Multi-Finger Haptics Enhanced Virtual Instrument Interfaces

Jose James1,2, Gianluca Mazzilli2, Sergio Rapuano2, Luca De Vito2, Pasquale Daponte2

1AMMACHI Labs, Amrita Vishwa Vidyapeetham, Amritapuri, India
2Department of Engineering, University of Sannio, Benevento, Italy

E-mail: josejames@am.amrita.edu, {gianluca.mazzilli, rapuano, devito, daponte}@unisannio.it

Abstract. Measurement interfaces are progressing, and the influence of new technologies in virtual reality and telerobotics made it more advancing. This paper presents a haptics enhanced virtual measurement interface model and demonstrates its usefulness for touchless and virtual instrumentation. Users can interact, locally or remotely, with the instrumentation by using motion tracking and haptics technologies. Attention has been paid to do the integration of multi-finger haptics and hand motion tracking systems for the effective interaction with the virtual instrument interfaces.

1. Introduction

The multimedia tools and new technologies like virtual reality and multimodal interfaces are influencing fields like entertainment, education, medicine or, professional training. They also enhanced the instrumentation and measurement field, and as a result, the concept of virtual and remote access to laboratory equipment was introduced many years ago [1]. In particular, Internet-accessible remote laboratories used for the distance learning on instrumentation and measurement have been the focus of increasing attention for years with the concepts of virtual measurement panels [2]. Measurement instruments integrated into e-Learning and virtual laboratories need to be operated virtually and remotely for performing collaborative tasks. Nowadays, a lot of remote experiments, lessons, and seminars are available on the web [3]. A virtual laboratory-based education system [4], and a platform [5] for remote electronic measurements and instrumentations were proposed already. Since the computer network is the physical mean between the user and the laboratory, the interaction between the user and the graphical interface relied essentially on the traditional keyboard and mouse input peripherals.

In the last years, new technologies [6] have been introduced which foster the effectiveness of interactive virtual and remote labs by exploiting the power of virtual reality to provide the user with a more immersive visual experience. Several applicative scenarios, like Industry 4.0 or medical radiodiagnosics, can be found where the users could benefit from using free hands to remotely and virtually operating laboratory or live instrumentation. This could be achieved by extending the remote laboratory interactivity in the human-to-computer direction with a motion tracking capability and a haptic interface.

Human motion tracking technologies were implemented in various areas of rehabilitation, assistive systems, skill training, entertainment for the full-body motion and joint tracking [7]. The authors of [8], for example, presented a Body Area Sensor Network (BASN) for measuring Range of Motion (ROM) of patients performing rehabilitation exercises. The human hand is a prehensile tool for the primary physical interaction with the environment. Therefore, monitoring and tracking human hand motion is beneficial for the progress of immersive virtual reality applications. Haptics is the technology of recreating the touch sensation (tactile or kinesthetic) by applying forces, vibrations or motions to the user. Haptic applications allow people to interact with the sense of touch, along with
visual and acoustic representations of objects and scenes [9] for virtual and remote environments [10]. The multi-finger haptics technology [11] together with motion tracking can enrich the virtual or remote laboratories to increase the immersive and realistic feel of measurement capabilities of the user in the real-time environment.

This paper presents a novel measurement instrument interface that extends the traditional Graphical User Interface (GUI) by adding novel, touchless, bi-directional, interaction modes in virtual instruments and remote laboratories. The users can interact with the instrument control panel in a Virtual Measurement Interface (VMI), using a Motion Tracking System (MTS) and get the haptic feedback through wearable finger caps providing the users with force feedback, vibrations and the feel of operating the actual instrument panel.

2. System Design and Architecture

The architecture of the proposed system has two modules: the MTS and the VMI as shown in Fig.1. The MTS contains the motion tracking devices for human body skeleton and hand fingers and the multi-finger haptic caps for feedback. The method and system described in [8] were used for measuring the Range of Motion (ROM) of the full-body segments. The Leap motion sensor [12] has been adopted for the precise tracking of hand fingers. The Leap Motion sensor is a small USB peripheral device which observes a roughly hemispherical area and tracks the motion parameters of fingers, palm, and wrist of user’s hand in the work-space area.

