Complementary Tactile Sensor and Human Interface for Robotic Telemanipulation

Emil M. Petriu, Pierre Payeur, Ana-Maria Cretu, and Codrin Pasca
School of Information Technology and Engineering
University of Ottawa
Ottawa, ON, Canada

***Abstract*—This paper discusses a complementary tactile sensing and human interface for the robotic telemanipulation of physical objects in interactive haptic virtual environments.**

Keywords-tactile sensor; tactile human interface; robotic telemanipulation; interactive virtual environments;

I. INTRODUCTION

Robotic telemanipulation has a large potential for a wide variety of applications such as: (i) remote robot-assisted handling of materials in hazardous environments, high risk security operations, nuclear power plants, or difficult to reach environments, such as under-water, extreme climate regions, and war zones, (ii) tele-learning in hands-on virtual laboratory environments for science and arts, (iii) telemedicine and medical training simulators for surgery, and patient examination, and (iv) e-commerce.

Robotic telemanipulation requires not only robotic arms and hands but also force, tactile, and kinesthetic robotic sensors for the precise control of the forces and motions exerted on the manipulated objects. It also requires complementary tactile human feedback interfaces placed on the operator's palm to allow the human teleoperator to virtually feel by touch the object profile measured by the tactile sensors placed in robot's hand as shown in Fig. 1.

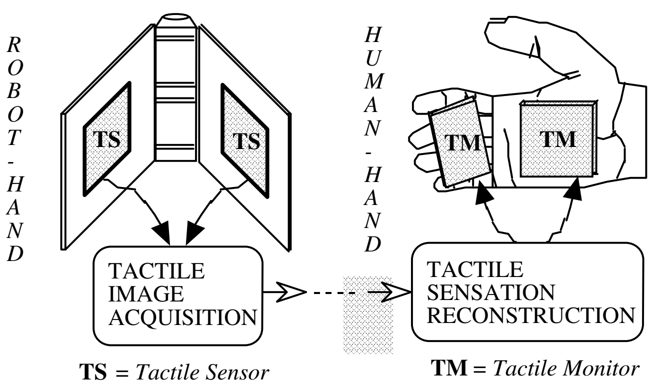


Figure 1. Complementary tactile sensor and human interface.

Human haptic perception involves two distinct sensing components: (i) *tactile,* or *cutaneous,* information from touch sensors which provide data about contact force, local geometric profile, texture, and temperature of the touched object-area, and (ii) *kinesthetic* information about the positions and velocities of the kinematic structure (bones and muscles) of the hand [1].

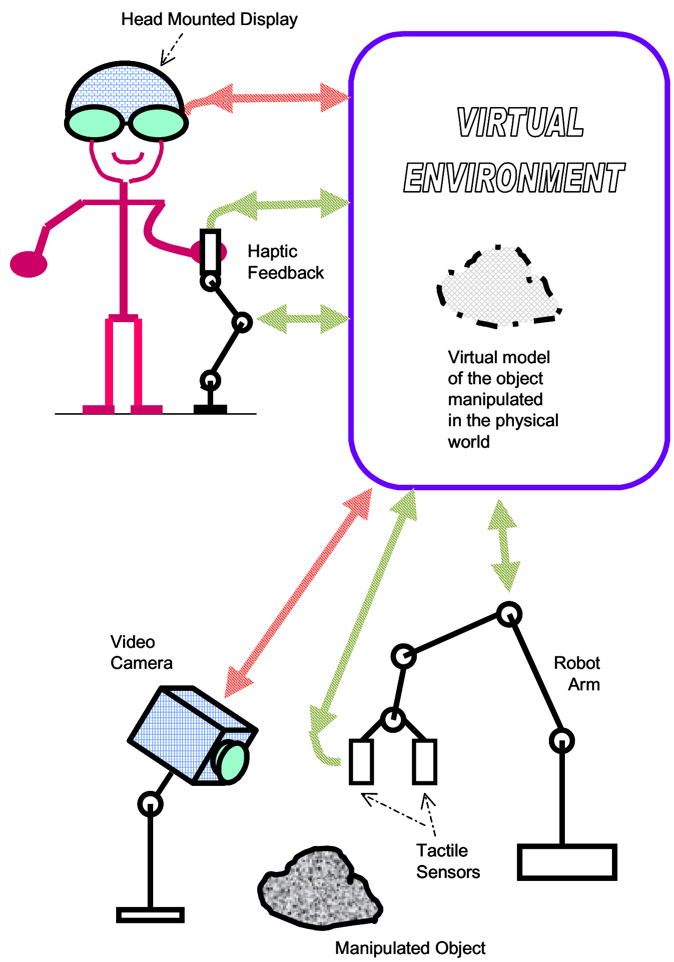


Figure 2. Interactive hapto-visual virtual environment.

