of the art of tactile systems [2] and current technologies available for humanoid robot [3]. Therefore, example of robotic system oriented to object grasping and manipulation are present in [4 - 15].

As respect to the previous realization [16], in this work the main optimization is the use of a different conductive silicone and the introduction of one protection layer useful to increase the lifetime of the sensor. In this paper architecture of the sensor within performances characterization along a straight line will be presented.

II. Fingertip Sensor Architecture

The fingertip sensor consists of a PCB (with twelve flat single electrode capacitance) wrapped around a plastic support. The PCB includes twelve flat capacitance connected to a programmable capacitance to digital converter (CDC AD7147 from Analog Device [17]) also placed on the PCB. The CDC measures and digitizes the values relative to the variation of capacitors and then it sends them via I^2C interface to a microcontroller housed on the hand of the robot, this way it is possible to reduce the number of wires used to connect the sensor to the rest of the robot (two for the communication and two for the power supply). In order to develop the tactile sensor, the PCB is covered with three different layers (see Figure 1):

- The first layer is made with a soft dielectric material (Soma Foama 15 from Smooth-On). Mechanical deformation of the soft dielectric material leads to capacitance variations; therefore it is possible to detect pressures applied on the fingertip.
- The second layer is made with a flexible electrically conductive RTV silicone (SR8850-1 from AI Technology INC). This allows the development of a single ground plane above all electrodes placed on the PCB thus enabling the detection of each type of object (conductive and non conductive). This layer is connected to the digital ground of the CDC by one flat pad on the PCB.
- The third layer is made with a soft dielectric material (Soma Foama 15 from Smooth-On); used such as such as a protection thus intrinsically increases the lifetime of the fingertip sensor.

Figure 1. Schematic section of the new architecture proposed for the development of the fingertip of iCub humanoid.

Figure 2 show photos of the fingertip during its production steps. In order to strengthen the adhesion between the conductive layer and the PCB pad, after the development of the first dielectric layer a gasket wire is soldered on the pad and then glued on the dielectric (see Figure 2.A). Therefore, a small conductive silicone is vulcanized at room temperature (see Figure 2.B) for 24 hours and then the last layer is developed (see Figure 2.C).

SMD parts included on the PCB of the fingertip sensor are subsequently covered by a fingernail [REF] when placed on the iCub Robot, whereas for static characterization on the test setup a dedicated support is used (see Figure 3).

III. Fingertip Sensor Characterization

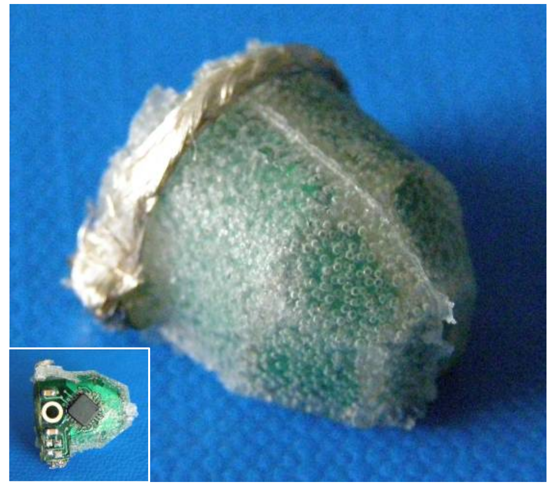
A. *The characterization setup*

The characterization setup consists of a cartesian robot (TT-C3-2020 from IAI) which moves one non-conductive probe against the fingertip. The non-conductive probe is fixed at the top of an off-center load cell (AS1 form Laumas) which measures independently the force applied to the fingertip by the probe during the test. A microcontroller records the CDC output and the load cell circuit output. Therefore the Data are stored in a computer by a dedicated graphic user interface made in Matlab®.

