

Designing Interactive Paper: Lessons from three Augmented Reality Projects

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ABSTRACT

Augmented Reality offers a new paradigm for interacting with computers, linking familiar, physical objects to powerful computer networks. Although still in its infancy, the field is expanding rapidly, due to a wealth of new materials and technologies and a shift away from conventional notions about human-computer interaction. The increasing power and decreasing size of computers, the development of materials such as electronic ink and paper, and the recent explosion of the world-wide web, make Augmented Reality the user interface of the future.

However, creating successful augmented reality applications is not simply a matter of coming up with a new technology, no matter how clever. Because of the potential for confusion between the real and the virtual, augmented reality requires a multi-disciplinary approach, with a strong emphasis on the user. New technologies may offer fundamentally new ways of empowering users; but successful applications will have to be integrated into real-world activities.

We are interested in a particular type of augmented reality, which we call "Interactive Paper". This position paper reports on our experiences with three augmented paper projects: Ariel provides augmented engineering drawings for construction engineers, Video Mosaic provides augmented storyboards for video producers and Caméléon provides augmented flight strips for air traffic controllers. Using these projects as a starting point, we examine paper from three perspectives: as a physical object, as a social artifact and as an augmented object. We argue that field observations of users and participatory design and prototyping approaches are essential for understanding the situated nature of the use of paper, which is, in turn, essential for developing effective interactive paper applications.

INTRODUCTION

Our work in augmented reality grows out of our observations of users who have held on to paper, despite powerful incentives to adopt electronic replacements. Contrary to what many believe, users are not Luddites, clinging to paper as a way of resisting change. On the contrary: most are excited by the benefits offered by computers and some are even accomplished hackers. Their resistance is, in fact, extremely practical. New computer systems are either less efficient or simply cannot perform many required tasks. Depending upon the situation, users either reject the new system entirely (such as air traffic controllers who refuse to use on-screen flight strips) or else increase their workload by juggling an awkward combination of the existing paper and new on-line systems (as in many office applications).

Augmented reality provides an interesting solution to this problem, directly providing a link between physical paper and a computer network. This "interactive paper" has the potential to offer the best aspects of both physical paper and electronic documents, by making the paper the user interface. However, Interactive Paper is not a panacea. A lack of understanding of the differences between physical and electronic paper, particularly when used in the context of the users work, can result in serious confusion. How do we provide users with feedback when aspects of the augmented paper break down or get out of sync? What happens when there are discrepancies between the real and virtual forms of paper?

We believe that understanding the pre-existing use of ordinary paper in the context of the user's work is critical. Using multi-disciplinary teams and participatory design techniques, we developed different augmented reality solutions to support users needs. In each case, we emphasized exploring the design space rather than focusing on a single technological solution. We wanted to address the mismatch between physical paper and on-line systems and understand how interactive paper would fit into and evolve within users' real-world work settings. This paper briefly describes three interactive paper applications and discusses their use of paper from three perspectives: as a physical object, as a social artifact and as an augmented object.

Three Interactive Paper applications

We have explored the concept of interactive paper, defined as using physical paper as the interface to a computer, in three different applications: Ariel provides augmented engineering drawings for construction engineers, Video Mosaic provides augmented storyboards for video producers and Caméléon provides augmented flight strips for air traffic controllers.

Ariel: Augmented engineering drawings

Our first interactive paper project, called Ariel (Mackay et al., 1993, Mackay et al., 1995), grew out of work for the EuroCODE European ESPRIT project. We were initially charged with developing a multimedia communication system for construction engineers building the (then) longest suspension bridge in the world, in Denmark. In our observations and interviews with the engineers, we discovered that, although all had computers in their offices, they rarely used them. Engineers are constantly on the move, from the boat, to the bridge, pre-fabrication sites, meeting rooms as well as their

offices, making an office-based multimedia communication system impractical. We observed that engineers centered their work around their engineering drawings. Although, in theory, they have access to thousands of on-line drawings, in practice, they use four or five at a time, which they fold and carry with them. Drawings are annotated to reflect major and minor changes, as many as a third of which are never entered on the computer. (Thus the paper drawings contain a much more accurate representation of the actual bridge design!)

