Mechanical Testing and Diagnosis
ISSN 2247 – 9635, 2012 (II), Volume 3, 18-27

FORCE SENSITIVE RESISTORS CALIBRATION FOR USE IN GRIPPING DEVICES

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ABSTRACT

This paper aims to present the calibration of a piezoresistive force sensitive sensor for the use in the gripping devices. A short review on existent sensors is presented, with information concerning the piezoresistive sensor functionality. The used calibration technique is presented in parallel to the hardware and software elements. Several test cases were developed in order to obtain the forces and the contact areas similar with the ones between the human fingers and different gripped objects. The differences between several sensors response and the accuracy on the forces applied in the range of 0.1 mN to 1 N were observed, allowing to obtain a whole surface mapping of the sensor response to the applied force, in a matrix touch pattern.

Keywords: Piezoresistive, gripping devices, whole surface mapping, Force Sensing Resistors (FSR)

1. INTRODUCTION

1.1. Short Introduction Regarding the Gripping Devices

In the robotic field, for a robot to be able to meet all the request tasks or to understand the variations of the surrounding environment, specific sensors, actuators and algorithms are required. More than 75% of the actual robots have manipulator elements, with different types of the end effectors. Some of the end effectors are anthropomorphic or non-anthropomorphic grippers, used in the object relocation from an initial point $A(x_0, y_0, z_0)$ to a final destination $B(x_n, y_n, z_n)$ and also to substitute the human movements or operations.

From a mechanical point of view, the gripping systems require at least two contact points between the gripper and the object. Latest researches are considering the development and the control of the grip forces by monitoring various tactile sensing information, similar to those of a human hand, for the use in areas such as industry, research, military operations and prosthetics.

The tactile sensing is strategic for implementing a safe control of the robots interacting

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with humans, objects and, possibly, in unstructured environments. In the classical robot interaction tasks (e.g., peg-in-hole problem), where the usual interaction is expected or planned at a specific robot location (typically at the end-effector tip), the force/torque sensors have been widely and successfully adopted. On the other hand, for the advanced robotic systems, e.g. the humanoid robots, a better capability of controlling more and more complex forms of interaction is required (e.g. whole hand or whole arm grasping and manipulation, gait stability control, etc.). The better controlling capability is needed, for example, where the location and the characteristics of the contact could not be exhaustively predicted or possibly modeled a priori. The skin-like sensors and the appropriate sensing methods for processing the distributed tactile information are needed, in order to enable the implementation of the safe interaction strategies and the real-time system response.

In comparison to animals that posess thousands of mechanoreceptors per square centimeter of skin, even the most sophisticated robots have a huge drawback.

The tactile sensors provide different information through the physical interaction with the surrounding environment [14]. They must be incorporated into the skin surfaces, for locally conforming to the surfaces and with an adequate friction for securely handling the objects. The sensors and the synthetic elastomeric skin must also be robust enough to survive to the repeated impacts, controlled or uncontrolled touch forces, as well as abrasions. Siciliano B. et al. [9] presented three basic tactile sensing scenarios concerning the interaction between a robotic gripper and the surrounding environment.

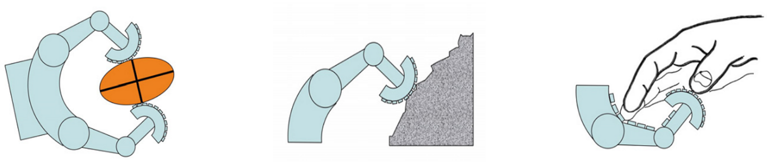
The interactions are presented as:

- manipulation (Fig. 1a), where the grasp force control, the surface contact locations, the kinematics and the stability appraisal are taken into account for a stable handling;

- exploration (Fig. 1b), with the detection and the mapping of the surface texture, the friction and the hardness, the different thermal and humidity characteristics or other different local features;

- environment response (Fig. 1c) in circumstances where the detection and the real time reaction to environmental factors is required.