As depicted in Fig. 2, haptic and visual perception modalities are well suited to complement each other. The resulting multi-sensor perception allows human operators to have a telepresence experience virtually identical with the one they would have had while manipulating real physical objects.

Lee and Nicholls [2] provide a thorough state-of-the-art review of the robotic tactile/cutaneous sensors, grippers, multi-fingered hands, and haptic sensory data processing over a 25

978-1-4244-4218-8/09/$25.00 ©2009 IEEE

year period from the 1970s to the late 1990s. Their survey has found a better recognition of the value of results from dexterous manipulation and telepresence systems. Despite of the progress made in tactile sensor technologies, Okamura *et al.* [3] note that there still is a lack of adequate tactile sensing capabilities for dexterous manipulation.

In a survey covering the period from the late 1980s to early 2000s, Benali-Khoudja *et al.* [4] provide a thorough review of the tactile human interfaces and their applications to teleoperation, telepresence, sensory substitution, 3D surface generation, Braille systems, laboratory prototypes, and games. El Saddik [5] has recently discussed the expanding potential of the haptic technologies for virtual environment applications.

The model-based approach provides a convenient representation of the dexterous manipulation mechanisms. Quoting Salisbury *et al.*'s survey of haptic rendering [6], *"improved accuracy and richness in object modeling and haptic rendering will require advances in our understanding of how to represent and render psychophysically and cognitively germane attributes of objects".*

Nevertheless there are interactive applications such as telemedicine that cannot rely on synthetic models of the manipulated objects and require instead that information is obtained from real-time measurements over real physical objects.

Extrapolating ideas published by authors over the years on particular aspects of the tactile sensing and human interfaces [7-13], this paper presents a coherent methodological framework for the development of complementary tactile sensors and human interface for the robotic telemanipulation of physical objects in an interactive hapto-visual virtual environment shown in Fig. 2, currently under development in our laboratory. The proposed robot telemanipulator consists of a robot arm and a two-finger hand equipped with fingertip tactile sensors.

The tactile human interface allows the human operator to experience a tactile feeling that is conformal to the reality. The tactile human interface represents an 1:1 mapping of the tactile sensor measurements that encode the elasticity and texture characteristics of the object held by the robot hand, on which the tactile sensors are mounted.

II. TACTILE SENSOR

Human tactile sensing is a multi-parameter sensing modality allowing for the measurement of a multitude of cutaneous parameters such as the contact force, topology, texture, and temperature of the touched area on the object's surface. The tactile sensor **is** employed in this context for the measurement of only one cutaneous parameter of the touched object, namely the topology (local geometric profile).

The tactile sensor array shown in Fig. 3 is a contact-type measuring instrument that provides the local *cutaneous* information about the touched area of the object. It consists of a 16-by-16 matrix of Force Sensing Resistor (FSR) elements spaced 1.58 mm apart on a 6.5 cm^2 area.

An elastic overlay provides a protective damping effect against impulsive contact forces and its elasticity resets the transducer when the probe ceases to touch the object. It also provides a geometric profile-to-force transduction function as shown in Fig. 4, [7]. The compliance of the overlay allows to increase even more the cutaneous information extracted by the tactile sensor under the force provided by the robot fingers

The robot arm provides the kinesthetic capability used to move the tactile probe around on the explored object surface. It also provides the contact force required for the probe to extract the desired cutaneous information.