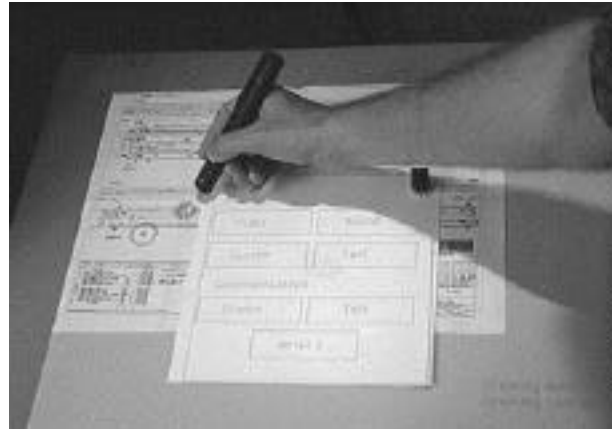


Figure 1a: Unix version with A0 graphics tablet. Figure 1b: MacIntosh desktop version.

We explored a variety of hardware and software configurations, based on discussions and collaborative prototyping sessions with the construction engineers, to let the drawings themselves act as the interface to the multimedia communication system. The first prototype used a large (A0) size graphics tablet (designed for making maps) to capture commands and gestures made by the user (Fig. 1a). Specialized software (written in C in Unix) projected relevant information onto particular drawings, let users create, move and send multimedia annotations and linked them to the EuroPARC mediaspace (Mackay, 1992). To calibrate, we projected an "X" to each successive corner for the user to point at. Fig. 1b shows a later (MacIntosh) desktop version with a smaller (A2) graphics tablet, an Optima LCD video projector, a tiny video camera to detect a red light source (LED) and a hand-held scanner to capture hand-written annotations from the drawing. We experimented with turning blank sheets of paper (with an LED in the corner) into virtual windows, projecting menu and other information in the appropriate location on the desktop.

Video Mosaic: Augmented storyboards

Our next interactive paper project was Video Mosaic (Mackay and Pagani, 1994) designed to augment paper storyboards for video producers. This project grew out of Mackay's collaborations with professional film and video producers who rely



Fig. 2a: Interacting with Video Mosaic (Unix) with paper buttons, overhead camera, embedded video). Fig. 2b: MacIntosh version, storyboard element. Fig. 2c: MacIntosh version with barcodes and projected video.

on a paper artifact, the storyboard, in order to design and communicate story ideas. Even those with access to powerful, multimedia computers continue to use paper storyboards to work out and share ideas. Some storyboards are formal, such as pre-printed, translucent versions we used to create interactive multimedia software at Digital in the early 1980s. Others are simply sequences of sketches, with annotations. Yet all storyboards share certain basic characteristics, providing a linear presentation of a story, using a series of sketches or images (the "best frame" of a clip), with the script, shot

information and other annotations. Video producers often rearrange the elements of a storyboard, taking advantage of paper in 3-dimensional space to organize the linear presentation of the story over time.

We developed Video Mosaic to let video producers link individual elements of a storyboard to an on-line editing system, modeled after EVA (Mackay, 1989). The first prototype (written in C on a Sun workstation) used a video camera to capture commands from "paper buttons" or storyboard elements (Fig. 2a). A microphone under the table detected when the user tapped and caused the camera to grab the current image. We identified commands (play, stop, etc.) and storyboard elements with optical character recognition. We embedded a small video screen into the desktop to display video, projected related storyboard information next to it. Later prototypes (using a MacIntosh) used a barcode reader to identify the different storyboard elements, eliminating the need for a fixed camera (Fig. 2c). Commands were moved to the storyboard elements themselves (Fig. 2b), eliminating projected menu commands and paper command buttons. We also made it easier for users to rearrange the strips and control the overall storyboard (as opposed to simply the individual elements).

Caméléon: Augmented flight strips

Our most recent project is Caméléon (Mackay et al., 1998), designed to augment paper flight strips for air traffic controllers. Despite massive efforts to replace flight strips, air traffic controllers around the world continue to rely on them to control air traffic. After spending four months with a team of Paris en-route controllers, we discovered that paper flight strips serve a variety of functions that are difficult or impossible to duplicate with conventional interfaces. Caméléon is the result of a year-long participatory design project that explored augmented reality design solutions. Each prototype had to *track* the position of each paper strip in a stripboard, *capture* information from it, and *display* information onto it. Pre-existing technologies worked well for capturing information (video camera, graphics tablet, touch screen) and displaying information (video projection, regular monitor, touch screen), but tracking was more difficult. The best solution involved a frame with spring-loaded metal contacts along the sides (Fig. 3a), designed to hold modified stripholders each with a resistor embedded within. Inserting a stripholder completes the circuit, identifying the precise location of each strip. When placed over a graphics tablet, next to a touch screen (Fig. 3b), we could capture all hand-written annotations and present information specific to each strip. Our software (written in TCL/TK and C) was linked to the training simulator and RADAR, enabling us to link the paper strips to existing on-line tools.



Fig. 3a: Individual stripholders are detected by the electronic stripboard. The graphics tablet below captures annotations and information is presented on the touchscreen to the left or on the RADAR screen (Fig. 3b).