The tactile sensors must be distributed over the robot gripper surface, with particularly high concentrations in the areas such as the fingertips or the palm area.



a) b) c)

Fig. 1. Basic tactile sensing examples in robotics [7]: (a) robotic manipulation; (b) robotic exploration; (c) robotic tactile response

Taking into account these problems, we reviewed the characteristics of different tactile sensors. One possible tactile sensing solution could use the force sensing resistors, based on the piezoresistive principle. The analyzed sensors are suitable for the fingertips of an anthropomorphic gripper. Before the integration of these sensors, several calibrations and laboratory analysis are required. The force sensitive resistors were calibrated using the CETR-UMT-2 micro tribometer, a commercially available electronic development board and a custom made software platform.

The experiments provided sufficient extended information regarding the functionality of the sensors, and will allow us to extend the research towards integration of these sensors on anthropomorphic grippers.

1.2. Different Type of Sensors Used in Gripping Devices

The tactile sensing on different robotic systems and applications has been studied for a long time, a very large number of tactile sensing technologies and various design solutions have been reported in the literature [1].

The sensorial system for the robotic hands [2-6], the haptic devices or the anthropomorphic prosthetics, used in gathering different parameters regarding the grasping and the manipulation of different objects, in structured or unstructured environments, gained particular interest in the last two decades.

A wide variety of technologies have been applied to solve the tactile sensing problem in robotics and medicine [7]. The transduction mechanisms, such as optics, capacitance, piezoresistance, ultrasound and conductive polymers, led to viable solutions, but only for limited environments or applications. For example, most MEMS sensors provide good resolution and sensitivity, but lack the robustness for the operation in unstructured environments. The conductive particles [8] suspended in elastomers can result in elastic materials whose resistivity changes with the deformation.

A recent enhancement of such materials called quantum tunneling composites, greatly increases the sensitivity and the dynamic range, but on the expense of the mechanical hysteresis and the simultaneous sensitivity to the temperature and the absorption of gases [8].

A robotic gripper ability to create stable, nondestructive and secure grasps, with different finger configuration is greatly increased using different type of sensors, various soft fingertips or sensors included in the elastomeric soft fingertip [9].

2. FORCE SENSITIVE RESISTORS AND CALIBRATION METHODOLOGY

A very important purpose, which is not well served by the wide range commercially available sensors, is to detect the contact in early stages, with as little force as possible, in order to minimize the probability of damaging both the robot and the manipulated objects or the environment.

To consider the development and the control of the grip forces by monitoring various tactile sensing information similar to those of a human hand, it is necessary to obtain similar sensor information as the tactile sense of the humans.

As the human tactile sense is very accurate, sensitive and repetitive, it is worthwhile to take a brief look at the biological hardware [12]. The human skin contains different types of tactile sensors, four of them being the Merkel, Ru□ni and Pacini corpuscles, plus the Meissner cells.

The first two corpuscles react to the static pressure on the skin surface, being considered as static receptors. Meissner cells roughly measure the speed of skin indentation, while the Pacini corpuscles usually react to vibrations or changes of the indentation speed. Both the dynamic and static receptors are of special importance for actively knowing the different surface properties (e.g. the roughness), the force feedback during grasping and the object slippage during manipulation [11].

Taking into account these types of receptors and the tactile sensors' attributes, we have turned our attention towards the piezoresistive force sensing sensors. In the following subchapters, the calibration methodology of the force sensitive resistors and the used equipment is presented.

2.1. Piezoresistive Force Sensing Resistors

The piezoresistive sensors change their internal electrical resistance under an applied pressure on the active surface. They are of interest because of the low weight, the flexibility, the small response time (under 3 μs as a response time) and the variable resistor functionality.

The force sensing range is between 0.1 N and 100 N, with an electrical resistance ranging from 10 MΩ without any load, down to 100 Ω at the maximum load applied on the sensitive surface.

Our tests were realized on five distinct Interlink Electronics FSR 402 series sensors, with 12.7 mm diameter circular active area, robust polymer thick film (PTFE) devices that exhibit a decrease in the resistance with the increase of the force applied to the sensor surface.

This force sensitivity is optimized for use in the human touch control of the electronic devices, such as automotive electronics, medical systems and in industrial and robotics applications.

The basic Force Sensing Resistors (FSR) consist of two membranes separated by a thin air gap. The air gap is maintained by a spacer (Fig. 2, the spacer adhesive) mounted around the edges of the membrane and by the rigidity of the two membranes.

