Real-Time Intelligent Gripping System for Dexterous Manipulation of Industrial Robots

Abhinav V and Vivekanandan S, *Member, IAENG*

Abstract—**This paper describes a concept and presents the experimental results for robotic end-effector operation for handling product items that are flexible or variable in physical properties such as size, shape or firmness and also describes a scheme by which a manipulator can use dynamic tactile sensing to detect when it is about to lose hold of a grasped object and take preventive measures before gross sliding occurs. This paper also elaborates the mechanical, sensing and control issues of such a system and presents results on a novel modular gripping system developed for this purpose. By detecting localized slips on the gripping surface which precede gross slip, the controller can modify the grasp force to prevent the object from slipping. Accurate knowledge of slip is essential when grasping fragile objects or manipulations with sliding. A tactile sensor enables a robot, cybernetic device or other appropriate automatic mechanism to sense an object, to measure the force of contact, and to determine the force required to seize an object. The tactile sensor used in this experiment predicts the partial slip of a tactile surface by sensing micro vibrations in tangential forces which are caused by the expansion of the slip regions within the contact area. Finally a summary of contributions is listed and the advantages of using this intelligent gripping system is elaborated.**

Index Terms—**Dexterous manipulation, Intelligent gripper, Slip prediction, Tactile array sensor.**

I. Introduction

SLIP may be regarded as the relative movement of one object surface over another when in contact. Relative movement ranges from simple translational motion to a combination of any translational and rotational motions [1]. When handling an object, the reduction of slip becomes necessary so as to prevent the object from being dropped due to the application of a low grip force. In an assembly operation it is possible to test the occurrence of slip [9] to indicate some pre-determined contact forces between the object and the assembled parts. For majority of the applications slip can be detected from the qualitative information from the output of a tactile sensor [1]-[4].

Manuscript received March 23, 2009.

Abhinav V is perusing Electronics and Instrumentation Engineering at VIT University, Vellore 632014, India.
Phone: +919884155007;
e-mail: abhinavv2006@vit.ac.in

Vivekanandan S is an Assistant Professor and a PhD Scholar at VIT University, Vellore 632014, India.
e-mail: svivekanandan@vit.ac.in

Tactile sensing is the detection and measurement of spatial distribution of forces perpendicular to a pre-determined sensory area, and the subsequent interpretation of the spatial information [3]. The tactile sensor enables a robot, cybernetic device or other appropriate automatic mechanisms to sense the object, to measure the force of contact, and to determine the force necessary to seize [5] the object. The tactile data contains information about the magnitudes, distributions and locations of forces. It also provides information about the contact area and the pressure distribution over it. The principal component of a tactile sensor is the touch sensitive sights on the sensor that are capable of sensing and measuring a variety of different properties. Some properties include the ability to measure contact forces [2], which can be used to identify the state of grip (successful pick up or fail to grasp the object), texture, impact, slip and other contact conditions generate specific force and position patterns. This information can be used to identify state of manipulation [6] or in other words, the object size, shape and mass can be used to test whether the object has been rotated ninety degrees or flipped vertically. The experiments [6]-[3] that have been performed involves five phases: approach, loading, manipulation, unloading & release, together with four contact events. A change in the contact events marks the transition from one phase to another. Robotic tactile sensors detect the contact events and trigger the transitions through these phases. In addition, information concerning vibration [1] can also obtained, which is helpful for contact event identification.

II. Types of Tactile Sensors

A number of tactile sensors are known to be useful in robotic and cybernetic applications, but each of the known devices suffers from disadvantages. The commonly used sensors along with the parameters they measure and location of mounting are given in Table. I.

The sensor that has received the most attention is the tactile array. Other successful transducer technologies include capacitive sensors and optical sensors [9]. Some variants of the array sensor measure only lumped parameters at the contact, such as the location of the pressure centroid or contact area. Some sensors directly measure object shape [4] by sensing the deflection of a complaint rubber covering. Others measure pressure usually by sensing strain [1].

