Mixed Systems: Combining Physical and Digital Worlds

Laurence Nigay[1], Emmanuel Dubois[3]“, Philippe Renevier[1],
Laurence Pasqualetti[4], Jocelyne Troccaz[2]

1 Universit de Grenoble
CLIPS-IMAG BP 53
38041 Grenoble cedex 9 FRANCE
(laurence.nigay,
philippe.renevier)@imag.fr

2 Universit de Grenoble
TIMC-IMAG, Faculty of Medicine
38706 La Tronche cedex FRANCE
jocelyne.troccaz@imag.fr

3 Universit de Toulouse
IRIT, 118 route de Narbonne
31062 Toulouse cedex 4 FRANCE
emmanuel.dubois@irit.fr

4 FT R&D DIH/UCE
38-40 rue G. Leclerc
92794 Issy-les-Moulineaux FRANCE
laurence.pasqualetti@francetelecom.fr

Abstract

The growing interest of designers for mixed interactive systems is due to the dual need of users to both benefit from computers and stay in contact with the physical world. Based on two intrinsic characteristics of mixed interactive systems, target of the task and nature of augmentation, we identify four classes of systems. We then refine this taxonomy by studying the fluidity and the links between the physical and digital worlds.

1 Introduction

In recent years, mixed interactive systems have been the subject of growing interest. The growing interest of designers for this paradigm is due to the dual need of users to both benefit from computers and interact with the real world. A first attempt to satisfy this requirement consists of augmenting the real world with computerized information: This is the rationale for Augmented Reality (AR). Another approach consists of making the interaction with the computer more realistic. Interaction with the computer is augmented by objects and actions in the physical world. Examples involve input modalities (Nigay & Coutaz, 1995) based on real objects, such as Fitzmaurice et al's bricks (Fitzmaurice, Ishii & Buxton, 1995) or Ishii & Ulmer's phicons (Ishii & Ulmer, 1997). Ishii has described this interaction paradigm as the Tangible User Interface.

This paper presents our analysis of mixed interactive systems that combine the real and digital worlds. We clarify the notion of mixed interactive systems by defining four classes of systems. After presenting and illustrating our taxonomy, we then refine its classes of mixed systems by studying the fluidity and the links between the real and digital worlds. The discussion is illustrated using three systems developed at the University of Grenoble, whose main features are presented in the next section.

2 Illustrative examples

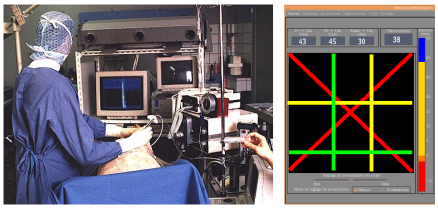
The first system, Mirror Pixel, enables a user to modify a digital drawing displayed on screen using a pen and a sheet of paper. To do so, as shown in Figure 1, a camera points to the sheet of paper used by the user to draw or write. On screen (Figure 1), the user can see the current drawing to be modified as well as her/hand and the pen. Displaying the hand and the tool superimposed on the drawing enables the user to precisely modify the drawing. The user

“ This work has been done while E. Dubois was a PhD student at the University of Grenoble in the laboratories CLIPS-IMAG and TIMC-IMAG.

focuses on the screen and does not look at her/his hand. The system has been developed by C. Lachenal and is described in (Vernier, Lachenal, Nigay & Coutaz, 1999).

The second system, CASPER (Computer ASsisted PERicardial puncture) (Chavanon et al., 1997), is a system that we developed for computer assistance in pericardial punctures. The clinical problem is to remove a build up of fluid (water, blood) in the region around the heart (pericardium), the effect of which is to compress the heart. This procedure involves minimal access to the chest. CASPER allows pre-operative acquisition and modeling of a 3D stable region in the pericardial effusion from which a target is selected and a safe trajectory is planned. During the surgery, guidance is achieved through use of an optical localizer that tracks the needle position. Figure 2-a shows the application in use during the intervention (guidance step). The system transforms the signal from the needle localizer into a graphical representation of the position and the orientation of the needle. In the same window on screen, presented in Figure 2-b, the current position and orientation of the needle are represented by two mobile crosses, while one stationary cross represents the planned trajectory. When the three crosses are superimposed the executed trajectory corresponds to the planned one.

Figure 1: Mirror Pixel system



(a) (b)

Figure 2: CASPER system

The third example, MAGIC (Mobile, Augmented reality, Group Interaction, in Context), is a generic hardware and software mobile platform for collaborative Augmented Reality. We first describe the hardware and then the software responsible for the fusion of the two worlds, the physical and digital worlds.