One of the membranes has two sets of interdigital contacts (Fig. 2, the active sensing area) that are electrically distinct, with each set connecting to one trace on a tail. The other membrane is coated with FSR ink (Fig. 2, the force sensitive layer, printed with carbon based ink). When pressed or touched, the FSR ink carbon based structures act as a short between the conductive traces from the contact area, resulting in a resistance that depends on the applied force [13].

When the two substrates are pressed together, the microscopic protrusions on the FSR ink surface shorten across the interdigital fingers of the facing surface.

At low forces, only the tallest protrusions make contact, while at higher forces, there are more and more contact points between the two substrates. The result is that the resistance between the electro conductive traces is inversely proportional to the applied force.

For a complete, accurate calibration and sensor selection, with a future use on an anthropomorphic gripper in mind, a CETR-UMT-2 micro tribometer was used as an actuator, for various and precise force loads response measurement.

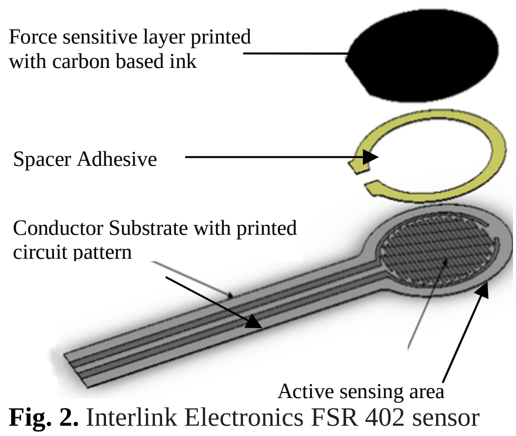


Fig. 2. Interlink Electronics FSR 402 sensor

2.2. The CETR-UMT-2 Microtribometer

For the calibration of the force sensitive resistors, we used the CETR-UMT-2 microtribometer, from the Tribology Laboratory of the Mechanical Engineering, Mechatronics and Robotics Department, Faculty of Mechanical Engineering, "Gheorghe Asachi" Technical University of Iaşi. Depending on the measurement sensors mounted on the microtribometer, the force measurements accuracy varies between 1 µN and 20 N.

The single-platform, multiple-configuration, fully-computerized unique acclaimed modular design can perform practically all common tribological tests on micro scales.

CETR-UMT-2 microtribometer was used to apply different load forces on the force sensitive resistor surface. In Fig. 3, the main configuration of the microtribometer used for the sensor calibration is presented with both front and side views. CETR-UMT-2 microtribometer is capable of precise movements, along *X*, *Y* and *Z* axis. The force sensors, suspensions and the pins are interchangeable according to the desired measurements and actions.

The FSR sensors were tested in a force range between 200 mN and 1 N, with pins having various stainless steel balls attached with diameters between 2 mm and 6.25 mm, in different touch patterns.

Having excellent accuracy on both touching forces measurement and *XYZ* axis movements, the CETR-UMT-2 micro tribometer allowed to design different tests, similar to the touch patterns between a human hand and different objects.

The touch patterns used in the calibration were the single point touch with constant and increasing force, the matrix style mapping with constant approach speed and touch force and the linear movement on both *X* and *Y* axes, with constant applied force and speed.

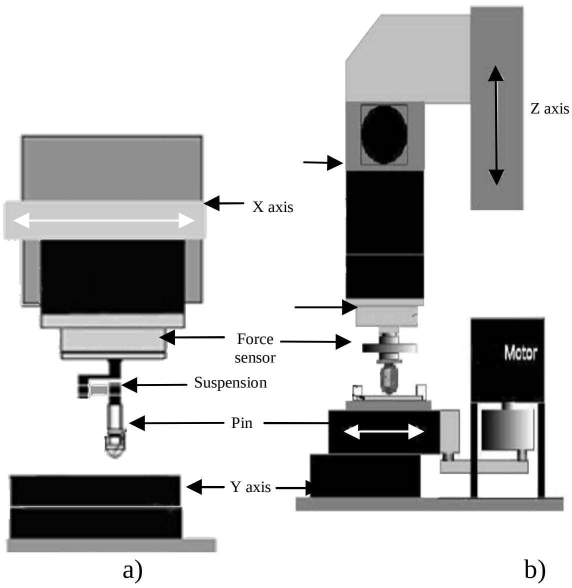


Fig. 3. CETR-UMT-2 micro tribometer: (a) front view; (b) side view

For the calibration, the sensors were mounted on a rigid surface board and attached to the *Y* axis linear movement platform of the micro tribometer (Fig. 4). The sequentially applied touch force on the five sensors is translated by the FSR into an electrical resistance variation, which influenced the voltage output (S.I. Volts) on the custom made individual voltage dividers.

