Proceedings of the 17th IEEE International Symposium on Robot and Human Interactive Communication, Technische Universität München, Munich, Germany, August 1-3, 2008

Surface Perception in a Large Workspace Encounter Interface

Emanuele Ruffaldi and Carlo Alberto Avizzano and Paolo Tripicchio
and Antonio Frisoli and Massimo Bergamasco, Member IEEE

Abstract— **Haptic interaction with virtual objects is typically tool mediated, or in alternative it constraints user's body in someway, like it happens in exoskeletons that cannot be totally transparent. Encounter type haptic interfaces aim at hands free haptic interaction, that is more natural and can be applied in contexts in which the user moves in the space around the interface. This paper presents a system that allows a palm based haptic interaction in a large workspace using the principle of encountered haptics. The system is evaluated in a surface exploration task and compared against the same task performed with a standard haptic interface. In this type of task this type of interface is better suited, providing a smoother feedback to the hand during the movement over the surface.**

I. INTRODUCTION

Haptic interfaces can be classified depending on the way the user interacts with the device, and in this particular classification there are two aspects that are taken into account. The first aspect is the distinction between direct contact and indirect contact of the user with the virtual objects. In the indirect contact the user interacts with the virtual environment through a tool, and in the real world he holds a stylus that is connected to or is part of the haptic interface like in the Phantom. [12] The direct contact is instead the case in which user's body part directly interacts with the virtual object. The second aspect is the mechanical attachment between user's body and the haptic interface, that in most of the cases corresponds to a single point of contact with the haptic interface, also when the user is not in contact with a virtual object. In the case of indirect contact the user holds a tool both in the real and in the virtual world for all the time. Instead in direct contact interfaces there are various degrees of connection, from multipoint exoskeleton devices, through fingertip haptic devices and encounter type interfaces [15].

Encountered-type haptic interface is a type of interface in which the user is not always in contact with the interface, but instead the device encounters the user when he is going to be in contact with the virtual object. This has been independently proposed by McNeely [1] and Tachi et al. [2] independently.

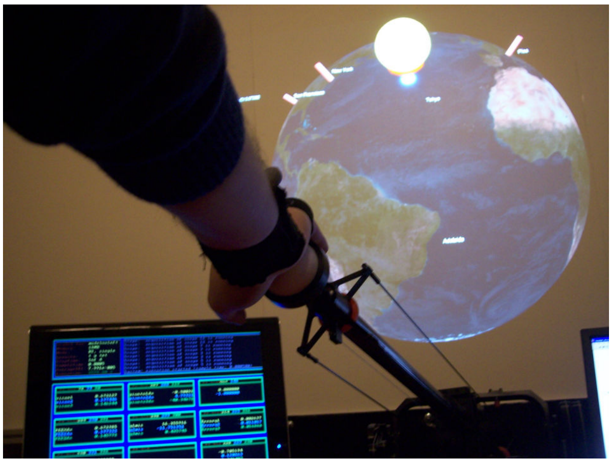

Fig. 1. This image shows the interaction between the hand and the haptic interface. In the background the white sphere corresponds to the user hand that is interacting with the virtual object.

In this paper, a large workspace encounter interface is being presented with the purpose of simulating the interaction of multiple objects, overcoming the limitation of knob like objects or simple planes. After a discussion of related works, the system is being described, followed by a demonstration application and an evaluation of the shape perception. The figure 1 shows a particular of the interaction of the user with the device while exploring the surface of a sphere.

The paper is structured as follows. First a review of related works and the main contributions of this paper are introduced. Then it follows an overview of the architecture of the system, completed by a section on the control scheme and one on an example application of use. The paper is concluded by the results of an experimental evaluation of the system itself in the context of shape perception.

II. RELATED WORKS AND CONTRIBUTION

In haptic interaction in general, and more specifically in direct contact interfaces, there is the need for rendering the perception of first contact with a surface, and then render the continuous contact with the surface itself. A possible solution for tool mediated interfaces have been addressed by event based haptics [13] using an open loop rendering of the contact impulse, but its application in direct contact has some limitations.

The objective of encounter interfaces is to twofold, to provide a hands free haptic stimulation and to render the first contact with the surface in a realistic way.

