PaperSketch: A Paper-Digital Collaborative Remote Sketching Tool

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ABSTRACT

Pen and paper support the rapid production of sketches. However, the paper interface is not always optimal for collaborative sketching as seen in brainstorming sessions where multiple parties would often like to communicate and participate in the sketching synchronously. Novel interactive paper solutions may provide the answer by bridging the paper-digital divide and allowing users to sketch on paper simultaneously while capturing the actions digitally. We present an analysis of collaborative sketching activities in working environments with remote participation. After highlighting the importance of paper for natural interaction in these settings, we introduce PaperSketch, an interactive paper-digital tool for collaborative remote sketching. We discuss the collaborative development of ideas based on the prototype and outline how important feedback issues have been addressed by utilising spatial constraints and multimodal features.

Author Keywords

Interactive Paper, Remote Collaboration, Sketching, Skype

ACM Classification Keywords

H.5.3 Information Interfaces and Presentation: Group and Organization Interfaces: Collaborative computing

General Terms

Design, Human Factors

INTRODUCTION

Sketching is extensively used to express emotions, ideas, thoughts and theories as well as recording content and information for later use. Regardless of the tools used in the sketching process, the ultimate aim is the rapid capture of visual information to be shared in the simplest possible way.

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A sketch often represents a tool to promote discussion and collaboration as seen in brainstorming sessions. Tang shows how sketching as an activity is commonly achieved, collaborated over and incorporated into designers' work practices [32]. However, sketching in collaborative environments can have some limitations due to the physical displacement of the different parties. The lack of support for collaborative activities and gestures that are naturally part of a face-to-face interaction might negatively influence the outcome of "remote" discussions [3]. These limitations can be overcome by using electronic aids supporting a thoroughly assessed mix of modalities [24]. A number of synchronous remote collaboration tools as well as distributed groupware applications based on textual, voice or video communication addressed sketching activities by supporting collaborative remote drawing. Nevertheless, these solutions often enable interactions based only on digital interfaces, neglecting the intrinsic nature of sketching. While Tablet PCs and electronic whiteboards investigated enhanced pen-based interactions, technical limitations prevented the integration of pen and paper interfaces in remote sketching solutions.

In this paper we present PaperSketch, a paper-digital tool for collaborative remote sketching activities. We start by analysing changes in sketching environments and outline how new requirements for collaboration, mobility and geographical distribution have influenced the use of sketching techniques for discussion and idea finding processes. In the analysis, we discuss current approaches for remote sketching and collaboration and highlight why the introduction of tangible paper interfaces is of particular interest. We show how a paper-digital remote sketching application was realised based on the outcome of this analysis. Furthermore, we provide details about the design of the PaperSketch tool, its architecture and functionality. In order to evaluate our prototype, we conducted an initial user observation session that generated positive results but also raised issues in terms of application feedback. Last but not least, we summarise the lessons learned while realising the PaperSketch tool and provide some design guidelines for future real-time applications using paper-digital user interfaces.

SKETCHING ON PAPER

The process of sketching is often used to express or explain new ideas. The combination of drawing and talking in sketching is a natural means of expression and an effective solution for communicating complex ideas in different fields including design, architecture and software engineering [10]. Idea generation techniques such as brainstorming are commonly applied in design discussions [34], where brief descriptions of ideas are depicted on paper in the form of sketches on flip-charts or large paper sheets.

Since sketching is a very descriptive form of communication, it is normally easier to explain or model something by sketching than to describe the same content in a verbal manner. Moreover, ideas can be explored more freely and quickly when sketched with pen and paper.

As Buxton observed [8], sketches are quick to make, timely (provided when needed), inexpensive, disposable, ambiguous, based on distinct gestures and show the peculiarities of an individual's handwriting. Sketches are used to preserve thoughts and design details before they are forgotten and their creation on paper results in a natural way to initiate a discussion and generate ideas in brainstorming sessions. A drawback of paper-based sketches is that the drawings are hard to modify as the design evolves and most of the time they must be copied and redrawn on new paper sheets. Moreover, annotations often tend to be more valuable than the sketches themselves [5], but paper sketches do not support *design memory* [16]. The sketches might be annotated, but it is normally not easy to search for facts about the reasons behind particular decisions.