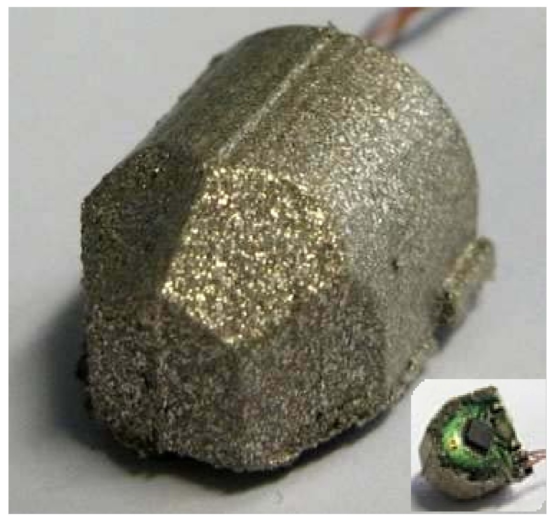
In this paper we present the sensor characteristics when it is excited along a straight line by different pressures.

B. *Characterization protocol*

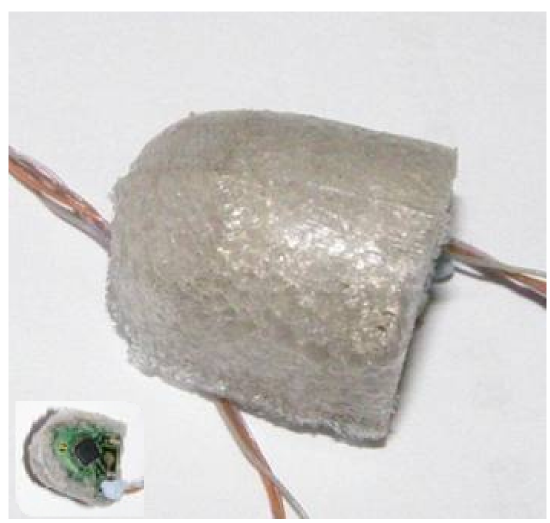
- One non-conductive probe of 4 mm diameter has been used. By the use of the Cartesian robot the non conductive probe applied different pressures to 13 positions on the fingertip separated by 0.5 mm and along a 6 mm long straight line (see Figure 3).
- In each position 16 different pressures have been applied to the fingertip by vertical displacement of the non –conductive probe.
- Each pressure has been applied for 2 seconds, with intervals of 10 seconds.
- In order to investigate sensor repeatability, the whole sequence has been repeated five times. It must be observed that, along the straight line the probe is perpendicular to the fingertip.



A

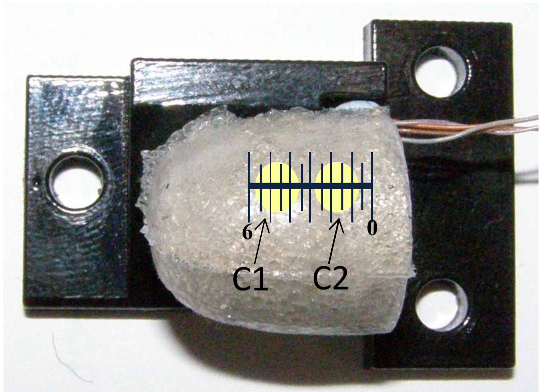


B



C

Figure 2. Photos of the fingertip during the production process; A) after the development of the first layer. B) after the development of the second layer. C) After the development of the protection layer.



C

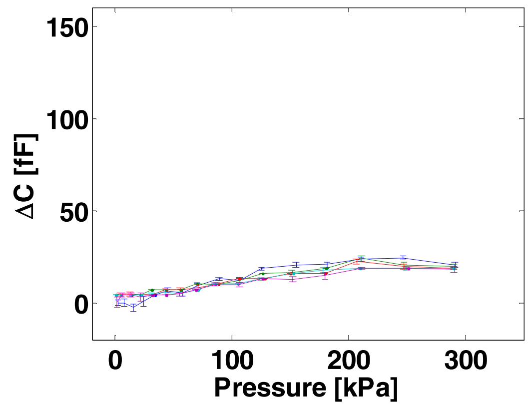
Figure 3. Fingertip sensor placed on the support used for measurements toghether with a pictorial representation of the straight line where measurements have been taken.