The hardware platform is an assembly of commercial pieces of hardware. We use a Fujitsu Stylistic 3400 pen computer. This pen computer is a PC, with a tactile screen having the size of a A4 sheet of paper. Its weight is 1,5 kg. Moreover, it has a video exit allowing the dual display, to which we connect a semi-transparent Head-Mounted Display (HMD). A camera is fixed between the two screens of the HMD (between the two eyes). The hardware platform also contains a magnetometer, which determines the orientation of the camera as well as a GPS which locates the mobile user. For sharing data amongst users and communication between users, a WaveLan network was added.

Based on the hardware platform described above, we designed and developed generic interaction techniques that enable the users to perform actions that involve both physical and digital objects. In order to smoothly combine the digital and the real, we create a gateway between the two worlds. This gateway (Figure 3) has a representation both in the digital world (displayed on the screen of the pen computer) and in the real environment (displayed on the HMD).

- Information from the physical environment is transferred to the digital world thanks to the camera carried by the user. The camera is positioned so that it corresponds to what the user is seeing, through the HMD. The real environment captured by the camera is displayed in the gateway window on the pen computer screen. Based on the gateway window, we allow the user to select or click on the real environment. The interaction technique is called "Clickable Reality".
- Information from the digital world is transferred to the real environment, via the gateway window, thanks to the HMD. For example the MAGIC user can drag a drawing or a picture stored in the database to the gateway window. The picture will automatically be displayed on the HMD on top of the physical environment. As shown in Figure 3, moving the picture using

the stylus on the screen will move the picture on top of the physical environment. This is for example used by archaeologists in order to compare objects, for instance a physical object with a digital object from the database.

- Another technique, "Augmented Field", consists of superimposing an image of an object in its original real context (in the real world), thanks to the semi-transparent HMD. Because a picture is stored along with the location of the object, we can restore the picture in its original real context (2D location).

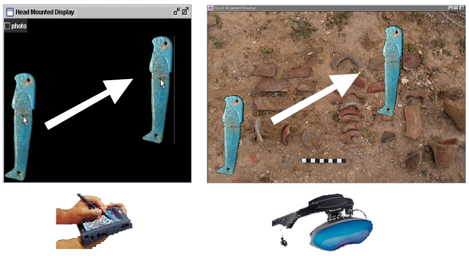


Figure 3: Gateway between the two worlds: Comparing a physical object with a digital one

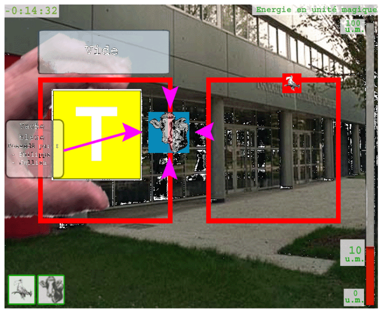


Figure 4: TROC: a mobile player is collecting a digital object.

Two systems have been developed using the MAGIC platform. The first one is dedicated to archaeological prospecting activities. It enables the archaeologists to perform ground analysis of the site and to communicate with other mobile archaeologists working in the site as well as with distant archaeologists. The complete software and its architecture are detailed in (Renevier & Nigay 2001). The second system based on the MAGIC platform is called TROC and is a collaborative game based on bartering. The mobile players must collect a set of digital objects such as a "blue cow" using physical cubes. Figure 4 presents a view through the HMD while a player is collecting a digital object using a physical cube.

3 Taxonomy of mixed interactive systems

We identify four classes of interactive mixed systems. We have defined these classes of systems on the basis of their intrinsic characteristics identified by first studying Computer Assisted Medical Interventions (Dubois et al.,1999). We first distinguish two classes of systems based on the two possible targets of the user s task, namely, the real world and the computer:

- In Augmented Reality systems (AR), interaction with the real world is augmented by the computer.
- In Augmented Virtuality systems (AV), interaction with the computer is augmented by objects and actions in the real world.

In Table 1, we locate these two classes along with graphical user interface (GUI) and purely physical tasks. Using CASPER and MAGIC, interaction with the real world is augmented by the computer. For example in both cases, the physical world is enriched by digital objects. They belong to the Augmented Reality class. On the other hand the mirror pixel system enables a user to modify a digital picture by drawing with a pen on a sheet of paper. The system is therefore an example of an Augmented Virtuality system.