Interactive Sketching

To solve the problem of missing update functionality for paper interfaces, various electronic design tools have been proposed. Sutherland's Sketchpad [30] was the first system to explore pen-based user interfaces for sketching support. After this early work, research in pen-based computing advanced and culminated in the early 1990s with the first projects addressing pen-based sketching through interactive tablets such as the Interactive Worksurface Project [22] or the NPL electronic paper project [7]. Other tools supported sketching through electronic pads, for example SILK [19] and the Electronic Cocktail Napkin [12] or by means of position tracking technologies such as the Wacom graphics tablet[1]. In parallel, also collocated sketching interactions started to be a subject of research. Liveboard [9] addressed pen-based interactions in the setting of larger whiteboard-sized interactive displays that were designed to be used for remote collaboration in conference and classroom settings. This system, like the previous ones, neglects the importance of gesturing alongside the drawing as an essential feature of the collaborative sketching process. Of particular importance in this setting are the findings put forward by Commune [4], VideoDraw [33] and TeamWorkStation [18], the earliest shared drawing systems exploring aspects of co-located collaborative sketching and interaction with gesturing.

[1]http://www.wacom.com

Remote sketching and gesture support was further addressed by TeleGraffiti [31], a classic camera-projector system enabling real-time tracking of paper document displacements and supporting gesture-based operations in terms of hand movements. Also MagicBoard [15], a whiteboard-based solution where cameras and video projections are used for the capture and remote sharing of gestures, finger movements and whiteboard content was used for co-located sketching activities.

These systems addressed the requirements for remote sketching tools and successfully supported sketch-based collaboration with remote parties. However, since people had to use electronic tools including graphics tablets or Tablet PCs as input devices, they did not retain the natural pen and paper-based sketch interaction. It has been demonstrated that remote collaboration highly benefits from the use of tangible interfaces [6]. The introduction of pen and paper interfaces is therefore expected to enhance remote sketching in collaborative settings. One attempt to investigate tangible interfaces in this setting has been realised in Synchronised Distributed Sketching [14]. The tool addresses the limitations of static paper interfaces in terms of the lack of feedback by integrating pen and paper technologies within a whiteboard-based digital remote sketching tool. Other recent research [25, 21, 28] corroborates the hypothesis that multimodal video and audio support is essential in supporting the fine-grained interaction that happens when people are (remotely) sharing paper resources.

Importance of Paper

Despite the prediction of the paperless office, paper is still regarded as an important medium for many reading and writing activities. Our bookshelves are filled with journals, magazines or books, and desks as well as computer screens are augmented with Post-it notes. It is also a fact that large digital documents are often still printed for deep reading and annotation. Different types of professionals, especially in the field of design, architecture and engineering, sketch and brainstorm mostly on paper. Paper is regarded as a flexible physical object which can be easily shared with other parties.

According to Sellen and Harper [27], the affordances of paper have ensured its retention as a key information medium, even though digital technologies have been widely adopted over the last 20 years. The physical properties of paper such as portability, lightness, cheapness, flexibility and robustness afford many different human actions including grasping, folding, carrying and manipulating as well as sketching and writing. However, paper interfaces present interactional problems due to the limits imposed by the physical nature of paper. Paper documents are difficult to amend and revise, to access remotely or to dynamically update with new information for user feedback. Nevertheless, different reading, writing and collaboration-oriented affordances of paper suggest that this medium might still be best suited for sketching-related activities. Lawson [20] outlines how sketching plays a fundamental role for designers who "*find it hard to think without a pencil in their hand*". Also Goel [11] observed designers who were asked to solve design problems by either

sketching on paper or by using a computer-based drawing program. He reports on how paper-based sketches allow the designer to focus on the proper design issues. Moreover, the physical properties of paper support important aspects of collaborative work such as face-to-face interaction, retrieval, reminding, organisation and the documentation of an individual's knowledge. As reported in [1], extensive collaborative sketching is performed in architectural practice and preliminary designs are mostly created on paper and/or in scale models before being represented digitally through specific computer aided design (CAD) applications. Only a hand of computer tools are available to assist architects and designers in these early conceptual design phases, where flexibility, speed, ambiguity and vagueness are needed to quickly create plentiful exploratory drafts.