C. *Data elaboration*

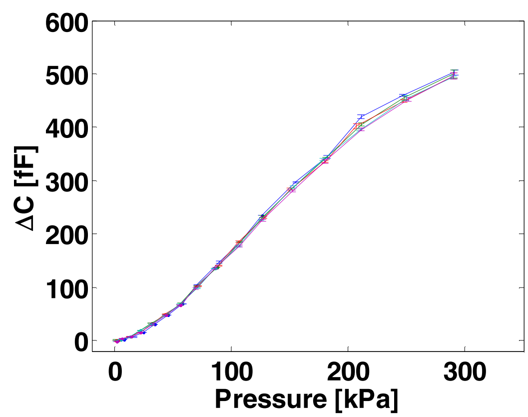
Only the steady-state responses at external pressures of the sensor have been taking into account during post elaboration. Data elaboration have shown that the movement of the probe along that straight line stimulates only two capacitors of the fingertip, indicated with C1 and C2 (see Figure 3); therefore the post processing is related only to them.

Figure 4 shows the steady-state response of C1 and C2 at 1 mm position. It is possible to observe a non linear trend of the capacitor variation as a function of the applied pressure. Therefore, the least squares method has been used to fit a polynomial model on each steady state response (norm of residual indicates 4th polynomial model order) at each position. Polynomial functions thus obtained were used to calculate the variation of capacitors C1 and C2 due to a fixed pressure as a function of position along the measurement line.

Results are presented in Figure 5 and Figure 6 report the variation of capacitors as a function of the probe position for two different pressure values of *50kPa and 100kPa*.



A



B

Figure 4. C1 and C2 steady-state response at 1 mm position point of the straight line of measurement.

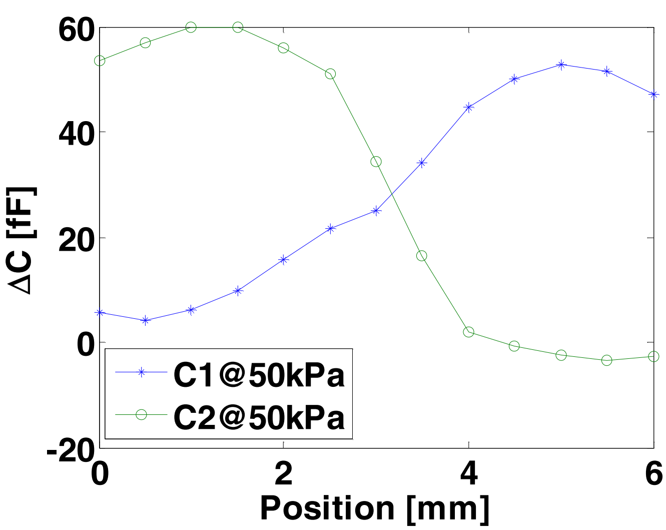


Figure 5. C1 and C2 variation as a function of different position of probe. The pressure applied by the probe is 50kPa.

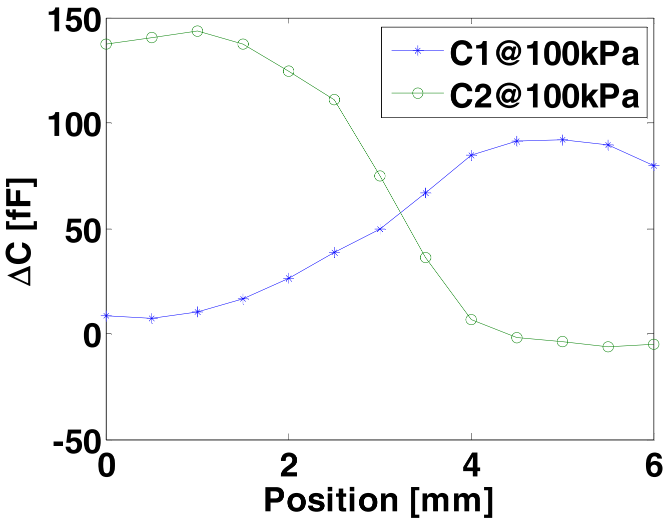


Figure 6. C1 and C2 variation as a function of different position of probe. The pressure applied by the probe is 100kPa.