The voltage output variation was gathered and stored for future work, using a microcontroller development board and a personal computer.

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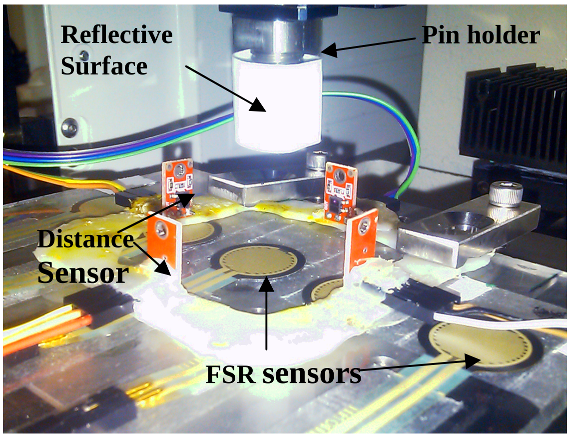

Fig. 4. FSR sensors mounted on a rigid board and attached to the *Y* axis linear movement platform of the CETR-UMT-2 microtribometer

The center point of the contact area between the pin on the microtribometer and the surface of the FSR sensor was determined using the displacements recorded both by the tribometer linear encoders and the four refractance distance sensors mounted on the rigid surface board, around each sensor (Fig. 4.-the distance sensors).

2.3. Data Acquisition and Visualization

The data acquisition from the FSR sensors is realized with the help of a development board, Mini Maestro 18-channel USB servo controller, created by Pololu Corporation. All the 18 channels available on the microcontroller board can be customized as analog or digital inputs/outputs.

For the analog to digital conversion (ADC) or the digital to analog conversion (DAC), the microcontroller is capable of 10 bit resolution, with a sampling rate up to 47.1 kHz. Because we need to observe the variation of the applied force on the active surface of the sensors and this variation is translated by the sensor into a variation of the electrical resistance, the use of a basic voltage divider is required (Fig. 5).

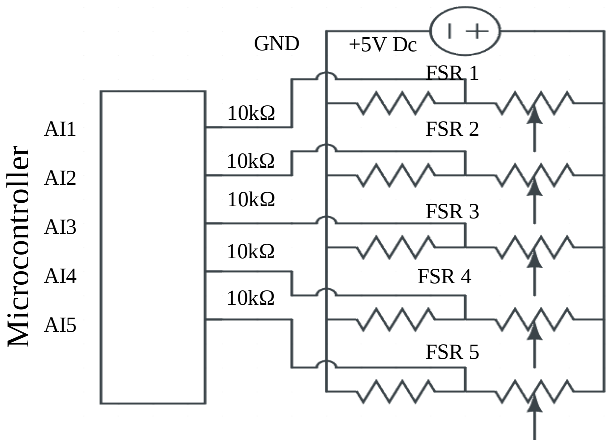

Fig. 5. Force sensitive resistors connection through a voltage divider to the analog inputs on the microcontroller

The basic voltage divider provides a 0÷+5 V Dc voltage range for each FSR, according to the applied force and the used resistor (Fig. 5, here of 10 kΩ). Each voltage divider output was directly connected into one of the microcontroller channels that was a priori set as an analog input.

For the internal data filtering and the low noise high frequency data acquisition, we decided to alternate the channels use due to the noise induced by some onboard capacitors on the channels data acquisition. The first six even channels were configured as analog outputs and to provide continuously 0 V Dc, mainly to force the internal capacitors discharge. The first five odd channels were used for the continuous data acquisition from the force sensitive resistors.

