A methodological tool for computer-assisted surgery interface design: its application to computer-assisted pericardial puncture.

Emmanuel Dubois ([1, 2]), Laurence Nigay ([2]), Jocelyne Troccaz ([1]),
Lionel Carrat ([1]), Olivier Chavanon ([3])

([1]) TIMC-IMAG / GMCAO
School of Medicine, IAB
Domaine de la Merci
F - 38706 La Tronche Cedex.

([2]) CLIPS-IMAG / IIHM
Rue de la bibliothèque
BP 53
F - 38041 Grenoble Cedex9.

([3]) Cardiac Surgery
Department,
Grenoble University Hospital,
F - 38700 La Tronche.

[Emmanuel.Dubois, Laurence.Nigay, Jocelyne.Troccaz]@imag.fr

Abstract

Computer Assisted Surgery systems are becoming more and more prevalent. Design processes currently used, pay only a small attention to the surgeon's interaction. To address this lack in design, we propose the OP-a-S notation: OP-a-S modeling of a system adopts an interaction-centered point of view and highlights the links between the real world and the virtual world. Based on an OP-a-S modeling, predictive usability analysis can be performed by considering the ergonomic property. We illustrate our method on the retro-design of a computer assisted surgical application, CASPER.

1. Introduction

Very few attention has been paid to interface design in CAS although we think it is a very important key to success and clinical acceptation. This work is based on our 15 years experience of Computer-assisted surgery (CAS) system development and evaluation. We launched, four years ago, a cooperative work based on the following partnership: a Computer Aided Medical Intervention group, a group specialized in man-machine interface design and the university hospital. This cooperation resulted in the development of methodological tools for CAS interface design and evaluation. These principles were used to evaluate a particular clinical application from the interaction point of view and to propose new developments which are in progress.

This work describes a new concept for man-machine interface design in CAS and makes uses of a clinical application for which a first release of computer-assistance exists and is entering clinical validation.

2. Our CAS Application: CASPER

A pericardial puncture consists in the manual insertion of a needle near the heart to remove a build up of a pathological fluid in the pericardium. In order to face some dangers of this surgery, mainly organs effraction, we have developed a computer assisted system that provides helpful guidance information to the surgeon performing the puncture. The first version consisted in the combined use of both an infrared based localizer tracking the patient, the needle and the imaging sensor (ultrasound probe) and a computer screen used to display the guidance information (planned and current trajectories). This system called CASPER, Computer Assisted PERicardial puncture is being validated at the Grenoble University Hospital [1].

From previous animal experiments, several drawbacks concerning the user interaction were identified. For example, the surgeon has to look at the patient but also at the screen to get the guidance information; he has to push the needle to cross several layers of tissues whilst controlling the insertion depth which is the critical parameter. An additional analysis based on our OP-a-S notation [2] has helped us to identify and explain other problems linked to the interaction. The next paragraph highlights two of them and briefly present the solutions we developed to overcome them.

3. Results

Our OP-a-S notation is a methodological tool that decomposes an interactive system into four kinds of components: user(s) (P), computer system (S), real objects (Ot and Oo) and adapters (IA and OA) that aim at transferring information from the real to the virtual (or electronic) world. Additionally, OP-a-S relations, i.e. exchange of information between OP-a-S components, enable the identification of the several parts of the interaction supported by the system. A diagrammatic representation of the system results from an OP-a-S analysis. Examples may be found in [2] and [3]. On the basis of a diagrammatic modeling, designers are then able to evaluate ergonomic properties to characterize the interaction. Next paragraphs illustrate the process on CASPER.

3.1. Cognitive consistency

With the OP-a-S modeling of CASPER shown in Figure 1, we were able to methodologically explain why the surgeon had some difficulties to interpret the guidance information displayed by the system. During the intervention, the surgeon manipulates a surgical needle in a 3D environment. But, the guidance information provided is represented with a 2D model. This consideration is an instance of the *cognitive consistency* ergonomic property that OP-a-S helps to identify: information caught by the user must be preferably expressed in a common "language". Our solution to this has been to develop a 3D representation of the planned and executed trajectories, in order to reduce the cognitive process of data interpretation during the intervention. An ultrasound image on which is superimposed a 3D cone, that represents the planned trajectory, constitutes the scene displayed to the surgeon. A representation of the needle is also perceivable. Experiments are in progress with psychologists to select the best reference system to display fully understandable information.