ISBN:978-988-18210-1-0

Table. I. Types of tactile sensors.

SENSOR	PARAMETER	LOCATION
Tactile array sensor	Pressure distribution, local shape	Outer surface of end-effector
Force-torque sensor	Contact force and torque vectors	In structure near end-effector
Joint angle sensor	Position, contact location	At joints or at motor
Actuator-effort sensor	Motor torque	At motor or joint
Dynamic tactile sensor	Vibration, stress changes, slip etc.	In outer surface

Performance considerations in tactile array designs include spatial resolution, temporal resolution, pressure or shape, range, accuracy, hysteresis, linearity, uniformity and stability. Although the design of tactile array sensors has dominated the research literature on tactile sensing [13]-[14]-[15], the relationship between sensor performance and task performance is far from clear. Considering the advantages and disadvantages of the sensors mentioned in Table. I, the sensor that has been used for experimentation is the tactile array sensor. To help understand the dynamics of the experiment, the construction and working of the tactile array sensor is given in the following section.

III. Tactile Array Sensor

The tactile array sensor relates to a contact or force sensing [10] means. It comprises of an insulating plate with inter-digital transducers of acoustic surface waves on one side and on the other it comprises of an oscillator and a diaphragm with projections. When contact with an object must be indicated, contact sensitive inter-digital transducers are disposed on the insulating plate and the diaphragm is situated above the contact-sensitive inter-digital transducers. When a force sensitive arrangement is also desired force sensitive inter-digital transducers of acoustic surface waves can be disposed on the same side of the plate as the contact sensitive transducers, or on the other side of the plate.

The input terminals of the inter-digital transducers can be connected independently or in series, and an alternating signal is received from the output terminals. Pairs of oppositely situated inter-digital transducers form a resonator which in turn is a part of the oscillator. A contact is indicated by the interruption of the acoustic surface wave propagation along the surface of the insulating plate and a zero output signal. When force sensitive transducers are used, information about the force of contact is also indicated. For acoustic wave transducers which respond to bending or distortion of the insulating plate the force is proportional to the change in frequency of the output signal.

The oscillator and compensating or calibration circuitry is placed on the insulating plate, thereby reducing the number of necessary conductors. Additional force sensors of different designs may be employed. The insulating plate provided force sensitive inter-digital acoustic wave transducers can be positioned 180 degrees with respect to the surface of the object so that the contact takes place head-on, and not from the other side of the transducers or the insulating plate. The transducers can be positioned so that contact from the side can be sensed and evaluated. When the arrangement is designed to detect and measure the contacts from the side, the diaphragm positions are smaller in width than the width of the inter-digital transducers, so that only a part of the acoustic surface wave is interrupted.

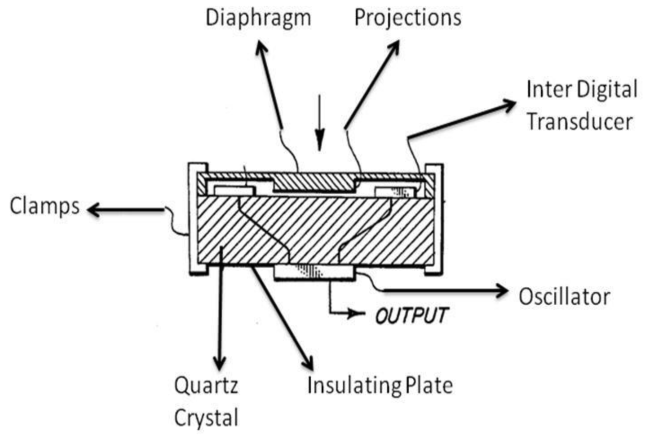

Fig. 1. Internal construction of a tactile array cell.