The feedback is provided by means of a haptic finger cap designed for this research work, a small cap with sensors and actuators that can be worn on the fingertips. These caps are responsible for providing haptic feedback to user’s fingers. Fig.2 shows the haptic interaction loop of the complete system. The finger tracking system measures the user’s motion parameters and transfers them to the VIM as shown in Fig.2. This module consists of a GUI and computation models for the effective rendering of haptic and visual parameters. Therefore, the motion parameters are processed to make respective grasping patterns corresponding to the hand gesture. A 3D hand model (Fig.2) is populated with selected touch patterns. Three kinds of haptic touch were integrated into the model: single-finger touch, two-finger pinch grasp, and three-finger tripod grasp. The user grasp gesture is transformed to one of the touch patterns described above to interact with the GUI. The GUI currently implemented as a general instrument panel display with basic controls like buttons, knobs and trigger switches as shown in Fig.2. The VMI has been developed using OpenGL and Chai3d haptic API [13].

Whenever the 3D hand model touches the control panel in the virtual interface, a collision detection algorithm detects the collisions and activates the haptic computation model (Fig.1). The haptic model, described in the following Section, renders the force values based on the user’s motion parameters and the control panel material properties. Based on the rendered force values, the actuators in the finger caps recreate the force and provide the haptic feedback to the user’s fingers.

3. Haptic Grasp Computational Model

The concept of the virtual finger [14] effectively reduces the many degrees of freedom of the human hand to those that are necessary to perform the grasping task. Here the concept of virtual fingers (VF)
was implemented to reduce the realistic five-finger grasping to three-finger grasping. The haptic computation model shown in Fig.3 was implemented to create the suitable force feedback for the virtual measurement interface. The proposed model including object and virtual fingers in the virtual interface measures collision and progress of interactions regarding applied forces and finger movements and computes the force feedback. A basic grasping touch in virtual reality is defined as a touch that provides vertical force feedbacks on the contact surface coincident with the reverse direction of the fingers in the space as shown in Fig.3.

**Figure 2.** The flow of data in the system model.

**Figure 3.** Haptic computation model for grasp in virtual measurement interface: (a) Finger grasp of the virtual knob and (b) Rotation of virtual knob.

When the collision detection algorithm detects a collision of each virtual finger with the virtual object on the instrument panel, these collision points act as simple virtual walls. Authors assume that the forces act at the grasp points only. Let $F_i$ be the force exerted on objects through each virtual finger. Based on the object shape, size and stiffness the applying forces on objects by the virtual fingers are different.

$$F_i = kx_i$$  \hspace{1cm} (1)

where $i = 1, 2, 3$ is the number of virtual fingers, $k$ is a constant that depends on the material of the object and $x_i$ is the change in position of each virtual finger in the direction of $F_i$.

$$F = [F_1, F_2, F_3]^T$$  \hspace{1cm} (2)

Let $R_i$ be the resultant force exerted on each virtual finger and $R$ be the vector.

$$R = [R_1, R_2, R_3]^T$$  \hspace{1cm} (3)

Force feedback on the grasping scenarios along virtual fingers has two components; the force feedback resisting the grasping motion and a frictional force $(F_r)$, represented by

$$R = uF + F_r$$  \hspace{1cm} (4)

where $u$ is the unit vector along the same direction of forces applied by the virtual fingers. These resultant forces are generated using finger caps and the user gets the haptic feedback of touching virtual knobs in the instrumentation panel interface. The rotation of the virtual knob is dependent on the force exerted on the knob and fingers angular movements. Linear displacement of the fingers in the 3D space is transformed into rotary motion of the knobs in a $y-z$ plane around the $x$-axis. This offers the possibility to obtain a linear translation of movements into rotary movement of knobs. The haptic finger caps can generate haptic feedback, thus enabling control in the rotation of the knob in virtual interface. Consider the resultant rotational movement of fingers around the $x$-axis is from position $P_i$ to $P_j$. The angle of rotation of the knob is given by

$$\theta = \frac{P_j - P_i}{r}$$  \hspace{1cm} (5)

where $P$ is the arc length corresponding to the resultant angular change in position of fingers from position $P_i$ to $P_j$ and $r$ is the radius of the knob.

