The Mini-Screen: an Innovative Device for Computer Assisted Surgery Systems

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Abstract. In this paper we focus on the design of Computer Assisted Surgery (CAS) systems and more generally Augmented Reality (AR) systems that assist a user in performing a task on a physical object. Digital information or new actions are defined by the AR system to facilitate or to enrich the natural way the user would interact with the real environment. We focus on the outputs of such systems, so that additional digital information is smoothly integrated with the real environment of the user, by considering an innovative device for displaying guidance information: the mini-screen. We first motivate the choice of the mini-screen based on the ergonomic property of perceptual continuity and then present a design space useful to create interaction techniques based on a mini-screen. Two versions of a Computer ASsisted PERicardial (CASPER) puncture application, as well as a computer assisted renal puncture application, developed in our teams, are used to illustrate the discussion.

1. Introduction

The main objective of Computer Assisted Surgery (CAS) systems is to help a surgeon in defining and executing an optimal surgical strategy based on a variety of multi-modal data inputs. The key point of a CAS system is to "augment" the physical world of the surgeon: the operating theater, the patient, the surgical tools etc., by providing pre-operative information during the surgery. CAS systems are now entering many surgical specialties and such systems can take on the most varied forms. Although many CAS systems have been developed and provide real clinical improvements, their design is ad-hoc and principally driven by technologies.

In this context and as part of a multidisciplinary project that involves the (Human-Computer Interaction) HCI and the CAS research groups of the University of Grenoble, our research aims at providing elements useful for the design of usable CAS systems by focusing on the interaction between the user and the CAS system. In this paper we concentrate on interaction techniques based on a LCD mini-screen as an innovative device for displaying guidance information. In the next section, we motivate our work by presenting the existing solutions and the ergonomic issue they raise. We then present our approach based on the mini-screen: we describe a design space useful to create interaction techniques based on a mini-screen. In the final section, we present our first results drawn from our design space, namely the developed interaction techniques based on the mini-screen.

2. Ergonomic Problem: Perceptual Discontinuity

In CAS systems, Augmented Reality (AR) interaction techniques are based on the fusion of two worlds: the digital world (e.g., MRI, scan images, computed trajectory) and the real world (e.g., the patient's body, a needle). However, there is no consensus on a definition of AR techniques highlighting the problem of delimitating the frontier between the two worlds [2] [7]. As we defined in [2], the adapters are devices in charge of the fusion between the two worlds. We distinguish input adapters (inputs to the system) from output adapters (outputs from the system). The input adapters, such as an electro-magnetic localizer or a video camera, capture information from the real world that is transferred to the computing system, while the output adapters, such as a projector or a Head Mounted Display (HMD), convey information from the digital world to the real world. The results of the fusion thanks to the output adapters are either perceived in the digital world (e.g., a 3D brain model and a video of a patient merged on a screen [5]) or in the real one (e.g., a 3D model projected onto the patient's body [1] [4]). For example, using CASPER, a computer-assisted pericardial puncture application, the surgeon must look at the screen to get the guidance information, as shown in Figure 1.

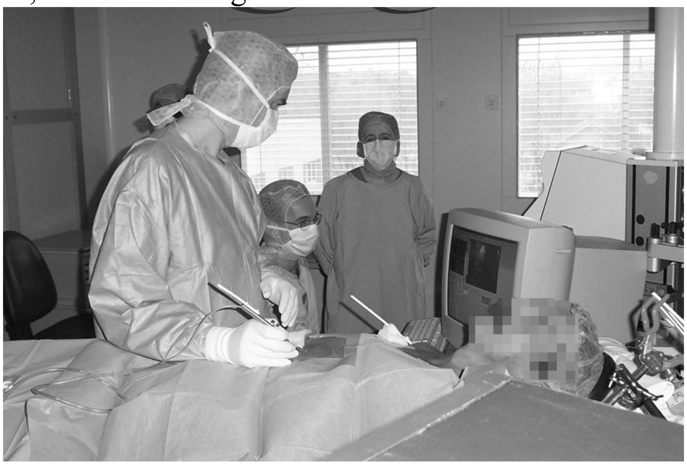

Figure 1. Our CASPER application in use.

