Encountered haptic Augmented Reality interface for remote examination

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ABSTRACT

This paper presents an interaction system for haptic based remote palpation and in general remote examination. In particular the proposed approach combines 3D representation of the remote environment with encountered haptic feedback aiming at high transparency and natureleness of interaction. The paradigm is described as interaction design and system implementation.

Index Terms: I.2.9 [Artificial Intelligence]: Robotics—Operator Interfaces; H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, Augmented and Virtual Realities

1 INTRODUCTION

The increasing number of examinations required in the developed countries is leading to a lack of specialized doctors in many hospitals. The necessity for examinations is pushing doctors and engineers to meet and develop interfaces for remote examinations. The most common examinations are ultrasonography, auscultation and palpation. In these domains examination succeeds when the doctor is provided with a set of feedbacks that include visual and haptic modalities. For this reason we are proposing a 3D user interface for immersive multimodal tele-medicine. Research in tele-medicine has evolved from simple videoconferencing to tele-operation of robots such as in [1, 4] both applied to tele-sonography. In parallel to the tele-medicine domain virtual (VR) and augmented reality (AR) have been employed together with haptics for training purposes. For example PalpSim [3] is an AR system for palpation and needle insertion with haptic feedback using chroma key for showing doctor's hands. With the introduction of real-time 3D cameras it is possible to adopt the AR paradigm not only in training but also in the context of tele-medicine streaming to the doctor the 3D environment. This is specifically important when the interaction requires understanding of spatial depth. The other relevant aspect is the nature of the haptic interaction: the typical paradigm of haptic interaction is tool based, meaning that the user interacts with the remote or virtual scene through a handheld tool. A different approach is pursued by encountered haptics interfaces that present maximum transparency when the hand of the operator is not in contact with a surface. Then when the hand enters in contact with a virtual surface the haptic end-effector is ready to provide feedback to the hand according to the surface properties. The encountered haptic paradigm has been initially applied to simulated knobs or button, and then adapted also to dynamic entities such as [9]. The encountered end-effector is typically a simplification of the effective surface in terms of geometry, such in [5]. This work contributes to the fields in the adoption of an encountered haptic approach for remote palpation combined with an Augmented Reality (AR) paradigm for visual feedback.

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2 DESIGN

The proposed interaction paradigm is based on the idea of providing the doctor with immersiveness while keeping the doctor inside its own environment. For this reason it paradigm is based on the concept of virtual window instead of full immersiveness as provided by a Head Mounted Display (HMD). As in the real examination task the doctor looks down to the patient through a large screen and interacts with the patient scene with the primary hand. Differently from PalpSim [3] the interaction occurs with a real patient environment. In the present configuration the patient geometry is enhanced with a haptic model that is virtual in the case of training, or recorded in the case of rehearsal. This approach will be extended closing the examination loop with a robotic arm. In the palpation scenario the haptic feedback is provided through an encountered haptic approach in which the end-effector is in contact with the hand of the doctor only when the virtual hand is in contact with the remote environment. This approach aims at increasing transparency and natureleness of the interaction.

3 IMPLEMENTATION

On the Patient site a Kinect camera acquires the scene from above and the acquired video is streamed over the network. On the Doctor site a computer acquires the patient stream and uses the point cloud for visualization and for haptic interaction. The same machine tracks the hand of the doctor by means of a Leap Motion camera placed underneath the 3D screen. This device has been chosen thanks to various properties: good speed (100Hz), short range (2 cm), good tracking properties [10], support for tracking of hands and fingers. The resulting hand pose is used for representation of the avatar hand, and for haptic interaction. The information about the contact with the virtual surface and the hand pose are used for computing the haptic feedback. The chosen haptic interface is a 3 Degrees of Freedom (DoF) arm with large workspace and high force [2] with the following configuration: two motors actuate a differential mechanism that provides two rotational joints, whereas a third motor actuates a prismatic joint. The workspace of the chosen device is 300x400x600mm limited by the workspace of the Leap Motion. The proposed interaction is shown in Figure 1 where the haptic interface end-effector is placed below the 3D screen.

3.1 Software

There are two main software elements involved in the architecture: the newly designed Compact Components (CoCo) framework and Matlab Simulink. CoCo is a recently developed component framework for AR/VR and Mixed reality setups that is based on the assumption leaving to the run-time system the management of threading and data exchange policies: the component developer is mainly unaware of the threading model and synchronization. Coco takes inspiration from Orocos's RTT with the support of execution pattern typical of AR/VR systems, and a lighter complexity being implemented in C++11. In particular CoCo aims at supporting the reliable and efficient exchange of data scaling from small data types to point clouds for supporting low latency AR/VR interaction.

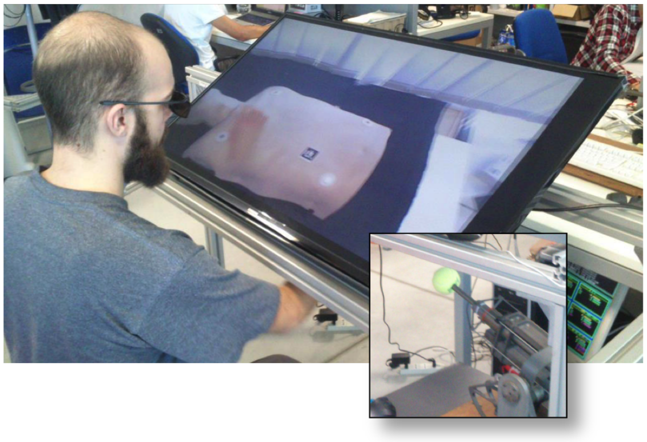

Figure 1: Doctor's site photo with the operator looking at the patient site and manipulating the virtual hand with the hand under the screen. The inset shows the haptic interface below the screen.