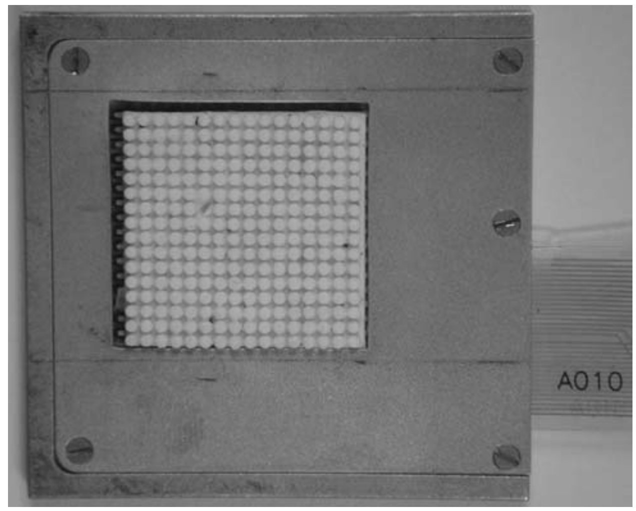


Figure 3. The 16-by-16 tactile sensor array.

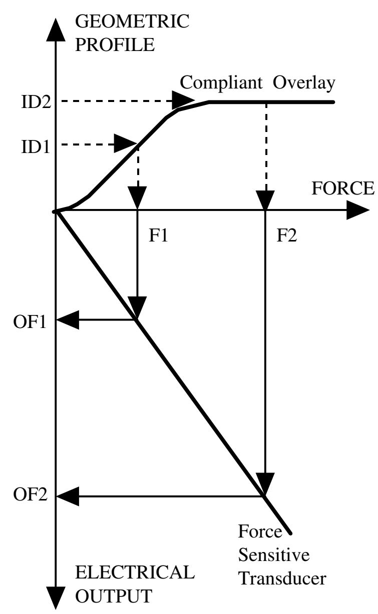


Figure 4. The geometric profile-to-force transduction function of the elastic overlay.

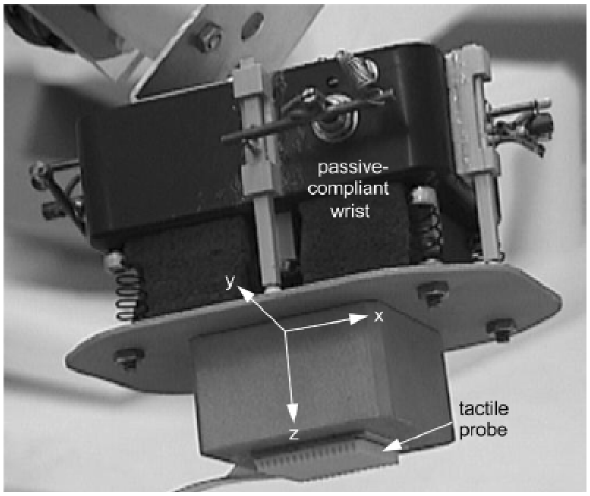


Figure 5. Passive-compliant support for the tactile probe (from [12]).

A passive-compliant support [12], as depicted in Fig. 5 ensures the interface between the tactile probe and the robot's end-effector allowing the tactile probe to better accommodate the profile of the touched object surface. This increases the local cutaneous information extracted during the tactile perception process under the force provided by the robot. It also minimizes destructive interactions that might occur when the probe is in contact with soft surfaces.

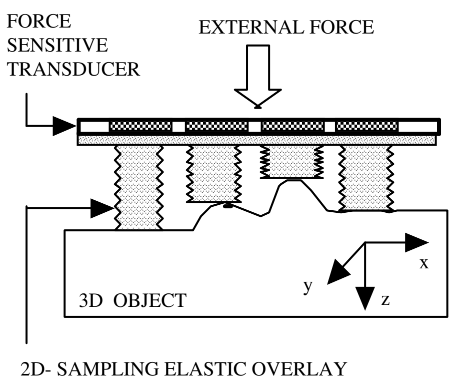
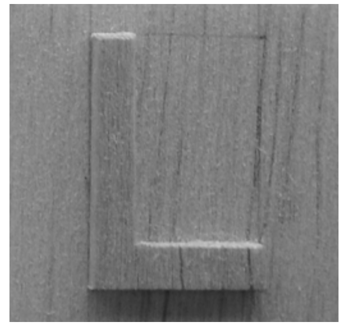