The tactile array cell comprises a sensing unit provided with an insulating plate, an oscillator placed on the other side of the plate. The constructional diagram of a tactile array cell is given in Fig. 1. A diaphragm provided with projections is situated above the insulating plate, on the side having inter-digital transducers and is secured in place by clamps. A gap is left between the projections of diaphragm and the surface of plate. In this contraption, the insulating plate is quartz, the oscillator is fixed to one side of the plate and operates within the range of tens of megahertz, and a pair of inter-digital transducers is affixed to the other side of the plate. The oscillator and at least one of the transducers form a resonant circuit which propagates acoustic surface waves along the surface of the plate.

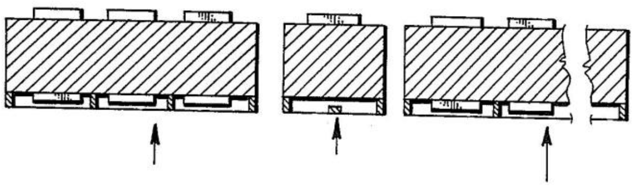

Fig. 2. Tactile array sensor (Side View).

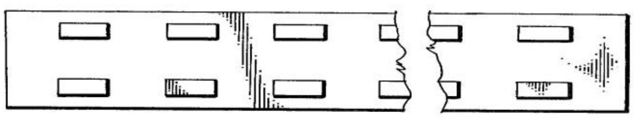

Fig. 3. Tactile array sensor (Top View).

If contact or pressure occurs within a certain region of the diaphragm with projections situated between a pair of inter-digital transducers, and if projection is at least the same width as the pair of transducers, then the projection touches the surface of insulating plate and thereby interrupts the flow of acoustic waves propagated along its surface by the resonance circuit formed by oscillator and the pair of transducers. This results in a zero signal output at oscillator and indicates contact by an object with the sensor. To determine the pressure or force of contact by an object with diaphragm whose projections are in contact with the plate, a narrower projection is used. This force sensitive contraption employs a projection that is smaller in width than that of the transducer, thereby only partially interrupting the acoustic surface waves propagated along the surface of the plate by the resonant circuit formed by oscillator and the pair of transducers. In addition, increasing pressure causes bending or deformation of the insulating plate, which prolongs the path of the acoustic surface waves and results in a change in the output frequency of the oscillator. The degree of interruption and the changes in frequency are proportional to the pressure on diaphragm, which indicates the force of contact with the sensor. The insulating plate must be adequately supported to permit bending.

Aside from its use in determining curvature, pressure distribution information is important in sliding. To prevent the occurrence of unwanted slips, estimation of the large forces and torques with which the contact friction can sustain without slipping is required. Likewise, to plan or control sliding manipulation, it is important to be able to predict the relationship between sliding motion and applied forces and torques. For pure translation the force required to cause slip is simply given by the coefficient of friction times the total normal force. Under the usual coulomb friction conditions this is independent of the details of pressure distribution. To find the torque required to make the contact start to slip in rotation requires pressure information. If the pressure concentrated in a small area, then the contact can sustain less torque before slipping than if the pressure is distributed over a wider area. If both translation and rotation are occurring, the relation between force and torque is complex, which involves measurement of the coefficient of friction, total normal force and the normal pressure distribution. Then the combinations of total sheer and torque that will cause slip can be calculated, along with the direction of the resulting motion. Alternatively if a given motion is desired, the required torque and sheer can be calculated.

The main advantage of this tactile sensor is that positive information is provided about a contact with an object by interruption of an output signal from digital acoustic transducers, which also may be used to indicate the force of the contact. The sensor is simple in design and may be miniaturized and formed onto groups and matrices so that complex sensing tasks such as prevention of slip and tactile activities can be carried out.