Once the microcontroller has been configured and programmed to locally acquire the analog data, several Python scripts were created to allow the data transfer to a personal computer. The information obtained almost in real time from the microcontroller, using a USB connection and a Pololu proprietary protocol, allowed us to record and to visualize the voltage variation on each sensor, according to the applied forces and to obtain valuable data towards FSR calibration.

For the real time data visualization, several Python libraries were used for the graphical user interface (GUI), combined with Mayavi2, a Scientific 2-D and 3-D data visualization software, and Signal and Image Filtering Tool v0.2.6 (Sift). A real time signal visualization interface can be seen in Fig. 6, where one of the custom made visualization interfaces displays the values recorded from one ADC channel on the microcontroller. 1,000 samples per second for each of the five FSR sensors monitored in parallel and up to 8,600 samples per second for only one FSR sensor were gathered, visualized and locally saved. This translates into 1 kHz data acquisition frequency for the first case, and 8.6 kHz data acquisition frequency for one FSR at a time.

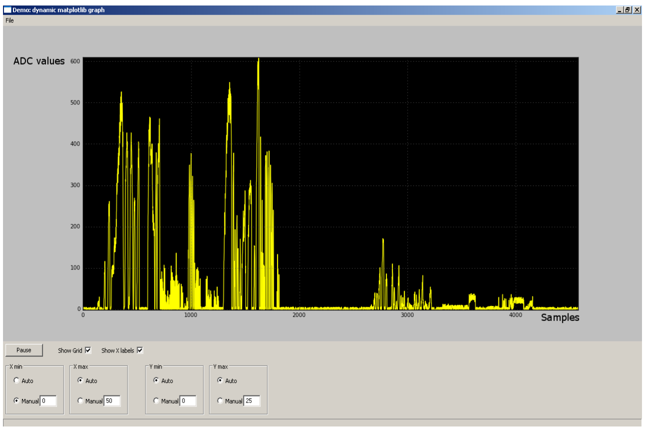

Fig. 6. Real time ADC values visualization of one FSR, with random force generated by a human finger

3. EXPERIMENTAL RESULTS

For the force sensitive resistors calibration, three key elements were used: the FSR with the voltage divider, the microtribometer connected to a computer with National Instruments DAQ boards and the microcontroller development board connected via USB serial connection to a laptop computer.

As mentioned above, in chapter 2.3, the experimental results were obtained using different touch patterns, with the same microtribometer pin, with a diameter of 6.25 mm. The obtained FSR calibration is valid in the 200 mN÷1000 mN range.

The first method, using a single touch area in the center of the FSR, consists on multiple actuations realized by the microtribometer, at increasing forces value, between 200 mN and 1000 mN, with the step of 100 mN. Several tests were done using this method and applied on five different FSR. Between each actuation, the microtribometer pin was retracted from the touch surface (on the Z axis movement), and the desired force was increased by 100 mN, for the next actuation.

Using this method, a voltage variation graphic was obtained (Fig. 6), as a comparison between four FSR voltage response to the applied forces between 200 mN and 1,000 mN.

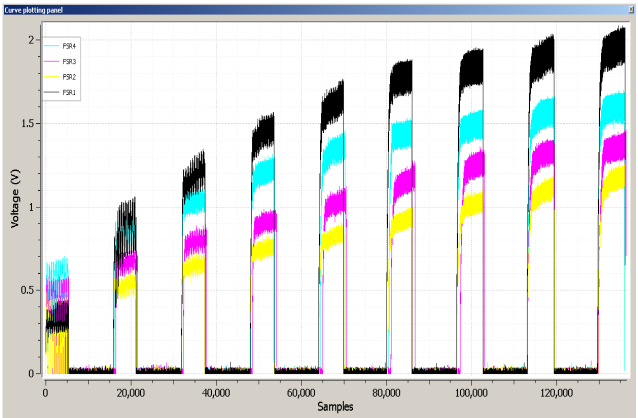

Fig. 6. FSR response to applied forces between 200 mN and 1000 mN. Four different FSR were used

From Fig. 6, the sensibility and response variation of the different FSR are visible, using the same contact area and touch forces, ranging between 0.32÷0.62 V up to 1.18÷2.09V. For this range of forces, a quasi-linear response can be observed on 3 of the 4 sensors.