The analysis of sketching activities, collaboration requirements and paper-based interactions highlights the lack of a solution supporting sketching in an integrated way. Such a solution should provide natural pen and paper interactions on the one side, but be powerful enough to support synchronous and asynchronous communication in remote and local settings on the other side. We envision such a solution for *remote sketching on paper* and, in this paper, we describe the realisation of the PaperSketch tool based on interactive paper technologies and standard communication tools.

Interactive Paper

A number of digital pens are commercially available based on Anoto's Digital Pen and Paper technology[2]. This technology is able to track a pen's position on paper documents based on the combination of a special position-encoding dot pattern printed on paper and a camera inside the pen. The almost invisible dot pattern encodes (x,y) positions in a vast virtual document space. Camera images are processed in real-time, delivering up to 70 positions per second. The technology was originally developed for the digital capture of handwriting and several pages of handwriting can be captured and stored within the pen before being transferred to a PC via a Bluetooth or USB connection. Anoto, Hitachi Maxell and Logitech have all released pens that can be used in streaming mode where position information is transmitted continuously. This makes it possible to use the pens for real-time interaction as well as for offline writing capture.

In order to provide access to the Anoto technology and offer the corresponding functionality for paper-based interactions, several frameworks have been introduced. The Paper Augmented Digital Documents infrastructure (PADD) [13] developed at the University of Maryland supports the basic management of documents across the paper-digital divide. Advanced solutions for the management of complex interactive paper applications have been developed at ETH Zurich in form of the iPaper framework [23] and at Stanford University in a solution called PaperToolkit [37].

In particular, the iPaper framework enables a flexible management of paper-based resources and digital applications. It supports the definition of paper-based active areas, such as paper buttons and sketching areas, that can be linked to digital resources (e.g. images, videos and web pages), services (e.g. handwriting or gesture recognition functionality) or applications (e.g. Skype). Based on the iPaper framework, Anoto's digital pen and paper technology can therefore be used in much the same way as a mouse would be used in web browsing for following links to static resources as well as to trigger specific application calls.

[2]http://www.anoto.com

INFORMING THE DESIGN

To inform the design of our PaperSketch solution, we analysed user needs, combining them with the analysis of the sketching activities introduced in the previous section. In order to better understand requirements, we conducted an online survey investigating current habits of designers, architects and engineers and introducing our vision for a paper-based remote sketching solution. The aim of our analysis was to collect general information about user habits and their initial feedback in order to define the requirements for the design and implementation of a first prototype. The performed analysis was structured in four main blocks looking at different aspects of the participants: general demographic data, basic information about the use of digital tools in the everyday work, the usage of particular communication or collaboration tools and the potential of a tool for remote sketching on paper. In the last block, participants were asked about particular situations where they would use such a tool and the specific functionality that they would like to use.

Participants were recruited through advertisements on public and private mailing lists of companies, universities and design schools as well as other institutions. Target user groups were selected among people communicating via such tools or using sketches as part of their professional activities. The total number of participants at the time of the evaluation was 63 (n=63). Most of the participants were between 20 and 35 years old; 40% of them were female and 60% male. Mainly professional designers, researchers and students from design, architecture and art schools participated in the online survey. Working both in the private industry and within educational institutions, most of the participating designers usually assume a double role, that leads them to foster remote collaboration between academic and industrial settings. The participants of the survey were quite comfortable using computer technologies since most of them work more than 4 hours per day with a computer. Software to make Voice-over-IP phone calls, chat or communicate in other ways with people over the Internet was used by 87% of the participants. The remaining participants (13%) motivated their resilience to using these communication tools with the lack of colleagues using the same tools or personal preferences to use more traditional technologies such as regular phones.