Table 1: Four types of interaction

	Interaction using physical objects	*Interaction using digital object*
Task in the physical world	Physical interaction	**Augmented Reality Mixed Interaction (1)**
Task in the digital world	**Augmented Virtuality Mixed Interaction (2)**	Graphical User Interface

Then we consider the augmentation provided by the system. It can take on a number of different forms. If we refer to the Theory of Action (Norman 1986), augmentation can be dedicated to the execution phase (action) and/or to the evaluation phase (perception). For example the mirror pixel system augments the execution phase by defining new modalities involving real objects (a pen and a sheet of paper). On the other hand, augmented evaluation in the real world consists for example of superimposing digital objects on physical objects as in MAGIC.
To sum up, the *target of the task* (AR and AV) and *the nature of augmentation* constitute two orthogonal classification axes that further lead us to define four classes of mixed systems. The four classes are fully described and illustrated in (Dubois et al.,1999).

The above four classes of mixed interactive systems are not sufficient to fully capture the differences in terms of interaction between mixed systems. For example CASPER and MAGIC belong to the same class while the interaction techniques they offer are quite different. Due to the various sources of information from the computer as well as from the physical world, we need to additionally consider the perceptual and cognitive continuity that increases the fluidity between the two worlds:

> *Definition*: Perceptual continuity (Dubois, Nigay & Troccaz 2002) is verified if the user directly and smoothly perceives the different representations of a given concept. Cognitive continuity is verified if the cognitive processes that are involved in the interpretation of the different perceived representations lead to a unique interpretation of the concept resulting from the combination of the interpreted perceived representations.

When assessing continuity, the perceptual environments involved in the interaction must be identified as well as the different representations of involved objects. For example, in CASPER the surgeon has to look both at the real needle to avoid any distortion of the tool and at the screen to get the guiding information (represented as a stationary cross) according to the virtual needle (represented as two mobile crosses). Keeping the trajectory aligned and controlling the depth of the needle by referring to the visual display was difficult to implement. The required switch between the screen and the operating field was disturbing to the surgeon. Perceptual continuity is not verified here. Likewise, at the cognitive level, two cognitive processes are involved and are very different. Indeed, the representation of the needle on screen (the two mobile crosses) is bi-dimensional, while the position of the real needle is of course three-dimensional. The matching between the real object and its representation is far from direct. Cognitive continuity is transgressed. On the other hand, using MAGIC, the user is looking at the physical environment that is augmented by digital objects. There is only one perceptual environment. Nevertheless the digital objects are pictures, bi-dimensional objects, while the physical objects are three-dimensional. As a conclusion, the perceptual continuity is verified but at the cognitive level, the digital objects are not completely integrated in the physical environment. For example the TROC players told us that they have the feeling that the digital objects they are looking for (cats, cows, etc.) are floating in the air. Finally in the pixel mirror system, and as opposed to CASPER and MAGIC, perceptual and cognitive continuity is verified. The user focuses on the screen (one single perceptual environment) : the display of her/his hand using the tool on the top of the drawing enables precise modifications (cognitive continuity).

In addition to the perceptual and cognitive continuity, we also study the links between the two worlds. Two axes are relevant to characterizing these links: the owner of the link (i.e., he/she who is defining the link) and their static/dynamic character. For example, in the pixel mirror system, the designer conceived the link between the two worlds, by using a camera pointing to the user's hands. This link is static. Likewise, the designer of CASPER decided to combine the digital representation of the puncture trajectory with the representation of the current position of the needle thanks to a 3D localizer. Such a link is again static. On the other hand, using MAGIC, the users dynamically define new digital objects that are combined with physical objects. As pointed out in (Mackay 2000), instead of fixing the relationship between the two worlds during the design, "another strategy is to explicitly give the control to the users, allowing them to define and more importantly, continue to evolve, the relationship between the physical and virtual documents". A promising avenue to let the users specify such links is multimodal commands (McGee, Cohen & Wu, 2000). For example in our TROC system, the player could issue the voice command "this door is now a trap for others" while designating a door.

4 Conclusion

We have presented a classification space that describes the properties of mixed interactive systems. This classification highlights four main characteristics of such systems: (1) the two possible targets of the user s task, namely, the real world / the computer, (2) the two possible types of augmentation, namely augmented execution / evaluation, (3) the perceptual and cognitive continuity between the physical and digital worlds,(4) the links between the physical and digital worlds, defined by the designer / the user and their static/dynamic character.

The contribution of our classification space is two-fold:

1. Classes of existing mixed interactive systems are identified. We illustrated this point using three systems that we have developed.
2. By identifying and organizing the various aspects of interaction, our framework should also help the designer to address the right design questions and to envision future mixed interactive systems.

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