This work has been founded by the European Commission inside the SKILLS Integrated Project (IST-035005) entitled Multimodal Interfaces for Capturing and Transfer of Skill.

Emanuele Ruffaldi is with PERCRO, Scuola Superiore S.Anna, 56100 Pisa,Italy `e.ruffaldi@sssup.it`

Carlo Alberto Avizzano is with PERCRO-SSSA `c.avizzano@sssup.it`

Paolo Tripicchio is with PERCRO-SSSA `paolo3px@libero.it`

Antonio Frisoli is with PERCRO-SSSA `a.frisoli@sssup.it`

Massimo Bergamasco is with PERCRO-SSSA `bergamasco@sssup.it`

978-1-4244-2213-5/08/$25.00 ©2008 IEEE

Several types of encounter interfaces have been developed, each focusing on specific aspects of the contact. Some of them simulate the interaction of specific types of objects, like knobs or switches [3], [2], [1], [10], typically using a robot for the purpose. For this type of object in the limit case of one single object the device is kept in a fixed position and it is being moved only when the user interact with it.

The encountering aspect can be limited to the specific interaction between the fingertip and the virtual object, and this is the area of fingertip haptics research. In [4] user's finger is placed inside a tracker and the device stimulates the finger with a plate that encounters the fingertip only when it gets in contact with a virtual surface.

Because encounter type interfaces tend to keep the user finger free from mechanical constraints it is possible also to stimulate multiple fingers, in particular using a set of patches one for each finger [9], [8], [7]. The aim of a multiple finger interface is to provide not only the exploration of objects but also the grasping of objects [14].

The registration between the visual channel and the haptic channel has been proposed through the concept of WYSIWYF (What You See is What You feel) [10], making use of a head mounted display. In the proposed system the visualization is frontal respects of the user, with the objective of maintaining the free and natural movement, clearly this is an aspect that depends on the specific application that has been selected for the encountering system.

To date none of the existing approaches are extending the interaction beyond knob based types or plane patches, in particular for the rendering of complex shapes.

This paper presents an encounter type haptic interface with large workspace in which the haptic feedback happens at the level of the palm: the large workspace allows us to implement complex geometries and manipulation effects. In this system, the human motion tracking that drives the haptic feedback, is provided by a motion capture system that tracks the user's hand. The main contributions of this work are in the palm based haptic interaction, using the principle of encounter interface, and the design of a system that allows the perception of various shapes. The system is being described and completed with an experimental evaluation of the perception of a spherical surface.

III. ARCHITECTURE

This section discusses first the architecture of the proposed system and the specific control scheme adopted.

The encounter interface described in this paper is based on two parts, the motion capture system and a robotic device. The motion capture is a VICON MX Motion Capture, in particular a setup of 6 MX-20 cameras, that provides a precision up to 0.2 mm, having placed the cameras in a circular configuration above the user and the haptic interface. The robotic device used for the interaction is the GRAB Haptic interface [16], a large workspace 3-DOF haptic interface that has been previously used for single or multiple fingers interaction. In particular the device has a box workspace of 400 mm depth, 400 mm high and 600 mm wide. This haptic device is able to generate continuos forces at the end-effector of 4 N in the worst condition while the peak forces are up to 20 N, the device has a position accuracy at zero load less than 1 percent, i.e. 1mm over 100 mm. The robotic device was placed in the center of the capture space, and behind that a front projection screen was placed presenting a virtual environment. Figure 2 shows a schematic representation of the system, while 3 shows the system in its demonstration configuration. The system uses two PCs: the first is an embedded PC for the low level control of the haptic interface, while the second, the main PC (an Intel Core 2 Duo 1.86 GHz with GeForce 8800 GTX) computes the motion capture, the high level control of the device and the 3D rendering of the graphics.