IV. Gripper Design

The construction of the gripping device can be explained as given below. Here the gripping device is the end-effector which is to be used with an industrial manipulator. A diagram depicting the internal construction of the gripping system is shown in Fig. 4. The gripper has two parallel fingers. The fingers are rectangular in shape and flat. The gripper is designed as a modular structure, consisting of three modules. The modules can be classified as drive system, sensor system and fingers. A base plate carries all these modules and links the gripper mechanically to the industrial manipulator. The drive system comprises of DC-servo motors with encoders for position measurement. This system drives the fingers on a ball screw, guided by a linear bearing system. The gripper fingers are specially equipped with a textured surface to secure the grasp efficiently. The faceplate is compliant to assist force distribution and reduce the pressure exerted on the object.

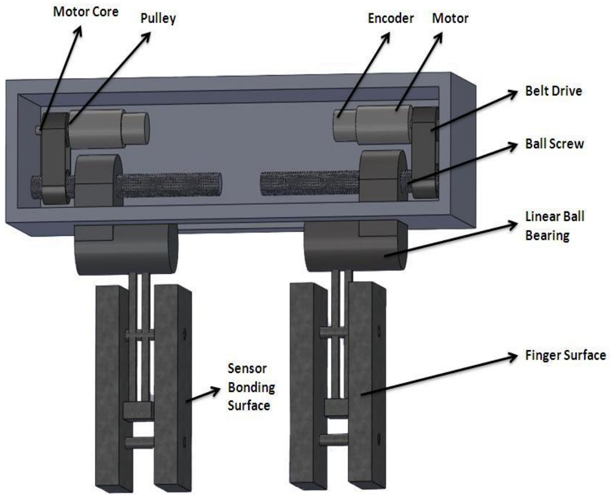

Fig. 4. Cross-sectional view of the gripping system.

V. Experimental Set Up and Inference

The tactile interaction was implemented in a real system which consists of an industrial manipulator having six degrees of freedom. The system consists of “IRB 1400” industrial manipulator and “IRC 5” controller of “ABB Ltd”. The sensor system consists of “Tact array sensor (ITS)” and “Tact array line of signal conditioning electronics”, both of “PPS Inc”.

Grasp experimentation was performed with this setup. Two experiments were conducted in which the least force required for prehension was identified. In the first experiment, a glass bottle of mass 650 gms and with dimensions 82.75 mm diameter and 204.09 mm height is retained between the gripping fingers above the surface. Grasp force is then reduced until the first occurrence of pre-slip is detected and the applied force is noted as the minimum retention force. In the second experiment, a cork ball of mass 155.9 gms and 224 mm circumference is grasped by the manipulator and is held above the surface. The minimum retention force is then determined by active force variation. A Photograph of the manipulator grasping a cork ball is shown in Fig. 5.

Both the experiments were divided into phases and in each phase the signals sensed by the tactile sensors were noted. The least force required for prehension was also reassigned a value. An accelerometer was mounted on the fingers to detect the pre-slip. If tactile sensing is to be the sole source of feedback in controlling the manipulators task, it must be possible to characterise this task in terms of variables that can be observed using tactile sensing. Furthermore, it must be possible to regulate these variables through the actions of the manipulator.

Fig. 5. Manipulator grasping a cork ball.

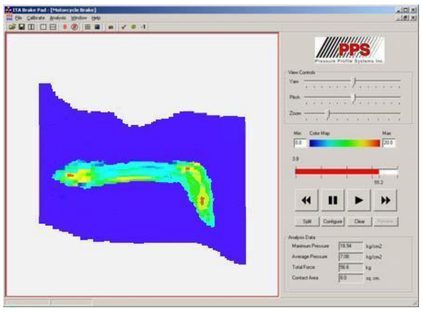

Fig. 6. Screenshot of the software displaying pressure distribution.

Several displaying techniques [10]-[12] involving the measured tactile data have been demonstrated earlier. Real-time visualization and acquisition software was used to display the pressure array data in multi-color grid formats. A screenshot of this software is shown in Fig. 6. This software displays the pressures on the actual shape to which the sensors were bonded. Therefore the exact location where the slip occurred could be seen. The output voltage of the accelerometer which was used to detect pre slip was plotted against time and is shown in the graphs in Fig. 7 and Fig. 8.