A second method was used, in order to obtain the entire sensor surface response to constant touch force. This method relies on touching almost the entire FSR surface, with a constant approach speed and a touch force and with Δ_x and Δ_y displacements between two consecutive touches center of contact ellipsoid, in the range -1 mm, 0 mm or 1 mm.

As the FSR sensitive area is circular, a rhomboidal pattern inscribed in the FSR active contour was imagined, with a total of 85 touch points. This method relies on a constant touch force of 450 mN, applied on all the 85 points, in parallel with the visualization of the obtained response, in a 3D representation (Figs 7 and 8).

Different variations regarding the sensitivity and the internal variations of the electrical resistance in the FSR surface were obtained, information that could be used in a later research on the estimation of the contact ellipsoid center local coordinates.

The third method is based on the pin linear movement on the FSR surface, movement obtained with the microtribometer displacement on both X and Y axes, with a constant applied force of 450 mN and a movement speed of 0.1 mm/s.

For each experiment realized on all the FSR sensors, the total distance traveled by the pin on the active surface was of 12 mm, equivalent to a diagonal crossing from two opposite interior tangential points of the spacer adhesive.

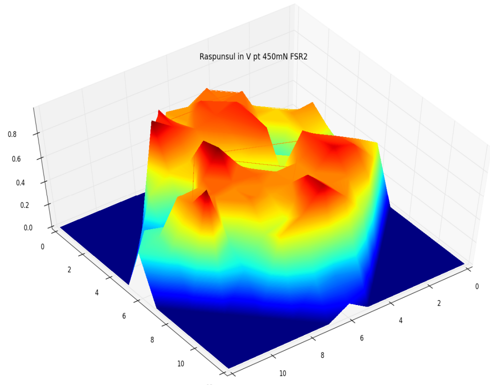

Fig. 7. FSR2- 85 points surface voltage response mapping, for a constant 450 mN touch force

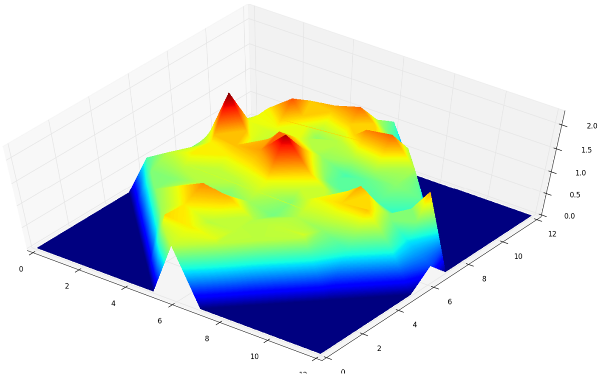

Fig. 8. FSR1- 85 points surface voltage response mapping, for a constant 450 mN touch force

Due to the internal structure of the FSR sensor active surface, more precisely, the interdigitated electrical traces and the wear that appears between these traces and the force sensitive layer printed with carbon based ink, the sensibility of each FSR sensor varies according to the previous usage and the applied load on the active surface.

The FSR5 sensor response to the linear touch movement along 12 mm on the *Y* axis, with a constant force of 450 mN, can be seen in Fig. 9.

The influence of the internal wear on the sensor response could be observed by comparing the surface voltage response mapping between two different sensors. The difference is visually observable as a difference of almost 1 Volt in the response mapping, between Fig. 7 and Fig. 8.

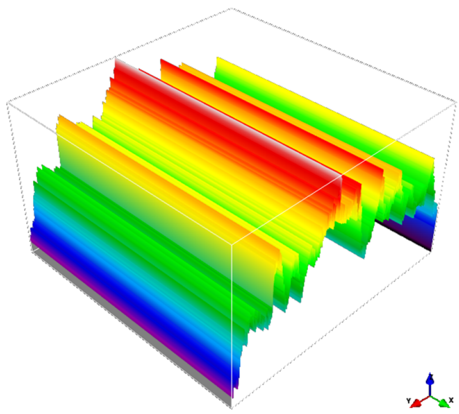

Fig. 9. FSR5-response to the linear touch movement along 12 mm on the *Y* axis, with a constant force of 450 mN

4. CONCLUSIONS

As a conclusion, all the three calibration methods used for the FSR sensors will allow future fine sensitivity tuning. Having various information concerning the surface voltage response mapping for different touch forces could allow the approximation of the contact area between each sensor mounted on a robotic gripper and an external object and also it could allow the detection of the slipping objects between two fingers of a robotic gripper.