3.2 Performance Issues

Due to the nature of the proposed system performance issues arise in the communication between the Patient and Doctor site, and in the devices employed on the Doctor site. On the Patient site the CoCo framework acquires and streams the RGB-D images from a Kinect (30Hz). The color channel is compressed using x264 with the real-time profile that provides about 435kbps with few milliseconds latency. The depth channel is compressed using the xn16 codec from OpenNI that provides state-of-the-art depth compression at 21Mbit/s. The depth information is used both for visual display and for haptic interaction. The point cloud is filtered and augmented with the surface normals. The resulting point cloud is used to build, at 30Hz, a KD-Tree that allows to query the nearest point and normal to the doctor's hand, at 100Hz. The KD-Tree approach is good because it is performed per frame, and for this reason is subject to the Kinect noise ([7]), at least for Kinect V1. Alternative solutions are based on the creation of a surface model based on the point cloud data [8], that could be extended to deformable haptic rendering [6]. On the Doctor site the system requires to combine the RGB-D stream from the Patient site with the interactive part that is based on Leap Motion for hand tracking (100Hz) and the Haptic interface (2kHz). The components and their connection on the Doctor site are shown in Figure 2. The Leap Motion has an input latency of about 16 ms, and it is sufficient because it is used only for providing the haptic interface the hand pose before the contact with the surface.

4 Interaction Evaluation Plan

In the current setup there is no palpation sensor or robot on the Patient site and only the RGB-D channel is acquired. The initial evaluation of the interaction paradigm is based on the creation of a virtual stiffness model of the remote environment. The virtual stiffness model combines a single surface stiffness value with the embedding of a virtual tumor at a given depth with the proposed task of identifying the location of the virtual tumor while exploring the remote body. The task currently proposed to subjects is to identify the virtual tumor exploring the interface.

5 Conclusions

In this short paper we have presented the foundations of an interaction paradigm that combines encountered haptics with AR display. Two aspects are being investigated: the first is the evaluation of the approach in terms of precision of the exploration for the identification of abnormal tissues in the virtual model. The second is the improvements of bandwidth requirements mainly for the depth data. These requirements can be reduced by taking advantage of the two uses of the depth information: for the visual display a lossy approach can be introduced taking into account depth perception limitations. For the haptic interaction several techniques can be employed such as region of interest around the end-effector, or local model computed on the patient site. Finally the proposed system can be adapted to ultrasonography by using a probe shaped end-effector that, in this case is hand-held and is based on the traditional haptic rendering scheme.

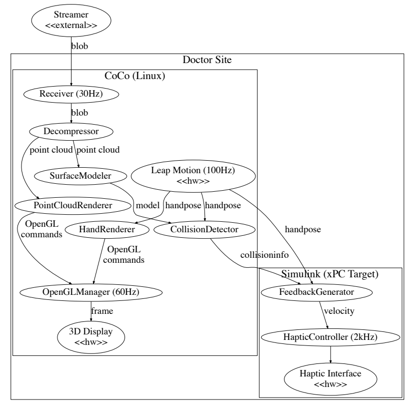

Figure 2: Connections between the components on the Doctor's site

Acknowledgements

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References

[1] P. Arbeille et al. Use of a robotic arm to perform remote abdominal telesonography. *American Journal of Roentgenology*, 188(4):W317–W322, 2007.

[2] M. Bergamasco, C. A. Avizzano, A. Frisoli, E. Ruffaldi, and S. Marcheschi. Design and validation of a complete haptic system for manipulative tasks. *Advanced Robotics*, 20(3):367–389, 2006.

[3] T. R. Coles et al. Integrating haptics with augmented reality in a femoral palpation and needle insertion training simulation. *Haptics, IEEE Transactions on*, 4(3):199–209, 2011.

[4] C. Delgorge, F. Courrèges, et al. A tele-operated mobile ultrasound scanner using a light-weight robot. *Information Technology in Biomedicine, IEEE Transactions on*, 9(1):50–58, 2005.

[5] S. P. Diez, E. B. Vander Poorten, G. Borghesan, and D. Reynaerts. Towards palpation in virtual reality by an encountered-type haptic screen. In *Haptics: Neuroscience, Devices, Modeling, and Applications*, pages 257–265. Springer, 2014.

[6] A. Frisoli, L. Borelli, C. Stasi, M. Bellini, C. Bianchi, E. Ruffaldi, et al. Simulation of real-time deformable soft tissues for computer assisted surgery. *The International Journal of Medical Robotics and Computer Assisted Surgery*, 1(1):107–113, 2004.

[7] A. Leeper, S. Chan, and K. Salisbury. Point clouds can be represented as implicit surfaces for constraint-based haptic rendering. In *ICRA*, pages 5000–5005. IEEE, 2012.

[8] R. A. Newcombe et al. Kinectfusion: Real-time dense surface mapping and tracking. In *ISMAR*, pages 127–136. IEEE, 2011.

[9] E. Ruffaldi, P. Tripicchio, C. A. Avizzano, and M. Bergamasco. Haptic rendering of juggling with encountered type interfaces. *Presence: Teleoperators and Virtual Environments*, 20(5):480–501, 2011.

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