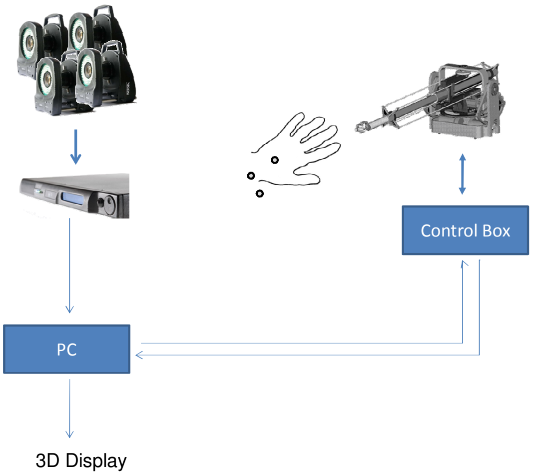

Fig. 2. The architecture of the proposed system showing the GRAB robotic device (top right), the motion capture (top left) and the PC (bottom left) for the computation of the hand position, control of the device and graphic visualization.

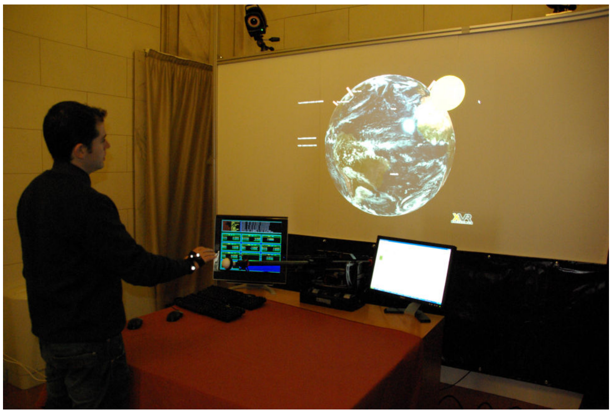

Fig. 3. Overall system setup with the demonstration application. The user hand is the white sphere displayed over the Earth globe

In its standard configuration the GRAB device has a thimble as end-effector allowing the user to directly interact with virtual objects. In this system the thimble has been replaced by a partially soft hemisphere with 2.25 cm of radius (R). The size and the shape of the contact element have been selected for providing a good interaction with the palm of

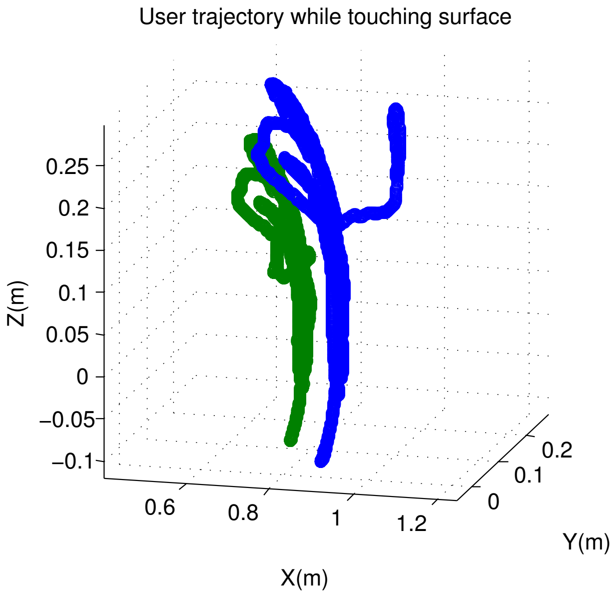

Fig. 4. Plot of the exploration trajectory over a spherical surface, showing the offset respect the surface point of the haptic interface and the dorsal position provided by the motion capture. A typical value of such offset is of 7.2 cm.

the hand, being satisfactory for the demonstration application and the evaluation. This type of end-effector has been chosen because the robotic device has only 3 degrees of freedom and it is not possible to present an oriented surface. Although this solution limits the possible types of surface gradients, the applications for which fingers do not get in contact with the object from the back can be adequately implemented. Applications of full hand interaction for exploration purposes like Museum of Pure Form [11] are particulary well suited for this type of interface.

The encountering system is obtained by tracking the user hand with the motion capture, having placed a configuration of three markers over the dorsal part of the hand, leaving the palm of the hand for the interaction with the device. The position and orientation information of the hand is used for controlling the end-effector of the device allowing the display of a surface under the hand of the user, in particular the device is controlled in position with a simple motion planning scheme.