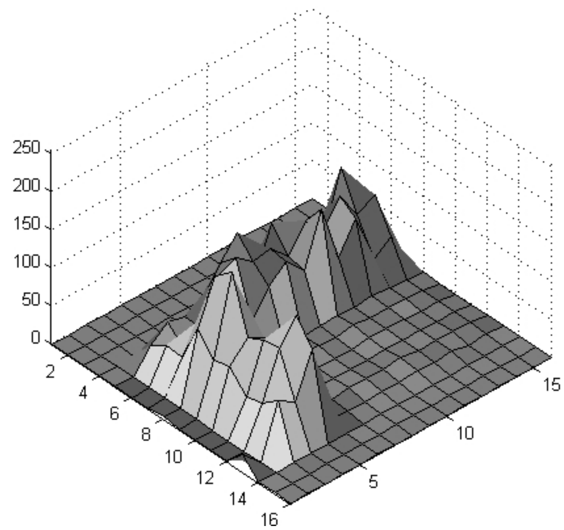
Figure 6. Round tabs of the elastic overlay can be compressed individually without cross talk (from [12]).

In order to reduce the blurring distortions generated by the crosstalk effect present in one piece elastic pads, our specially designed elastic overlay consists of a relatively thin membrane with protruding round tabs arranged in a 16-by-16 array. The tabs are positioned such that there is a tab on top of each node of the FSR matrix. This provides a 2D spatial sampling of the extracted cutaneous information.

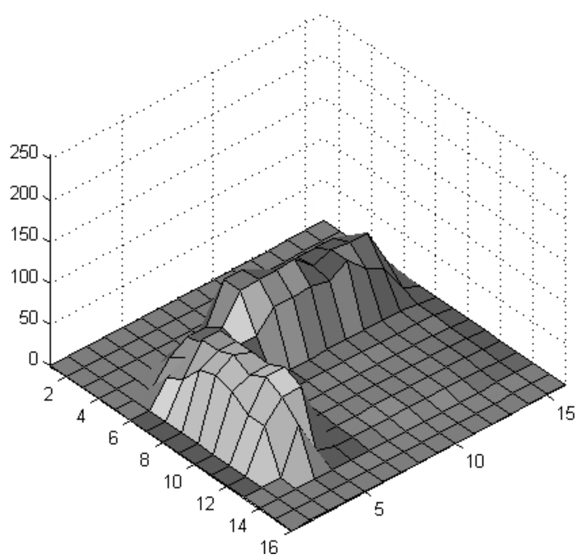
The tabs can expand without any stress in the *x* and *y* directions as shown in Fig. 6. This allows each tab to compress in the normal direction *z* proportionally with the stress component $\varepsilon_z = \sigma_z / E$ in the normal direction, where E is the elastic overlay's modulus of elasticity, σ is the stress, and ε is the strain.



a) Probed L Shape



b) Raw data



c) Median filter, n = [3 3]

Figure 7. The raw-data and the median filtered tactile image of an L shaped profile.

Each tactile sensor has an individual microcontroller-based electronic interface allowing to record the 16-by-16 array of normal forces and to perform signal processing of the measured array of data [14].

After the tactile sensor data is collected, a median filter is applied in order to remove the noise without affecting sharp details in the tactile image and therefore preserving the edges. Fig. 7 shows as an example the 16-by-16 array of raw measured data and the median filtered image of an L shaped profile.

The local information provided by the tactile probe is integrated with the kinesthetic position parameters of the passive-compliant support, resulting in a composite haptic model that includes the geometric and elastic profiles of the explored 3D object.

A composite tactile image is assembled incrementally from a sequence of overlapping tactile probe images. We are using the information provided by the position sensors in the robot joints and in the passive-compliant support of the tactile sensor to improve the accuracy of the composite tactile image. Bidimensional cross correlation is used to correct the misalignment errors between successive images when there is a common profile feature. A detailed discussion of this tactile sensor integration method is given in [9].

Fig. 8 shows as an example the composite tactile image assembled from individual tactile images of four symbols embossed on an object surface [11].