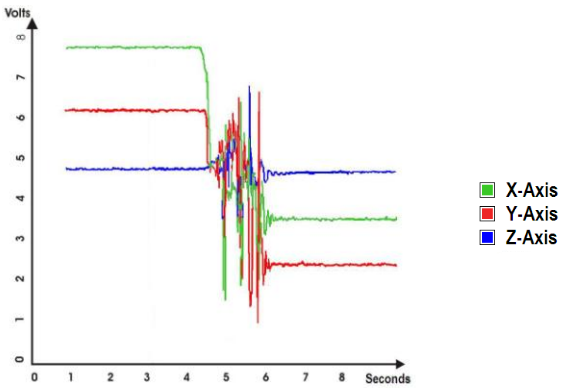

Fig. 7. Output of the Accelerometer for the glass bottle experiment.

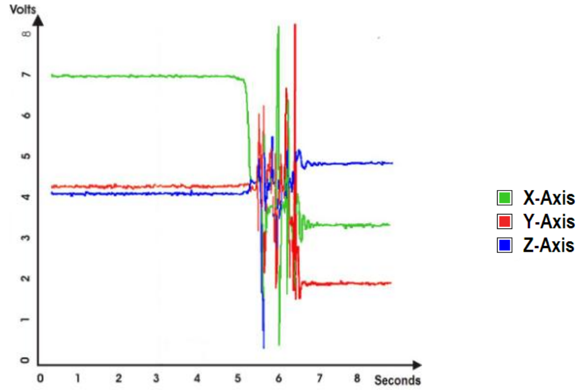

Fig. 8. Output of the Accelerometer for the cork ball experiment.

During the experiment, each time the controller detects a pre-slip signal it continues increasing the grasping force to get a proper grip (until the state before no slip is achieved). Another graph of Tactile Data vs. Time and Slip vs. Time were obtained and is shown in the graphs in Fig. 9, Fig. 10, Fig. 11 and Fig. 12.

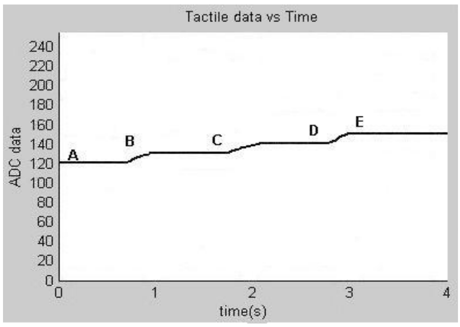

Fig. 9. Output of the tactile elements for the glass bottle experiment.

Point B in the graph in Fig. 9 is the point when the controller first senses pre-slip. Force is then increased until the tactile data reaches to point C. As the pre slip frequency is not sensed, the manipulator prolongs the degree of force while examining the response. At point D when the frequency at the tactile surface meets the pre-slip condition, the manipulator increases the force until the sensed tactile data reaches point E. The graph in Fig. 10 exhibits the resulting frequency summation sensed from all the tactile elements.

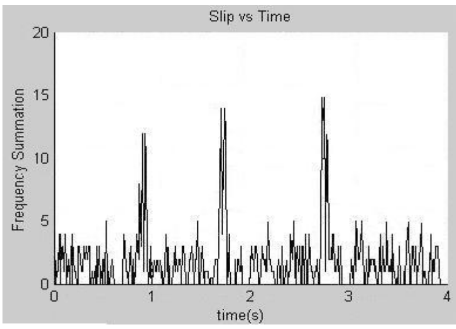

Fig. 10. Frequency summation of the tactile elements for the glass bottle experiment.