The motion capture system is running at 300 Hz, while the control loop of the haptic interface is running at 1 kHz. The cases of missing information from the motion capture and the difference between the two rates are handled using an estimation of the movement of the hand, depending on the state of contact. The velocity has been limited for safety reasons but nevertheless it works up to 200 mm/s, usually working around 50 mm/s.

IV. CONTROL SCHEME

In the current control scheme the system has two reference positions, the hand position $\vec{h}$ and the device position $\vec{p}$, both referenced to the same device coordinate system. The hand position $\vec{h}$ is obtained from the motion capture system, applying some filtering operations that take into accounts the errors in the capture itself, mostly related to the delays in the tracking. The low level control of the device is based on position control with velocity saturation that moves the current position $\vec{p}$ toward the target position $\vec{t}$. The higher level control computes the target position $\vec{t}$ based on the current position $\vec{p}$, the position of the user hand $\vec{h}$ and the objects in the virtual environment. In the current system this control law is simplified and it yet does not take into account the possible collisions with the user's hand. Objects S_i are currently represented by implicit surfaces $f_i(x,y,z) = 0$.

The high level control has two states, a free space state and the touch state. When in free space the control identifies the obejct S_i that is nearest to the user's hand and it sets the target position depending on the point $\vec{w}$ of the object S_i nearest to the user's hand $\vec{h}$. The target position $\vec{t}$ is computed adjusting the point $\vec{w}$ with the size of the end effector R and the hand thickness H:

$$\vec{t} = \vec{w} - \vec{n}R - \vec{h}_z H \tag{1}$$

In the above equations $\vec{n}$ is the normal of the surface S_i at point $\vec{w}$ computed from the gradient of the implicit function. The motion capture system allows to track not only the position but also the orientation of the hand, and in particular the vector $\vec{h}_z$ is the Z axis of the hand reference system, coming out from the back of the hand. The offset between the tracked position $\vec{h}$ and the device position $\vec{p}$ is shown in figure 4.

During the touch state the system tracks the contact between the user's hand and the end effector, moving the target point $\vec{t}$ along the surface, and exiting the touch state when the distance between the end effector and the hand is higher than a given threshold. More work is needed in this area for taking into account the relative velocities of the hand and the end effector.

V. APPLICATION

The capabilities of the proposed system have been tested with an interactive visualization application. This application allows to manipulate a representation of the Earth globe that is controlled through the interaction with the device. The planet is represented by a sphere placed in front of the user, and visualized with a detailed visualization of the planet surface. At the first level there is the interaction of the user with the surface of the planet, and in particular the user can perceive and explore the surface. The transparency of the atmosphere is increased while the user's hand reaches the surface, allowing to see the surface's details.

The interaction with the globe is not limited to the surface exploration, indeed it is possible to use the interface to push the surface. When the user pushes the surface over a certain threshold it is possible to rotate the sphere with a dragging operation. An additional interaction paradigm is the grabbing of the end-effector, that allows to modify the point of view of the user by zooming out.

VI. EVALUATION

The system proposed has been evaluated in terms of the capacity of the user to perceive and follow the spherical surface. In particular the users have been asked to follow the surface of a sphere of radius 30 cm using the palm of the hand in two particular cases, the first while the sphere surface is visible, while the second only with haptic feedback. In this evaluation the objective is to measure the cases of loss of contact and the case of excess force applied by the user for following the surface. The first evaluation has been compared against the same exploration task with the haptic interface using the standard thimble based approach.

In the encountered type evaluation 5 male users were tested, asking to explore the surface and keep the contact of the surface. The evaluation has been introduced by a brief phase of free interaction with the device allowing to understand the way it reacts to the user.

During the evaluation the position of the device and the position of the user's hand were recorded at the rate of 300Hz, and transformed into polar coordinates respect the center of the sphere. Only trajectories after the first contact are being used for the evaluation. During the evaluation the radius of the polar representation of the hand position is taken into account adjusted by the hand offset. The hand is simply considered in contact if the radius is less than the sphere radius.