We asked participants to describe their current collaboration practices by underlying what techniques they currently use. 71% of the participants used a software solution to foster collaboration in their projects where 79% consist of some sort of communication software, with Skype being the tool used by more than half of them. As shown in Figure 1,

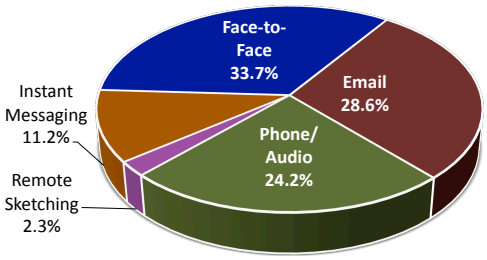


Figure 1. Preferred collaboration techniques

different techniques for collaborative work were exploited by the survey's participants, but a significant number of them (33.7%) preferred face-to-face communication and interaction. In order to better characterise such collaborative tasks, participants were asked to rate the importance of 7 predefined components, usually leading to collaborative work. As illustrated in Figure 2, *communication*, *coordination* and *brainstorming* play the most important role. Let us compare these results to the high percentage of people using email or audio communication highlighted in Figure 1 and consider the tendency towards synchronous collaboration with geographically separated people. It seems to be evident that support for remote collaboration based on email and audio communication becomes a very important issue.

Activity	Ranking			
	#1	#2	#3	∑ #1-3
1 Communication	47%	23%	10%	80%
2 Coordination of the parties	14%	29%	30%	73%
3 Brainstorming/sketching of ideas	14%	17%	21%	52%
4 Relationship building	13%	13%	6%	32%
5 Discussion of the joint work	1%	14%	16%	31%
6 Individual work	10%	3%	13%	26%
7 Evaluation of the results	1%	1%	4%	6%

Figure 2. Relevance of collaboration components

When asked about the use of virtual sketchpad applications or digitiser tablets, 89% of the participants answered that they never used such a tool. However, 90% of them stated that they would use a similar tool for remote sketching based on a pen and paper interface. The arguments against their use generally included the missing physical co-presence as well as the inability to express gestures.

A number of potential functionalities for a sketching tool were proposed to the study participants. Examples ranged from controlling the interface based on paper-based buttons or gestures, colour or drawing tool selection (e.g. pencil, pen or eraser) as well as zooming, panning and scrolling functions. Since the envisioned prototype is a mixed paper-digital application, the participants were asked to state their preference in terms of providing a certain functionality on paper or via the digital application. Most of them answered that the flexibility could be increased if the functionality would be accessible via both interfaces. They further suggested interesting functionality such as undo/redo operations, tools for sketching diagrams and drawings and the use of transparent overlays to support the layering of sketches.

Since our goal was to introduce paper sketches within working environments, our PaperSketch solution should not replace existing tools but rather be integrated with them. Therefore, we asked the participants to judge the importance of integrating the new functionality with different applications. The results shown in Figure 3 highlight that sketching should be part of a wide range of digital applications. Participants mainly suggested to integrate such a sketching solution in both digital imaging and office applications, but also underlined the importance of augmenting existing communication technology and tools such as Internet telephony over Skype with sketching functionality.

Application	✓	✗	N/A
1 Digital imaging	73%	10%	17%
2 Office	70%	14%	16%
3 Internet phone (i.e. Skype)	67%	14%	19%
4 CAD	57%	14%	29%
5 Digital publishing	49%	21%	30%
6 Instant messaging	16%	35%	49%

Figure 3. Integration of sketching in digital applications

When asking users about the potential integration of collaborative sketching tools within their preferred applications, the number of participants that would use collaborative sketching on paper rose from 90% to 94%. Among the different positive comments that we received as feedback, there was one participant who stated how he *"was waiting for a long time for a tool like this one"*. This quote is significant since it is a good summary of the outcome of our survey. Participants were generally enthusiastic about the proposed solution and showed interest in the development and potential deployment of the PaperSketch tool. Based on our requirements analysis, we can confirm the importance of pen and paper for sketching and brainstorming in collaborative and remote settings. We further observed that the integration of a paper-based sketching solution with communication or design tools seems to be of major interest. Even though the participants of the survey were mainly active in research and education, we foresee that our results will also be applicable to other professionals. This is further supported by studies addressing sketching and early drawings in design professionals and architectural settings [1].