Future studies could monitor the substructure wear of the sensors, after different and prolonged uses, allowing to estimate the applied force/ voltage/ internal electrical resistance variation in time, as a response to the permanent use of prosthetics or grippers.

ACKNOWLEDGEMENTS

This paper was realised with the support of POSDRU CUANTUMDOC "DOCTORAL STUDIES FOR EUROPEAN PERFORMANCES IN RESEARCH AND INNOVATION" ID79407 project funded by the European Social Fund and Romanian Government.

REFERENCES

1. **Lee M. H., Nicholls H. R.,** 1999, Tactile sensing for mechatronics-a state of the art survey, *Mechatronics*, Elsevier, vol. 9, pp. 1-31.
2. **Liu H., Meusel P., Hirzinger G. A.,** 1995, A Tactile sensing System for the Three-Finger Robot Hand, *International Symposium on DLR Measurement and Control in Robotics*, pp. 91-96.
3. **Kawasaki H., Komatsu T., Uchiyama K.,** 2002, Dexterous Anthropomorphic Robot Hand with Distributed Tactile Sensor: Gifu Hand II, *IEEE Transaction on Mechatronics*, vol. 7, no. 3, pp 296-303.
4. **Martin T. B., Ambrose R. O., Diftler M. A., Platt R., Butzer M. J.,** 2004, *Tactile Gloves for Autonomous Grasping with the NASA/DARPA Robonaut, Proceedings of the 2004 IEEE International Conference on Robotics & Automation*, New Orleans, LA.
5. **Carrozza M. C., Vecchi F., Roccella S., Zecca M., Sebastiani F., Dario P.,** 2003, The CyberHand: on the design of a cybernetic prosthetic hand intended to be interfaced to the peripheral nervous system, *IROS 2003*, Vol. 3, Oct. 27-31, 2003, pp. 2642-2647.
6. **Cannata G., Maggiali M.,** 2005, An Embedded Tactile and Force Sensor for Robotic Manipulation and Grasping, *IEEE-RAS International Conference on Humanoid Robots Humanoids 2005*, December 5-7.
7. **Tegin J., Wikander J.,** 2005, Tactile sensing in intelligent robotic manipulation — a review, *Ind Robot*, 32, pp. 64-70.
8. **Bloor D., Donnely K., Hands P. J., Laughlin P., Lussey D.,** 2005, A metal-polymer composite with unusual properties, *J. Phys. D Appl. Phys.*, 38, pp. 2851–2860.
9. **Siciliano B., Khatib O.,** 2008, Springer Handbook of Robotics, Springer.
10. **Wettels N., Santos V.J., Johansson R.S., Loeb G.E.,** 2008, Biomimetic Tactile Sensor Array, *Advanced Robotics*, 22, pp. 829–849.
11. **Wettels, N. Fishel J.A., Su Z. Lin C.H. Loeb G.E.,** 2009, Multi- modal Synergistic Tactile Sensing, Tactile Sensing in Humanoids – Tactile Sensors and Beyond, *Workshop 9th IEEE - RAS International Conference on Humanoid Robots*, December 7- 10.
12. **Wettels N., Parnandi A. R., Moon J. H., Loeb G. E, Sukhatme G. S.,** 2009, Grip Control Using Biomimetic Tactile Sensing Systems, *IEEE/ASME Transactions on Mechatronics: Focused Section on Anthropomorphism in Mechatronic Systems*, vol. 14, no. 6, pp. 718-723.
13. **H. Chin Ng, S. Yin Foo, S. Yan Ru Cheng, Galvin T**., Otter PrintShooter, Design Review, Spring 2012 available on-line: http://www.interlinkelectronics.com/sites/default/files/2010-10-26-DataSheet-FSR402-Layout2.pdf
14. **Platt R., Fagg A.H., Grupen R.A.,** 2010, Null-Space Grasp Control: Theory and Experiments, *Robotics, IEEE Transactions* 26.2, pp. 282-295.