Based on the percentage of contact and the statistics during contact we are able to obtain a preliminary result of the ability of the users to follow the surface. In particular the percentage of contact has little changes respect the presence of the visual stimuli, given the fact that the haptic stimulus is sufficiently realistic. Figure 5 shows the percentage of contact among the various users. Analyzing the depth of penetration during contact among the user is possible to identify how the haptic only exploration gives better results, probably because users where more focused. Figure 6 shows the box plot for each trial, in which each pair of trials is for one user, with first the case with the graphics displayed. Decomposing the velocity of the hand over the surface allows to verify that users keep a small radial component, in particular Figure 7 shows the mean value of the radial velocity expressed as percentage of the total velocity.

In the second phase of the evaluation we took another set of 6 users for testing the sphere exploration using the standard haptic rendering algorithm. In this case the user is constantly holding the end-effector and the application computes the response of the interaction between a point and the sphere of 30cm. Two of the users were present in both experiments and in the graphs they correspond to the first and last of the encounter type evaluation. In the classic rendering the contact percentage is above 80 percent for most of the users. In particular it is interesting to compare the contact percentage for the two users in both the experiments, resulting in a conflicting result about the coverage, as shown in Figure 8. In the case of the depth penetration, instead, it appears that the two users have a higher penetration with the

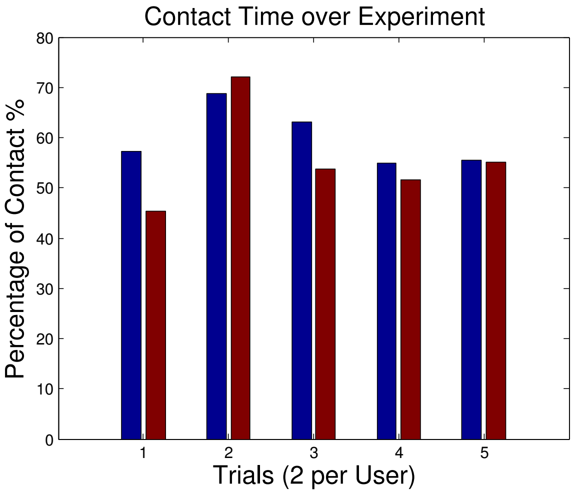

Fig. 5. Percentage of contact during the experiment among the different users. The bars in blue show the graphic and haptic test, while the red ones the haptic only.

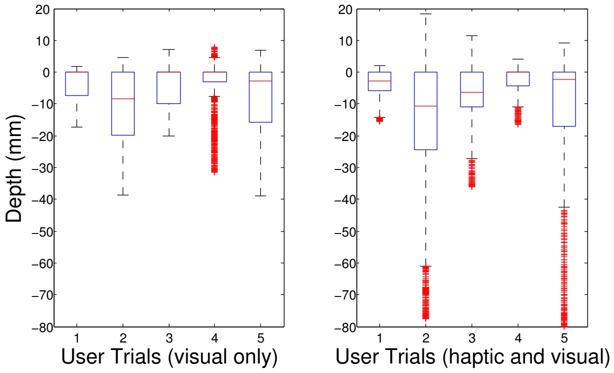

Fig. 6. Penetration depth of the user hand while in contact with the device. The left plot shows the experiment with haptic and visual feedback, while the red one only the visual feedback.

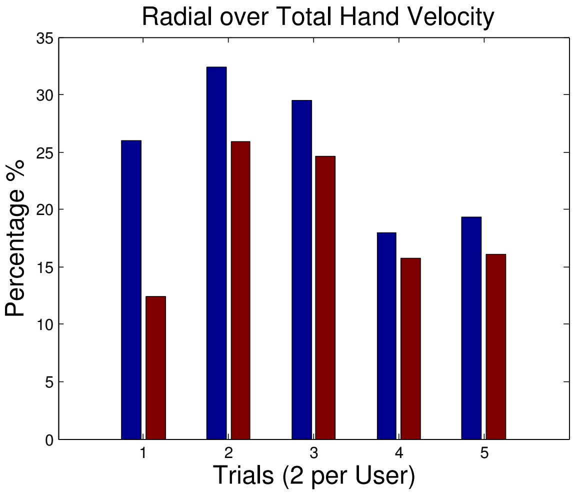

Fig. 7. Evaluation of the radial velocity respect the total hand velocity during exploration. For all the user it remains under 30 percent. . The bars in blue show the graphic and haptic test, while the red ones the haptic only.