REFERENCES

[1] H. Nicholls and M. Lee, "Tactile sensing for mechatronics - a state of the art survey," Mechatronics, vol. 9, 1999

[2] H. Nicholls and M.Lee, "Tactile sensing for mechatronics – a state of the art survey, Mechatronics, vol.9, 1999.

[3] R.S. Dahiya, G. metta, M Valle and G. Sandini, "Tactile sensimng: from humans to humanoids", IEEE Transaction on Robotics, vol.26, no.1, 2010.

[4] H. Liu, P. Meusel, N. Seitz, B. Willberg, G. Hirzinger, M. H. Jin, Y. W.Liu, R. Wei and Z. W. Xie, "The modular multisensory DLR-HITHand," Mechanism and Machine Theory, vol. 42, no. 5, pp 612-625, 2007.

[5] T. Mouri, H. Kawasaki, K. Yoshikawa, J. Takai and S. Ito, "Anthropomorphic Robot Hand: Gifu Hand III," in Proc. Int. Conf. ICCAS, pp 1288-1293, 2002

[6] P. Dario, C. Laschi, A. Menciassi, E. Guglielmelli, M. C. Carrozza, M. Zecca, L. Zollo, G. Teti, L. Beccai, F. Vecchi, S. Roccella "A Human-like Robotic Manipulation System Implementing Human Models of Sensory-Motor Coordination," in Proc. 3rd IEEE-RAS Int. Conf. on Humanoid Robots, 2003

[7] L. Natale and E. Torres-Jara, "A sensitive approach to grasping," in Proc. 6th Int. Conf. on Epigenetic Robotics, 2006

[8] Shadow Hand Company, Shadow dexterous hand (2008) [Online]. Available: http://www.shadowrobot.com/hand/

[9] S. Miyazaki and A. Ishida, "Capacitive transducer for continuous measurement of vertical foot force," Med. Biol. Eng. Comput., vol.22, pp. 309316, 1984

[10] Z. Chu, P. M. Sarro, and S. Middelhoek, "Silicon three-axial tactile sensor," Sens. Actuators A, vol. 54, pp. 505-510, 1996

[11] B. L. Gray, and R. S. Fearing, "A surface micromachined microtactile sensor array," in Proc. Int. Conf. on Robotic Automation, 1996

[12] R. J. D. Souza and K. D. Wise, "A very high density bulkmicromachined capacitive tactile imager," in Proc. Int. Conf. Solid-State Sens. Actuators, Transducers, pp. 1473-1476, 1997

[13] P. A. Schmidt, E. Mael, and R. P. Wurtz, "A sensor for dynamic tactile information with applications in human-robot interaction & object exploration," Robot. Autonomous Syst., vol. 54, pp. 1005-1014, 2006.

[14] M. Maggiali, G. Cannata, P. Maiolino, G. Metta, M. Randazzo, and G. Sandini, "Embedded tactile sensor modules," presented at the 11th Mechatron. Forum Biennial Int. Conf., 2008

[15] G. Cannata, R. S. Dahiya, M. Maggiali, F. Mastrogiovanni, G. Metta and M. Valle, "Modular Skin for Humanoid Robot Systems," in 4th Int. Conf. on Cognitive Systems, 2010

[16] A. Schmitz, M. Maggiali, L. Natale, B. Bonino and G. Metta "A tactile sensor for the fingertip of the humanoid robot iCub", Intelligent Robots and Systems (IROS), 2010 IEEE/RSJ International Conference on, pp.2212-2217, 18-22 Oct. 2010, doi: 10.1109/IROS.2010.5648838

[17] Analog Devices Inc., CapTouch Programmable Controller for Single-Electrode Capacitance Sensors - AD7147 (2007). [Online]. Available: http://www.analog.com/