CASPER assists the surgeon by providing in real time the position of the puncture needle according to the planned strategy. On screen, the current position and orientation of the physical needle are represented by two mobile crosses, while a stationary cross represents the planned trajectory. When the three crosses are superimposed the executed trajectory corresponds to the planned one. A graphic gauge translates the current depth of the performed trajectory according to the pre-planned one. Ergonomic evaluations of CASPER highlighted that the required shift between looking at the graphics on screen (i.e., the crosses and the gauge) and looking at the operating field (i.e., the patient and the needle) was disturbing to the surgeon. Indeed keeping the trajectory aligned and controlling the depth of the needle by referring to the visual display was found difficult to do. The interactive system does not respect the ergonomic property of perceptual continuity. In [2] we define the perceptual continuity by having no perceptual gap between the real and the digital worlds: the user can perceive all the relevant information for her/his task within the same perceptual environment (e.g., the same visual environment).

To address this problem we developed a new version of CASPER using a different output adapter: a see-through Head Mounted Display (HMD). The see-through HMD eliminates the problem of perceptual/visual discontinuity: the surgeon can see the operating field (i.e., patient and needle) through the HMD as well as the guidance data in the same location. The fusion of the digital and real worlds is then perceivable in the real world and the needle is no longer represented: only the planned trajectory as well as the depth control are displayed on the HMD. But display latency problems that can only be resolved by technical improvements as well as the HMD weight on the surgeon's head led us to set aside that second version.

3. Solution and Method

Different strategies for designing AR interaction techniques are defined in [6]. The target of augmentation can be the user (i.e., the surgeon), the environment (i.e., the operating theater) or the physical objects (i.e., the needle). Having already explored the possibility of augmenting the user (HMD), our solution consists of augmenting the environment or the needle. In this context, several possibilities for presenting the information from the system to the surgeon exist: some studies explore the usage of non-visual interaction techniques such as touch [9] or sound, while others explore the combination of such techniques (output multimodal interfaces). Our work focuses on visual information. Instead of techniques based on a projector such as in [1], we use mini-screens in order to augment the operating field or the needle with display capabilities.

While a mini-screen is an innovative interaction device for CAS systems, such a small device is being increasingly studied in the HCI domain and leads to the definition of new interaction paradigms like the Embodied User Interfaces defined in [3]. From those techniques, we have established a design space to characterize interaction techniques based on a mini-screen. Beyond standard technical features of a LCD screen as size, weight and resolution, our design space is based on more interaction-centered characteristics. Indeed, as shown in Figure 2, our framework is comprised of two orthogonal axes namely (i) Characterization of the displayed information (ii) Characterization of the usage of the device itself.

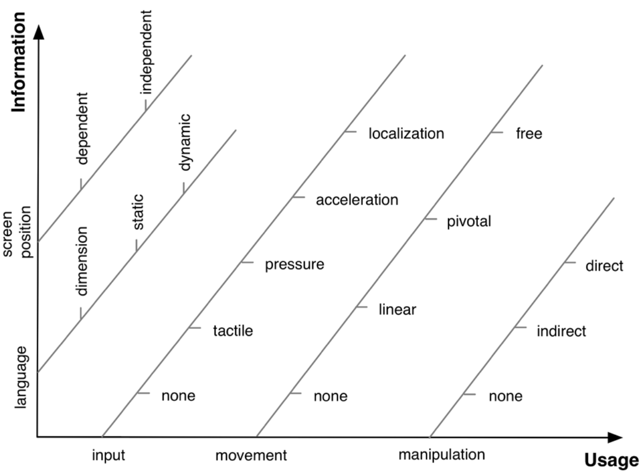

Figure 2. Our mini-screen design space:
A 2-D space to characterize interaction techniques based on a mini-screen.

The first dimension, namely "Information", is used to describe how the device conveys information to the user. First we consider the form of the displayed information ("interaction language") that we characterize in terms of the dimension of the displayed data (1D, 2D, etc.) and of its dynamic capabilities. Secondly we consider if the displayed data is dependent on the screen's position or not. For instance, if the screen is tied to a tool handled by the surgeon, and it conveys guidance information, then the output data may be dependent on the screen's position: the displayed data change according to the screen's positions over the patient's body. Other kinds of data (e.g., blood pressure, body temperature) may be independent on the screen's position in that same case.