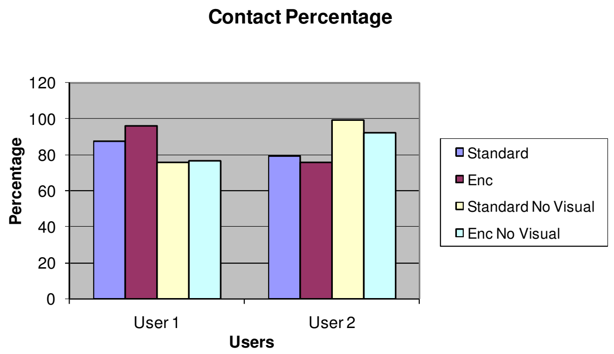

Fig. 8. Comparison of the contact percentage over the experiments for two users present in both the evaluations

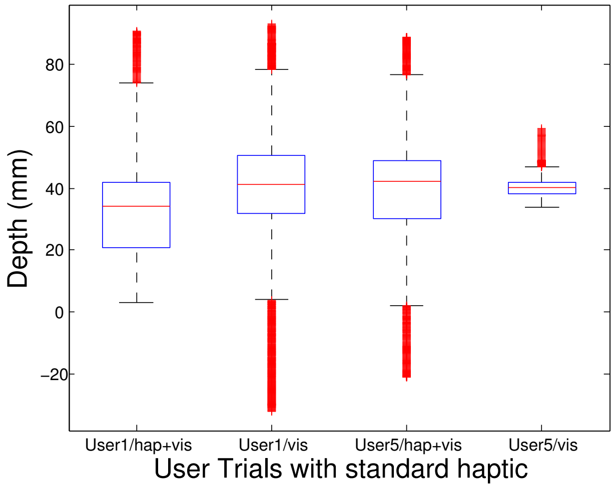

Fig. 9. Depth penetration for the two users during the standard haptic evaluation. The two users correspond to the first and last in the previous trials. For every user two tests are shown. The one with white boxes is the one using graphic display, while the other is the one with only the haptic feedback.

standard haptic interface respect the encounter type, with the effect of perceiving higher forces as shown in Figure 9. The evaluation of the radial component of the velocity respect the total cartesian velocity shows that with the standard haptic interface there is an higher radial component, probably caused by the lower precision of following the surface of the sphere. Indeed both the two common users have an increase in the radial component of the velocity, as show by Figure 10 compared by the previous Figure 7.

VII. CONCLUSIONS

In this paper we have presented and evaluated an encounter type haptic interface with large workspace and the possibility of exploring surfaces. The presented system provides a palm based haptic interaction with virtual objects for performing hands free haptic interaction and multiple interactive modalities. The objective of this work is to present a system that provides both the first contact response of the encountered haptics, and the surface following of standard haptic interfaces.

There are several aspects of the interface that can be extended and investigated, in particular possible alternatives to the current hemispherical end-effector, the relationship between the radius of the hemisphere and the types of objects that can be rendered. Finally a more in-deep evaluation of shape discrimination should be performed, eventually enhanced by the introduction of a force sensor on the end-effector for providing a relationship between the device position and the applied force.

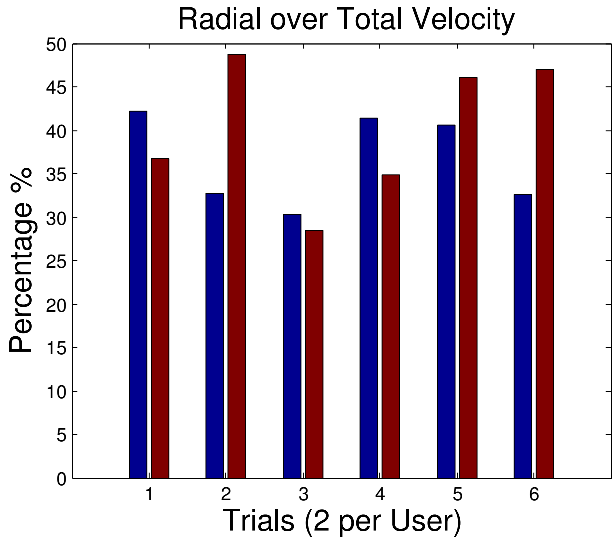

Fig. 10. Evaluation of the radial velocity respect the total device velocity during exploration. It grows up to 60 percent. The bars in blue show the graphic and haptic test, while the red ones show the haptic only.