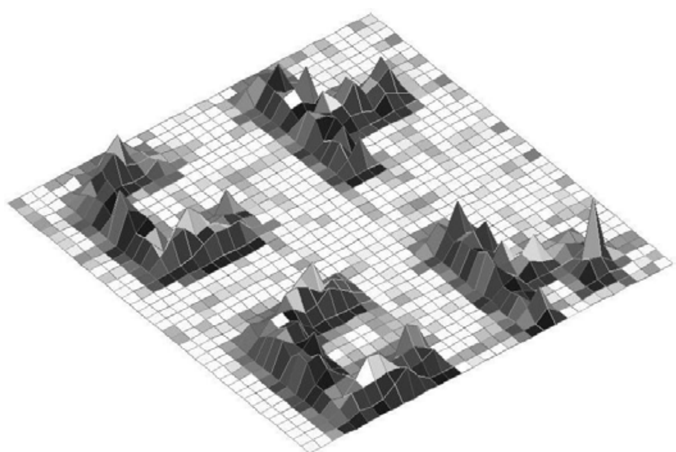


Figure 8. Example of composite tactle image (from [11]).

III. TACTILE HUMAN INTERFACE

In order to provide feedback to an operator, cutaneous/tactile perception is essential for the dexterous manipulation of the objects [3, 15], [16]. In general, the cutaneous/tactile human interfaces should meet the requirements summarized in [4]. While there are commercial human interfaces that provides force feedback, or a full-hand kinesthetic component, as shown in Fig. 9, the existent commercial solutions can provide only a rudimental low resolution cutaneous experience that doesn't allow to discriminate between specific locations on the palm and doesn't allow neither any fingertip touch experience.

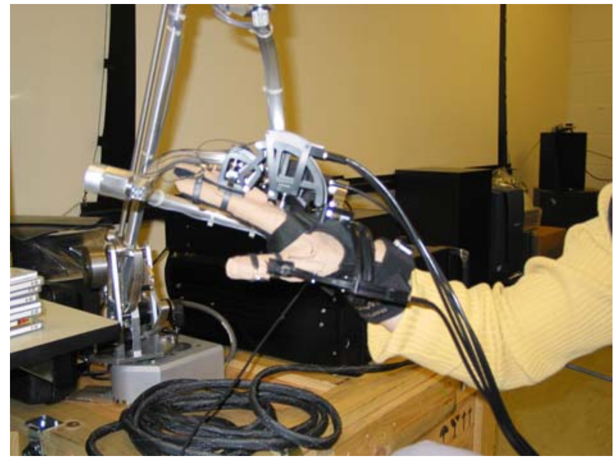


Figure 9. Commercial *Virtual Hand Toolkit for CyberGlove/Grasp* providing the kinesthetic human feedback interface.

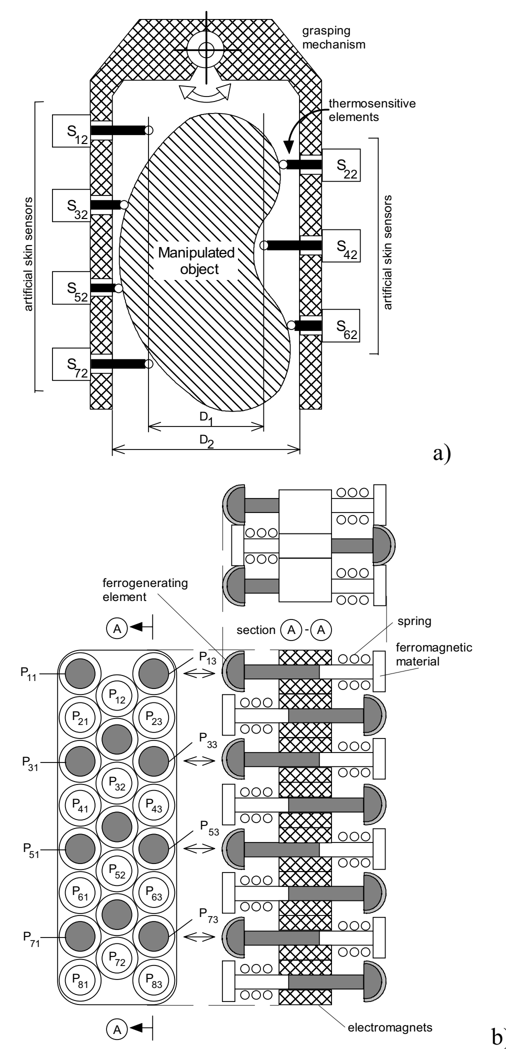


Figure 10. Complementary tactile sensor (a), and tactile human interface (b), developped in the early 80's for robotic telemanipulation (adapted from [7]).