The second dimension, namely “Usage”, characterizes the usage of the mini-screen itself by the user. Along this dimension, we identify three sets of characteristics let the designer answer three questions.

- Does the mini-screen convey information to the computer system and how (Input dimension) ?
- Does the mini-screen move during the operation and how (Movement dimension) ?
- Is the mini-screen manipulated by the surgeon during the operation and how (Manipulation dimension) ?

4. Results: Developed Techniques Based on a Mini-Screen

4.1 Developed Interaction Tec hniques

We developed two techniques based on a mini-screen that have been integrated in a computer assisted renal puncture application. According to our design space, both techniques have different characteristics along the dimension “Usage” but share the same characteristics along the dimension “Information”.

For both interaction techniques, the surgeon can see on the mini-screen either a pre-operative scan image of the patient’s pelvis along with the planned trajectory as well as the current position of the needle, or the current position of the needle according to the planned trajectory as three 2D colored-crosses and a gauge (same representation as the one in the first version of CASPER). In Table 1 we summarize the characteristics of the two designed techniques for the dimension “Information”. The surgeon can switch between the two views by a pedal command. We plan to add speech recognition to let the surgeon switch via voice commands. In addition the mini-screen size influences the displayed information. For the developed techniques, we used a 3.5 inches LCD screen. We are currently studying a new representation of the guidance information, without the graphical gauge: for example the depth information can be encoded by the size of the lines of the three crosses in order to save pixels on the mini-screen (theory of graphical excellence [8]).

Table 1. Characterization of the two interaction techniques: Design choices for the dimension “Information”.

Information	Language	Screen position
	(2D, dynamic) or (3D, dynamic)	independent

Both techniques differ by their characteristics along the dimension “Usage”. For the first interaction technique, the mini-screen is positioned near the operating field. This first technique is solely a spatial improvement as compared with the first version of CASPER. We take advantage of the mini-screen small size which enables it to be closer to the operating field than a standard computer display. The mini-screen is stationary while the surgeon performs the puncture. Based on our design space, Table 2 characterizes the designed technique along the dimension “Usage”.

Table 2. Characterization of the first technique: Design choices for the dimension “Usage”.

Usage	Input	Movement	Manipulation
	none	none	none

For the second technique, the mini-screen is tied with the puncture needle, acting like a viewfinder. Such a difference in comparison with the first technique is captured within our design space by the characteristic “manipulation” that is equal to indirect for this technique. As for the previous technique and although the screen is tied with the needle, the displayed information is not dependent on the position of the screen. As a consequence the screen is not localized (Input = none). The design choices for this second technique are listed in Table 3.

Table 3. Characterization of the second technique: Design choices for the dimension "Usage".

	Input	Movement	Manipulation
Usage	none	none	indirect

So far we have developed two interaction techniques and we have characterized them within our design space. We need to develop other techniques based on different characteristics and to experimentally compare them for evaluating the ergonomic values of our characteristics.

4.2 Display Strategies: Standard Screen / Mini-Screen

While designing the techniques on mini-screen, we faced the problem of extending existing applications relying on a standard screen. We therefore studied the relationships that can be maintained between the information displayed on the standard screen and the one displayed on the mini-screen. We have identified three main display strategies.

The three strategies are presented in Figure 3. On the left part of Figure 3, the strategies (a) and (b) are based on the replication of information. On the right part of Figure 3, the strategy (c) is based on the distribution of information. The strategy (a) corresponds to the most generic approach. It consists of a raw copy of a part of the big screen, pixel per pixel. That strategy works without knowing what is displayed and is therefore independent of the surgical application. For defining what is displayed on the mini-screen, the user places one or several transparent windows on screen. What is visible through a transparent window is also visible on the mini-screen. The user can freely move and resize the transparent windows. Only one transparent window has the focus at a time, so only the content of that window is copied to the mini-screen. The switch between transparent windows is achieved by a pedal or voice commands. The drawback of that strategy is that the user has to place and size all the transparent windows. The strategy (b) also relies on replication but is application-dependent. It is a replication of a specific workspace of the application. The workspaces that can be replicated must be defined by the designer. At last, in the strategy (c), a specific workspace is displayed on the mini-screen and only on it. There is no redundancy between the standard screen and the mini-screen.