REFERENCES

[1] W. A. McNeely: Robotic Graphics: A New Approach to Force Feedback for Virtual Reality. In: Proc. of VRAIS93, pp.336-341 (1993)

[2] S. Tachi et al.: A Construction Method of Virtual Haptic Space In: Proc. of Int. Conf. on Artificial Reality and Telepresence (ICAT94), pp.131-138, (1994).

[3] P. E. Gruenbaum et al: In: Implementation of Robotic Graphics For a Virtual Control Panel In VRAIS-95 Video Proc, (1995).

[4] G. Cini, A. Frisoli, S. Marcheschi, F. Salsedo, M. Bergamasco: A novel fingertip haptic device for display of local contact geometry In: WHC 2005. First Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, pp.602–605, (2005).

[5] A. Bicchi, M. Raugi, R. Rizzo, N. Sgambelluri: Analysis and Design of an Electromagnetic System for the Characterization of Magneto-Rheological Fluids for Haptic Interfaces In: Proc. IEEE Transactions on Magnetics, Vol.41, No.5, pp.1876-1879, (2005).

[6] W. R. Provancher, M. R. Cutkosky, K. J. .Kuchenbecker, G. Niemeyer: Contact Location Display for Haptic Perception of Curvature and Object Motion In: Proc. The International Journal of Robotics Research, Vol.24, No.9, pp.691-702, (2005).

[7] K. Shigeta et al.: Motion Planning of Encountered-type Haptic Device for Multiple Fingertips Based on Minimum Distance Point Information In: Proc. of the World Haptic Conference, (2007).

[8] Y. Yokokohji, N. Muramori, Y. Sato, and T. Yoshikawa: Designing an Encountered-Type Haptic Display for Multiple Fingertip Contacts based on the Observation of Human Grasping Behavior In: Proc. International Journal of Robotics Research, Vol.24, No.9, pp.717-730, (2005).

[9] Y. Yokokohji, N. Muramori, Y. Sato, T. Kikura, and T. Yoshikawa: Design and Path Planning of an Encounteredtype Haptic Display for Multiple Fingertip Contacts based on the Observation of Human Grasping Behavior In: Proc. IEEE International Conference on Robotics and Automation, pp.1986-1991, (2004).

[10] Y. Yokokohji, R. L. Hollis and T. Kanade: What You can See Is What You can Feel -Development of a Visual/Haptic Interface to Virtual Environment In: Proceedings of 1996 IEEE Virtual Reality Annual International Symposium (VRAIS96), pp.46-53, (1996).

[11] M. Bergamasco,A. Frisoli, F. Barbagli: The Museum of Pure Form In: Proceedings of IEEE International Conference on Advanced Robotics, Coimbra, Portugal, (2003).

[12] T. H. Massie, J.K. Salisbury: The PHANTOM Haptic Interface: A Device for Probing Virtual Objects. In: Proceedings of the ASME Winter Annual Meeting, Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, Chicago, IL, (1994).

[13] Jonathan Fiene, Katherine J. Kuchenbecker, Gnter Niemeyer: Event-Based Haptics with Grip Force Compensation In: Proceedings of the Haptic Symposium, Washington, WA, (2006).

[14] A. Frisoli, S-L Wu, E. Ruffaldi, M. Bergamasco: Evaluation of multipoint contact interfaces in haptic perception of shapes In: Multipoint Interaction with Real and Virtual Objects,Springer, (2005).

[15] M. Bergamasco: Force replication to the human operator: the development of arm and hand exoskeletons as haptic interfaces In: Proceedings of 7th International Symposium of Robotics Research, (1997).

[16] Carlo Alberto Avizzano, Teresa Gutierrez et al.: GRAB: Computer graphics access for blind people through a haptic and audio virtual environment In: Proceedings of Eurohaptics 2003,Dublin,Ireland, (2003).