An early tactile human interface, Fig. 10, providing a temporary replica of the local geometric and/or force profile at the contact areas of the object that are virtually being touched was proposed in 1982 by Petriu *et al.* [7].

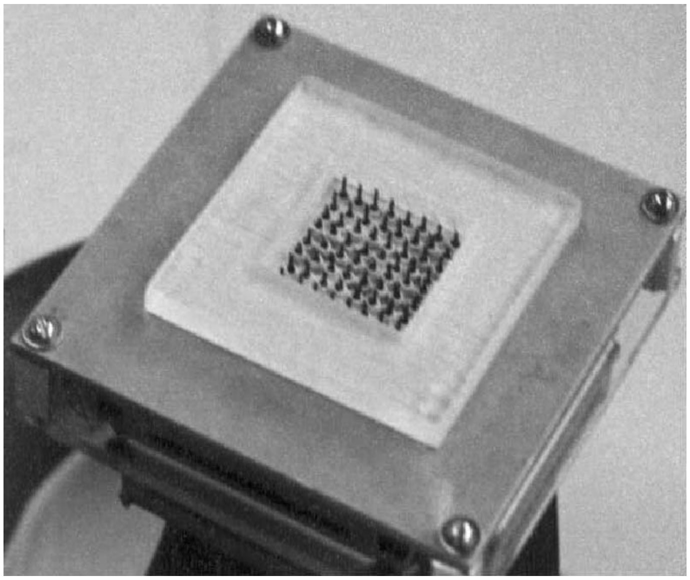


Figure 11. Tactile array human interface consisting of an 8-by-8 array of vibrators.

We further developed a tactile array human interface, shown in Fig. 11, which allows a human teleoperator to experience a virtual tactile feeling of the object profile measured by the robot's tactile sensor. It consists of an 8-by-8 array of electromagnetic vibrators covering a 6.5 cm^2 contact area. Each stimulator corresponds to a 2-by-2 tactile pixel window in the tactile sensor array. The vibro-tactile stimulator is used as a binary device which is activated when at least two out of four tactile pixels are on.

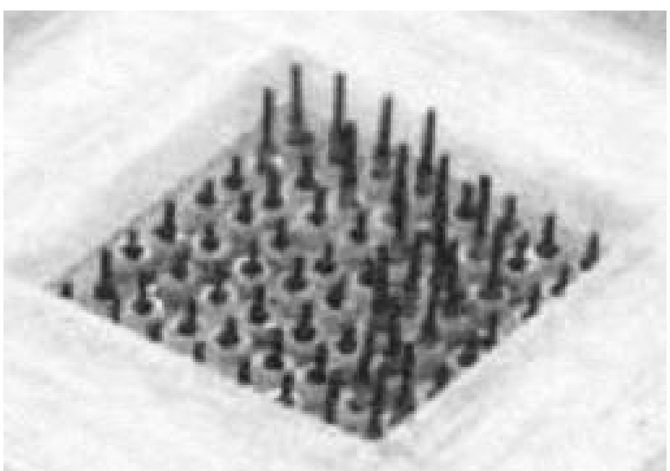


Figure 12. Curved edge produced by the tactile human interface.

Fig. 12 shows as an example the image of a curved edge feedback produced by the tactile human interface. Experiments have shown that it is possible to increase the resolution of the reconstructed local geometric profile by using a pseudo-random selection of the electromagnetic vibrators which are activated sequentially.

Figure 13. Tactile fingertip human interface.

We are currently studying a tactile fingertip human interface, shown in Fig. 13, which allows a human operator to interactively feel with his/her own fingertips the tactile properties of the manipulated object.