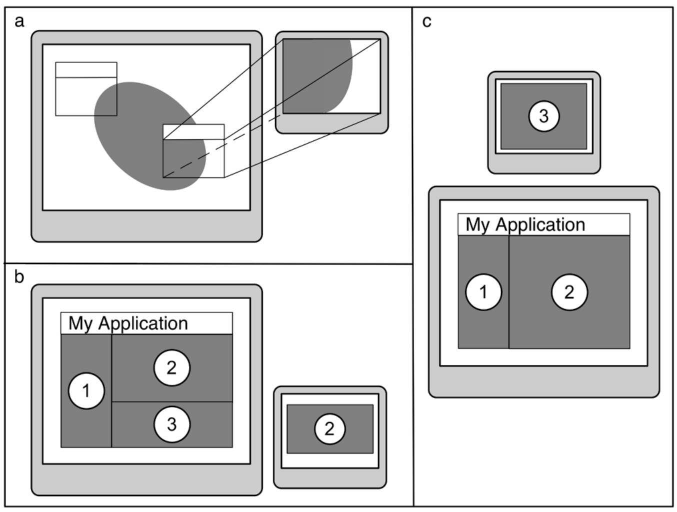

Figure 3. Three display strategies for two screens, a standard screen and a mini-screen.

For the moment, only the strategy (a) is developed and is going to be tested with our second technique (i.e., the mini-screen tied to the needle). The two other strategies must be developed.

5. On-Going and Future Work

As on-going work, in parallel to the software development of new techniques based on the characteristics of our design space, we need to experimentally test and compare our design solutions. Some experiments have already been made for the first technique, the mini-screen being placed near the patient's body. Such a solution clearly minimizes the perceptual discontinuity. Nevertheless we observed another ergonomic problem, related to the interpretation by the surgeon of the displayed information, namely cognitive discontinuity [2]. Indeed when the surgeon moves the physical needle, that movement has to be visualized in a coherent way on the mini-screen. Therefore, the mini-screen position according to the patient's body is important for interaction. The new solution must be developed accordingly and then experimentally tested by quantitatively comparing the technique with the first version of CASPER that relies on a standard screen.

As future work, we need to enrich our design space by considering technical issues such as connectivity and display resolution of the mini-screen: such issues also impact on the usability of the designed interaction techniques.

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7. References

[1] Blackwell, M., Nikou, C., DiGiola, A.M., and Kanade, T. An Image Overlay System for Medical Data Visualization. Proceedings of MICCAI'98, (1998), LNCS 1496, Springer-Verlag, 232-240.
[2] Dubois, E., Nigay, L., Troccaz, J. Consistency in Augmented Reality Systems. Proceedings of EHCI'01, (2001), LNCS 2254, Springer-Verlag, 117-130.
[3] Fishkin, K.P., Moran, T.P., Harrison, B.L. Embodied User Interfaces: Towards Invisible User Interfaces. Proceedings of EHCI'98, (1998), Kluwer Academic Publ., 1-18.
[4] Glossop, N., Wedlake, C., Moore, J. et al. Laser Projection Augmented Reality System for Computer Assisted Surgery. Proceedings of MICCAI'03, (2003), LNCS 2879, Springer-Verlag, 239-246.
[5] Grimson, W.E.L., Ettinger, G.J., White, S.J. et al. An Automatic Registration Method for Frameless Stereotaxy, Image Guided Surgery, and Enhanced Reality Visualization. in IEEE Transactions on Medical Imaging, 15(2), (1996), 129-140.
[6] Mackay, W. Augmented Reality: linking real and virtual worlds. Proceedings of ACM AVI'98, (1998), ACM Press.
[7] Milgram, P. A taxonomy of mixed reality visual displays. in IEICE Transactions on Information Systems, (1994), E77-D(12): 1321-1329.
[8] Tufte E. The Visual Display of Quantitative Information. Graphics Press Cheshire, CT, USA, 1983, ISBN:0-9613921-0-X.
[9] Vazquez-BuenosAires J.O., Payan Y. and Demongeot J. Evaluation of a Lingual Interface as a Passive Surgical Guiding System. Proceedings of Surgetica'2002, (2002), Sauramps medical, 232-237.