ISBN:978-988-18210-1-0

The final decision as to whether the slip has occurred or not depends on analysis of the complete data. Points B, C and D in the graph in Fig. 9 are found to have pre-slip and the least possible force shown by the tactile sensor that is needed to lift the object is 146. The output of the tactile elements obtained from the ADC are dimensionless. The occurrence of slip can also be verified by analyzing the output of the accelerometer and comparing the time of occurrence of slip with that of the tactile data. The accelerometer shows highly oscillatory behavior when slip occurs.

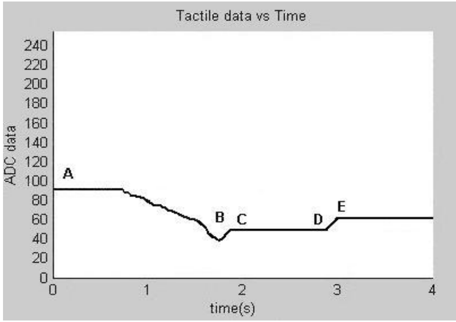

Fig. 11. Output of the tactile elements for the cork ball experiment.

The graph for the second experiment is shown in Fig. 11. At the onset, the robot will use a pre-determined force to grasp the object. When the inner surface of the gripper makes contact with the object, the robot will increase the prehension force, i.e. by incrementally decreasing the distance between the fingers. The tactile data is 92 at point A in the graph in Fig. 11. The result will gradually decrease to point B upon which the frequency response will be sensed. The graph exhibiting the resulting frequency summation sensed from all the tactile elements is shown in Fig. 12.

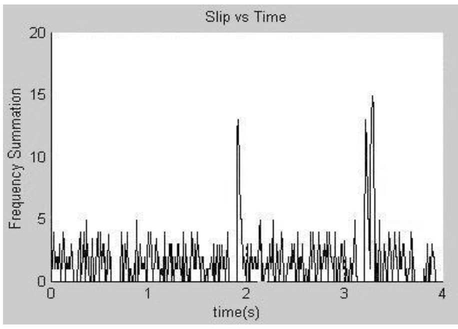

Fig. 12. Frequency summation of the tactile elements for the cork ball experiment.

To confirm the decision as to whether a pre-slip condition has been reached or not requires another account, as all the sensed signals do not result from pre-slip. For instance they may result from the nature of the material used to develop the surface of the tactile sensors, from the behavior of the localized contacts between tactile sensor and object surface. The minimum force cannot be determined by uni-directional increase or decrease in applied force. This means the same degree of force exerted at different time will result in different prehension stabilities. To exemplify at a certain point in time the force at point E lies between that and point A and C and is adequate for object prehension without pre-slip. The force required to retain the object now must be equal to or greater than that at point E. Hence the prehension force can be determined.

VI. Summary of Contributions

The major contributions of this paper are:

1. Cost Effective and Uninterrupted Process: The main advantage of tactile sensing is that a lot of cost can be curtailed by sensing slip. In many material handling industries which perform part-transfer, part-sorting and palletizing, if due to slip an object falls, the whole process is disrupted and must be stopped and restarted for proper functioning. Even after restarting there is no assurance that the object will not fall again. The held objects can be prevented from falling by pre-slip sensing thereby decreasing expenditure and increasing the overall efficiency.
2. Multifunctional End-effectors: Another benefit is that the same end-effector can be used to perform more than one task. For example an end-effector designed to pick up bottles cannot pick up boxes, because of its design limitations and its inability to determine the required force to do so. Whereas in the designed gripper, the intelligent sensor actuates this task by sensing slip and letting the controller know how much force to exert.
3. Ease of Automation: By using the specialised end-effector designed, objects in the same batch having different shapes and sizes can be handled by robots and automation of industries handling such products should be easily possible. This would increase the production in such industries by more than 60%.
4. Cheaper Cost for Automating an Industry: By incorporating the intelligent gripping system in industrial manipulators, the cost of automating an industry comes down to a great extent, as with the proposed technique the same manipulator can perform several tasks and handle objects of different dimensions.
5. A New Approach to Tactile Sensing: Tactile sensing has been scarcely explored in the field of industrial robotics. A more comprehensive approach has been shown, which widens the horizon in this field. By proper investigation, tactile sensors can be effectively used for many industrial purposes.