It consists of miniature vibrators placed on each fingertip. The vibrators are individually controlled by a microcontroller using a dynamic model of the visco-elastic tactile sensing mechanisms in the human fingertip. The microcontroller also provides the communication functions with the hand-level controller of the haptic-feedback interface.

IV. CONCLUSION

We have presented a bilateral sensory architecture for robotic telemanipulation. It allows a human operator equipped with a tactile human interface to connect in a transparent manner, from the haptic perception point of view, with a remote robotic manipulator equipped with complementary tactile sensors placed in the robot hand.

REFERENCES

[1] S.J. Lederman, D.T. Pawluck, "Lessons From the Study of Biological Touch for Robotic Haptic Sensing," in Advanced Tactile Sensing for Robotics (H.R. Nicholls, ed.), World Scientific, 1992.

[2] M.H. Lee, H.R. Nicholls, "Tactile Sensing for Mechatronics - a State of the Art Survey," Mechatronics, 9(1999), pp. 1-31, 1999.

[3] A.M. Okamura, N. Smaby, M.R. Cutosky, "An Overview of Dexterous Manipulation," Proc.ICRA'00 - IEEE Intl. Conf. Robot. Autom., pp. 255–262, Apr. 2000.

[4] M. Benali-Khoudja, et al., "Tactile interfaces: A state-of-the Art Survey," Proc. ISR 2004 -35th Intl.Symp. Robotics, Paris, March 2004.

[5] A. El Saddik, “The Potential of Haptics Technologies”, IEEE Instrumentation & Measurement Magazine, Vol. 10, No. 1, pp. 10-17, Feb. 2007.

[6] K. Salisbury, F. Conti, F. Barbagli, “Haptic Rendering: Introductory Concepts,” IEEE Computer Graphics and Applications, Vol. 24, No. 2, pp. 24 – 32, 2004.

[7] E.M. Petriu, D.C. Petriu, V. Cretu, “Control System for an Interactive Programmable Robot,” Proc. CNETAC Nat. Conf. Electronics, Telecommunications, Control, and Computers, pp. 227-235, Bucharest, Romania, Nov. 1982.

[8] E.M. Petriu, M. Krieger, "Robotic Sensing and Perception as the AI Frontier of the I&M," Proc. IMTC/92, IEEE Instrum. Meas. Technol Conf., pp.256-259, New York, NY, 1992.

[9] E.M. Petriu, W.S. McMath, S.K. Yeung, N. Trif, "Active Tactile Perception of Object Surface Geometric Profiles," IEEE Trans. Instrum. Meas., Vol. 41, No. 1, pp.87-92, 1992.

[10] S.K. Yeung, E.M. Petriu, W.S. McMath, D.C. Petriu, “High Sampling Resolution Tactile Sensor for Object Recognition,” IEEE Trans. Instrum. Meas., Vol. 43, No. 2, pp. 277-282, 1994.

[11] E.M. Petriu, S.K.S. Yeung, S.R. Das, A.-M. Cretu, H.J.W. Spoelder, “Robotic Tactile Recognition of Pseudorandom Encoded Objects, IEEE Trans. Instrum. Meas., Vol. 53, No. 5, pp. 1425 - 1432, 2004

[12] P. Payeur, C. Pasca, A.-M.Cretu, E.M. Petriu, “Intelligent Haptic Sensor System for Robotic Manipulation,” IEEE Trans. Instrum. Meas., Vol. 54, No. 4, pp. 1583 – 1592, 2005.

[13] K. Gilbank, D. Necsulescu, E.M. Petriu, “Instrumented Compliance for Tendon Driven Rotary Robot Joint,” Proc. 2006 Int. Conf. Autom. Quality and Testing, Robotics, vol. 2, pp. 215-218 Cluj-Napoca, Romania, May 2006.

[14] C. Pasca, Intelligent Tactile Sensor, M.A.Sc. Thesis, University of Ottawa, Ottawa, On. Canada, 2004.

[15] R.W. Harrigan, P.C. Bennett, Dexterous Manipulation: Making Remote Manipulators Easy to Use, Sandia Report, SAND2001-3622, Nov. 2001.

[16] G. Burdea, Ph. Coiffet, Virtual Reality Technology (2nd edition), Wiley, NJ, 2003.