INTERACTIVE PAPER

Paper is a physical object

Our experiences led us to reflect upon how the physical characteristics of paper and its social role affect the design of interactive paper applications. Paper has physical characteristics, called affordances, that affect how it is used. Not only is it lightweight and flexible, but it is easy to annotate and personalize. People take advantage of minute, seemingly irrelevant details (a dog-eared corner, a coffee stain, a hand-written mark) to quickly identify particular paper documents. People go beyond officially-sanctioned uses, inventing new uses based on the situation at hand. A newspaper can be a child's hat, a paper airplane or the lining for a bird cage; an envelope can be used as a scratch pad or a book mark. Our users were reluctant to give up paper, not because new computer systems didn't provide reasonable imitations of the "official" uses of the paper, but because the new systems were completely unable to handle their invented uses of paper. For controllers, the physical act of writing helps controllers remember what they wrote (whereas a selection from a menu is rapidly forgotten). Holding a strip in one's hand is an easy and effective reminder of which plane to handle next. We watched the video producers of a multimedia project arrange elements of the storyboard on the floor and walk around them in order to directly experience different storylines. Construction engineers scribbled ideas on their engineering drawings and shared copies with their colleagues. For each type of user, the paper interface was lightweight and intuitive, whereas the on-line imitations of the same actions were slow and inefficient.

Paper is a social artifact

People use paper within a historical and social context. Video producers use storyboards and construction engineers use drawings as the focus of collaborative work. Handing a physical document from one person to another implies a direct exchange of responsibility for it, particularly for construction engineers handling changes on drawings and controllers handing off planes. Marks on paper flight strips have evolved over several decades via a social process involving controllers. Conventions are agreed upon, adopted and shared throughout the control room. Paper documents (and flight

strips in particular) provide peripheral awareness of other people's activities, permitting low-cost tracking of each other's work. For video producers, storyboards are a creative document, with major differences in style from one person to another. Engineers work with drawings created by others, while controllers work with pre-printed strips, which may be annotated by other people. In each case, though, it is the users who decide upon the interface, the manner in which they individually and collectively interact with it. Few conventional computer systems enable users this level of flexibility and the ability to evolve the interface in the face of constant change.

Paper as an augmented object

Augmenting paper solves a number of problems when the physical nature of paper and its social role are important in the application. However, interactive paper can also introduce confusion. People intuitively understand the laws of nature with respect to physical objects. Although less reliable, people also have a set of beliefs about how the software they use works. But what happens when an augmented paper object combines both and these laws and beliefs conflict? For example, we understand how to erase pencil from a paper document. We may also know how a particular text editor erases characters. But what happens when an electronic mark is erased and not the physical counterpart? Or vice-versa? Our applications were designed to support occasional or frequent, but never constant, connections between physical and on-line paper, so it was essential to provide feedback about the nature of the link. We also ensured that "unwired" documents could be used in ordinary ways. Users must be able to understand what is happening when the system breaks down., particularly in safety-critical applications such as air traffic control. One of the nicest compliments about Caméléon was from a controller who said it was "invisible". He was delighted by the idea that he could continue using his current skills, while at the same time gaining access to a new set of functions provided by the computer. As long as a breakdown is immediately apparent, controllers can "work around" it; what is dangerous is when they rely on an aspect of the system without knowing that it is no longer functioning. We found that understanding aspects of the use of paper was important for deciding what to capture and how or if to interpret it. For example, controllers write notes to themselves, which need not be captured, they communicate information with others, which must be shared but not interpreted, and they make decisions which must be interpreted before being sent to software applications. We took advantage of the existing structure of the documents and gesture conventions to decide how and what to capture and where and what to present.

CONCLUSIONS

The "paperless office" is clearly a myth and paper continues to be an essential component of many complex, collaborative work settings. Augmented Reality provides a powerful alternative to the "keep it or replace it" choices traditionally faced by system designers. Yet, just as there are an almost infinite variety of paper and uses of paper, interactive paper offers an equally wide range of possible implementations. Although interested in the technological aspects of interactive paper, our main interest is how to embed it in real-world settings. We do not believe in an "ideal" interactive paper technology: Minor technological differences in how information is captured, interpreted and presented, as well as the registration between the real and virtual, may cause users to appropriate the technology in very different ways. The situated nature of paper "in use" has important design implications: designers must consider how users will adopt and co-opt interactive paper in the context of their daily work. This implies a strongly user-centered and participatory design process. We advocate exploring the design space with users, rather than immediately seeking a single solution. We also advocate "evolutionary design", which leaves much of the control of the on-going evolution of the application in the users' hands.

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