PAPERSKETCH

Based on the outcome of our analysis, we designed PaperSketch. Thereby, it became evident that the interface for interacting with our collaborative sketching tool should be based as much as possible on traditional sketching habits.

As mentioned earlier, different solutions have been proposed for developing paper-like user interfaces. However, systems that simulate pen and paper interactions are often rather expensive to develop and too heavy to be easily carried around. In addition, since the preferred collaborative setting is normally a face-to-face interaction, remote collaboration can only be achieved based on solutions for synchronous audio and video communication that are generally not portable and offer limited sketching support. In order to enable a natural sketching experience, we should aim for a fast, reliable and easy to learn solution. Users should be able to just grab a sheet of paper and start drawing on it, without having to carry any additional hardware or use complex software. Only an intuitive interface can ensure that users will focus on the sketching activity and not on how to use the software.

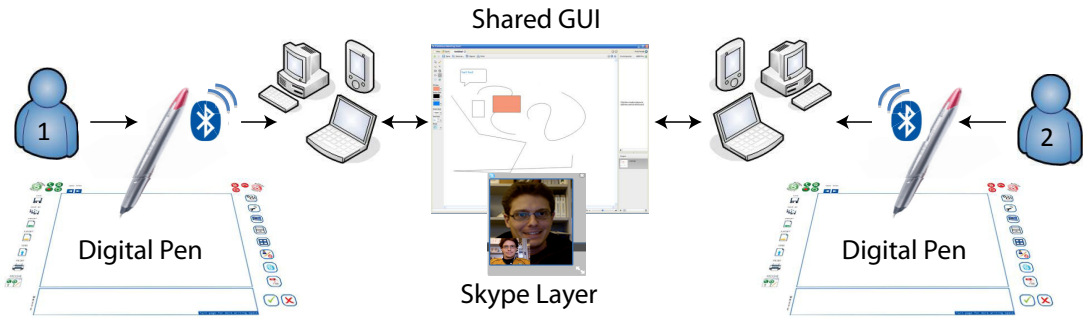


Figure 4. Collaborative paper-based sketching

We decided to base our collaborative sketching tool on a real pen and paper interface exploiting Anoto technology and the iPaper framework outlined previously and to digitally augment the sketching experience via visual tools showing digitised sketches in parallel with Internet-based audio and video communication. Both the local (paper-based) and the remote sketches are represented in the digital interface, allowing users to have a complete overview of the collaborative sketch on the computer's display. Even though this does not completely free the user of utilising special software and hardware, the current deployment of interactive paper documents as supported by the iPaper toolkit in combination with audio and video capturing functionality, make the deployment of such a tool easier than with the systems described earlier.

The main components of the resulting remote sketching application are highlighted in Figure 4: the digital pen and paper interface, a Graphical User Interface (GUI) and an underlying communication layer based on Skype. Multiple users can draw on paper and transfer the sketches in real-time to remote parties who can see them in their GUI as well as print them on interactive paper. During the sketching or brainstorming sessions, Skype-based audio and video communication can be initiated by interacting with specific paper buttons or clicking the corresponding controls in the digital interface. Users are able to store their drawings and retrieve digital sketches based on the currently used paper sheet.

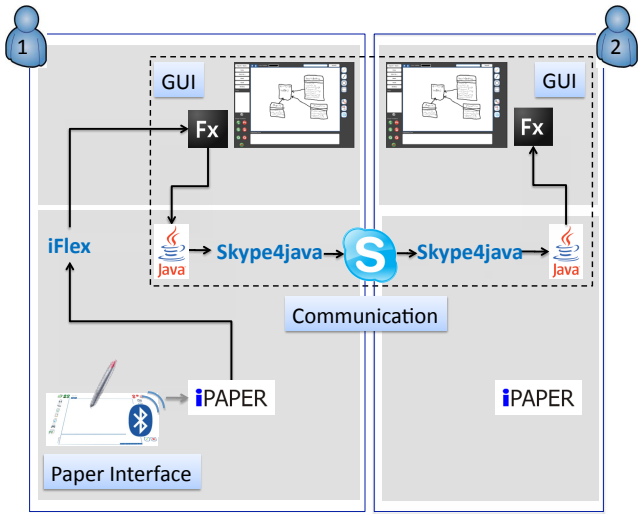


Figure 5. Information flow

Before presenting the most important functionality in more detail, we outline the technology that enables paper-based interactive sketching and the general architecture and interfaces that have been implemented.