The angular velocity of the knob is
The resultant torque applied at the center of the knob is given by

$$\tau = F_r \times r$$  \hfill (7)  

where $F_r$ is the resultant frictional force in the sideways.

4. Conclusions

This paper presents a haptics enhanced virtual measurement interface model for the touchless and bi-directional interaction modes in virtual instruments and remote laboratories. The users can interact with the virtual measurement interface, using motion tracking system and get the haptic feedback through wearable haptic finger caps providing the users with force feedback, vibrations and the feel of operating the actual instrument panel.

Acknowledgments

The research described in the paper has been carried out within the Erasmus Mundus LEADER Project.

References

[1] Ma, J., & Nickerson, J. V. (2006). Hands-on, simulated, and remote laboratories: A comparative literature review. *ACM Computing Surveys (CSUR)*, 38(3), 7.

[2] Rapuano, S., & Zoino, F. (2006). A learning management system including laboratory experiments on measurement instrumentation. *IEEE Transactions on instrumentation and measurement*, 55(5), 1757-1766.

[3] Achuthan, K., Sreelatha, K. S., Surendran, S., Diwakar, S., Nedungadi, P., Humphreys, S., ... & Gangadharan, R. (2011, October). The VALUE@ Amrita Virtual Labs Project: Using web technology to provide virtual laboratory access to students. In *Global Humanitarian Technology Conference (GHTC), 2011 IEEE* (pp. 117-121). IEEE.

[4] Andria, G., Baccigalupi, A., Borsic, M., Carbone, P., Daponte, P., De Capua, C., ... & Lanzolla, A. M. L. (2007). Remote Didactic Laboratory “G. Savastano,” The Italian Experience for E-Learning at the Technical Universities in the Field of Electrical and Electronic Measurement: Architecture and Optimization of the Communication Performance Based on Thin Client Technology. *IEEE transactions on instrumentation and measurement*, 56(4), 1124-1134.

[5] Grimaldi, D., & Rapuano, S. (2009). Hardware and software to design virtual laboratory for education in instrumentation and measurement. *Measurement*, 42(4), 485-493.

[6] Daponte, P., De Vito, L., Picariello, F., & Riccio, M. (2014). State of the art and future developments of the Augmented Reality for measurement applications. *Measurement*, 57, 53-70.

[7] Zhou, H., & Hu, H. (2008). Human motion tracking for rehabilitation—A survey. *Biomedical Signal Processing and Control*, 3(1), 1-18.

[8] Daponte, P., De Vito, L., & Sementa, C. (2013, May). A wireless-based home rehabilitation system for monitoring 3d movements. In *Medical Measurements and Applications Proceedings (MeMeA), 2013 IEEE International Symposium on* (pp. 282-287). IEEE.

[9] Srinivasan, M. A., & Basdogan, C. (1997). Haptics in virtual environments: Taxonomy, research status, and challenges. *Computers & Graphics*, 21(4), 393-404.

[10] Jose, J., Unnikrishnan, R., Marshall, D., & Bhavani, R. R. (2016, December). Haptics enhanced multi-tool virtual interfaces for training carpentry skills. In *Robotics and Automation for Humanitarian Applications (RAHA), 2016 International Conference on* (pp. 1-6). IEEE.

[11] Rahul, R., Jose, J., Harish, M. T., & Bhavani, R. R. (2017, June). Design of a novel Three-Finger haptic grasping system: Extending a Single point to Tripod grasp. In *Proceedings of the Advances in Robotics* (p. 39). ACM.

[12] Weichert, F., Bachmann, D., Rudak, B., & Fisseler, D. (2013). Analysis of the accuracy and robustness of the leap motion controller. *Sensors*, 13(5), 6380-6393.

[13] Conti, F., Morris, D., Barbagli, F., & Sewell, C. (2006). CHAI 3D. Online: http://www.chai3d.org.

[14] Baud-Bovy, G., & Soechting, J. F. (2001). Two virtual fingers in the control of the tripod grasp. *Journal of Neurophysiology*, 86(2), 60.