VII. Conclusion

Ten years ago a commonly-cited impediment to progress in developing intelligent gripping systems was the lack of suitable sensing devices and algorithms for interpreting the signals. Adequate devices and low level signal processing techniques have now been demonstrated. The next step will be the expanding use of these systems in manipulation to ascertain the information requirements.

REFERENCES

[1] C. Melchiorri, Slip detection and control using tactile and force sensors, Mechatronics, IEEE/ASME Transactions, 5, 3, 2000.
[2] R. D. Howe and M. R. Cutkosky, Dynamic Tactile Sensing: Perception of Fine Surface Features with Stress Rate Sensing, IEEE Trans on Robotics and Automation, 9, 2, 1993.
[3] A. Bicchi, J.K. Salisbury and P. Dario. "Augmentation of grasp robustness using intrinsic tactile sensing". In the Proceedings of the 1989 International Conference on Robotics and Automation, volume 1, May 14-19, 1989.
[4] J.F. Cuttino, C.O. Huey and T.D. Taylor. "Tactile sensing of incipient slip." In the Proceedings of the USA-Japan Symposium on Flexible Automation, 1988.
[5] P. Dario and D. De Rossi. "Tactile sensors and the gripping challenge". IEEE Spectrum, No 22, vol 5, August 1985.
[6] R.D. Howe, N. Popp, P. Akella, I. Kao and M.R.Cutkosky. "Grasping, manipulation and control with tactile sensing." In the Proceedings of the 1990 IEEE International Conference on Robotics and Automation, Cincinnati, Ohio, May 13-18, 1990.
[7] R.S. Johansson and G. Westling, "Influence of cutaneous sensory input on the motor coordination during precision manipulation." In Somatosensory Mechanisms, 1984.
[8] M.R. Tremblay, W.J. Packard and M.R. Cutkosky, "Utilizing sensed incipient slip signals for grasp force control." In the Proceedings of the 1992 Japan-USA Symposium on Flexible Automation, San Francisco, California, May 13-15, 1992.
[9] Dario P., Tactile Sensing: Technology and Applications. Sensors And Actuators A- Physical 26(1-3), 1991.
[10] Kammermeier, P., Buss, M., and Schmidt, G., "Dynamic Display of Distributed Tactile Shape Information by a Prototypical Actuator Array." Proceedings of the International Conference on Intelligent Robots and Systems, 2000.
[11] Rucci, M. and Dario P., "Development of Cutaneo-Motor Coordination in an Autonomous Robotic System." Autonomous Robots, vol. 1, 1994.
[12] Shimojo, M., "Tactile Sensing and Display." Transactions of the Institute of Electrical Engineers of Japan, Part E, vol. 122, 2002.
[13] Tremblay, M.R., Cutkosky, M.R. Estimating friction using incipient slip sensing during a manipulation taks. In: IEEE Int. Con5 on Robotics and Automation, Atlanta, GA, 2-6 May 1993. IEEE, Robot & Automat SOC, 1993,pp. 429-34.
[14] Holweg, E.G.M, Howev, H., Jongkind W., Marconi, L.Melchiorri, C., Bonivento, C. Slip detection by tactile sensors - algorithms and experimental results. In: IEEE Int. Con$ on Robotics and Automation, Minneapolis, MN, 22-28 April 1996; pp. 3234-9.
[15] Son, J.S., Monteverde, E.A., Howe, R.D. A tactile sensor for localizing transient events in manipulation. In: IEEE Int. Con$ On Robotics and Automation, San Diego, CA, 8-13 May. IEEE, Robot & Automat SOC, 1994; pp. 471-6.