3.2. Perceptual consistency

OP-a-S has also highlighted the difficulty for the surgeon to catch alternatively information on the screen and in the surgical field. This difficulty is linked to the more generic property of *perceptual consistency*. Perceptual consistency is expressed in OP-a-S modeling by a set of relations linked to the surgeon, carrying information of importance but perceivable at different locations. In CASPER, this is clearly the case with the trajectory information: the real one is perceived on top of the patient, while the "virtual" one is displayed on the monitor. Our solution to this second outcome has consisted in using a see-through Head-Mounted Display (HMD) in which guidance information are displayed and through which the surgeon can directly look at the position and orientation of the real puncture needle. In this case, the point of view of the information is the surgeon's point of view. Surgeon's head tracking is realized thanks a rigid-body mounted on top of the HMD. To be able to display the virtual information merged with the real one, a calibration of the HMD is required.

The calibration process we have implemented is composed of two steps. The first step consists in determining the position of each corner of both screens of the HMD. For each screen, averaging the coordinates of the four points provides a position that approximately correspond to the position of the eye of the surgeon. These positions are then used to generate the left and right images needed to display stereoscopic 3D information in the HMD. The second step permits the definition of the gaze direction. The surgeon is asked to look straight forward and to align the tip of a pointer with an OpenGL sphere displayed in the middle of the screen. Later, during the execution, this gaze direction is used to set the orientation of the OpenGL cameras. The Figure 1 is a picture taken through the HMD screens on which you can see that real and virtual data are aligned.

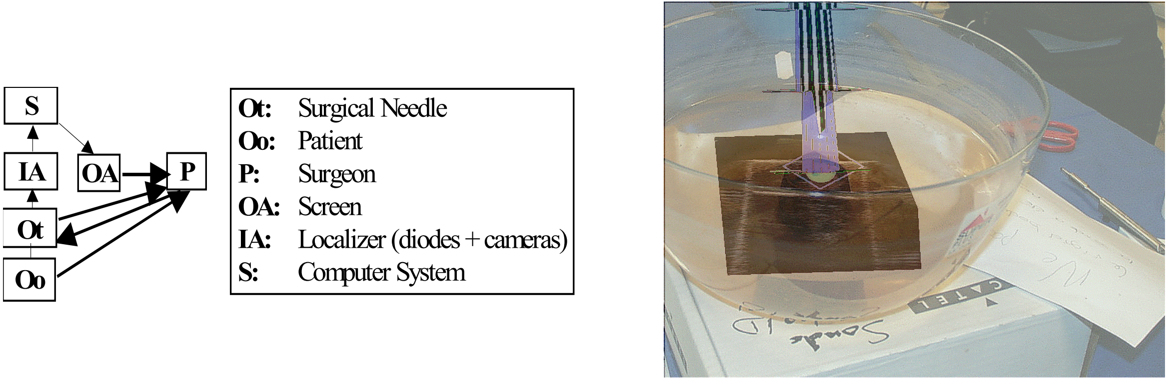

Figure 1: OP-a-S modeling of CASPER (Left) and
view of the trajectory and the reality through the Head-Mounted Display (Right).

3.3.Limitations

Currently the matching error between real and virtual data is far too big (up to 2 cm). This is clearly unacceptable in regard to traditional CAS applications. Most of this imprecision is due to a low accuracy of the HMD-calibration phase. However, work is in course to increase the precision of the calibration. Other methods will be implemented and tested.

Another limitation is directly linked to the actual state of see-through technologies. None of the devices we tried, permitted to modify the focus distance of the HMD. This means that the surgeon have to focus at 4 meters in front of him to get a real 3D stereoscopic information; the patient on which the surgeon is working, is never so far away from him. Nevertheless, we are quite sure that such devices will soon be usable.

4. Conclusion

Our methodological approach for the analysis of an existing system has revealed a set of deficiencies in the induced interaction. Future works will explore other ergonomic properties. Moreover, our approach has already proved to be valuable for the design of new interaction techniques, better suited to the surgeon's activity. Additionally, it has led us to the investigation of the optical see-through device domain which allows the surgeon to stay in direct contact with the real operating theatre. In regard to traditional VR or Video-See-Through techniques, the accuracy is not yet satisfying enough. Further work is still necessary to make it clinically usable.

5. References

[1] Chavanon, O., Barbe, C., Troccaz, J., Carrat, L., Ribuot, C., Blin, D., Accurate guidance for percutaneous access to a specific target in soft tissues, Journal of Laparoendoscopic and Advanced Surgical techniques, Vol. 9, No 3, (1999), p. 259-266.

[2] Dubois, E., Nigay, L., Troccaz, J., Chavanon, O., Carrat, L., Classification space for augmented surgery, an augmented reality case study, Conference Proceedings of Interact'99, Edinburgh - UK, (1999), p. 353-359.

[3] Dubois, E., Nigay, L., Augmented Reality: Which Augmentation for Which Reality ?, Conference Proceedings of DARE'2000, ACM, Elsinore - Danemark, (2000), p.165-167.