Architecture

To achieve an effective communication from paper to the local digital interface and via Skype to a remote GUI, different technologies have been integrated. These technologies have to seamlessly work together in order for the users to naturally sketch on interactive paper sheets. The sketches are visualised on the screen in real-time and sent via the Internet to other users who can annotate, sketch and interact with the digital sketches. To support the synchronous transmission of sketches, we developed a special *iFlex* component that opens a direct stream to the GUI, implemented in Adobe Flex[3] in combination with ActionScript 3.0. This component transmits the coordinates captured by the pen and renders the sketch in the digital application. It can also call specific Flex functionally such as the selection of different drawing tools. We use the iPaper framework to open a connection to the digital pen and interact with the pen-based information. Furthermore, we used the Skype4Java API[4] to exchange data between Java and Skype. Figure 5 provides an overview of the main information flow within the PaperSketch tool. The communication is initiated via pen and paper interaction which is processed by iPaper. The iPaper framework determines whether the selected coordinates are bound to a specific operation or if they represent some sketch interactions. The required command is transmitted to the iFlex component which acts as a bridge between iPaper and the GUI. In a next step, information about the sketches or the selected command are transmitted from Flex to a central Java controller that uses Skype4Java to transmit it via Skype. On the remote site, the received information is forwarded to the Java controller via Skype4Java and is finally visualised by the remote Flex GUI.

Note that PaperSketch also works in single-user mode when no Skype connection is available. In this case, local users still sketch on paper and the drawing is shown on the screen. Further, as illustrated by the dashed rectangle in Figure 5, the application also works without the iPaper infrastructure for collaborative mouse and keyboard-only sketching.

[3] http://www.adobe.com/products/flex/
[4] http://developer.skype.com/wiki/Java_API/

Design

Our PaperSketch solution is based on two different interfaces: a paper interface for sketching and annotation and the GUI for communication, collaboration and for visualising in parallel the remote sketch and the local sketch. The goal of the graphical user interface design was to minimise potential errors in interacting with the tool as well as the consequences of potential maloperation. Moreover, since the tool is going to be used by professionals and non-professionals, the system aims to be both accurate and easy to use. Pop-up windows with visual feedback (text and graphical) are provided and augmented with audio feedback that can be perceived by the users even when they are looking at the paper interface. When a remote user is for example starting a voice chat, audio feedback is provided and a message is shown on the user's screen as illustrated in Figure 6. Furthermore, the dark background with bright text should be helpful in the case of a strong light source pointing at the screen. When working in collaboration, users can be easily distracted by other remote or local collaborators. Therefore, the user interface helps resuming tasks or show updates by highlighting selected functions and drawing modes.

As we will see later, the sketching and communication tools have the same look as the paper interface to establish a strong correlation between the two interfaces and the sketching activity. The sketch area is placed right in the middle of the application window, directing the user attention to the sketching component which is the main functionality of the prototype. Since colours play a major role in visualisation due to their ability to code information, we applied colour coding patterns to our application as defined in [35]. For example, selected screen objects are generally shown with an orange border, while navy blue is used to represent interactive links and functionality that might be selected. Black and dark grey is used for screen backgrounds. The graphical user interface and its dialogues were developed by combining the results from our analysis with the ISO 9241-110 standard for ergonomics in human-system interaction [17].

The paper interface is based on an A3 landscape page with interactive buttons and a placeholder region for separate A4 pages which are used for the sketching. As shown in Figure 7(a), our initial paper interface offered almost the same functionality that is also provided in a standard digital GUI.

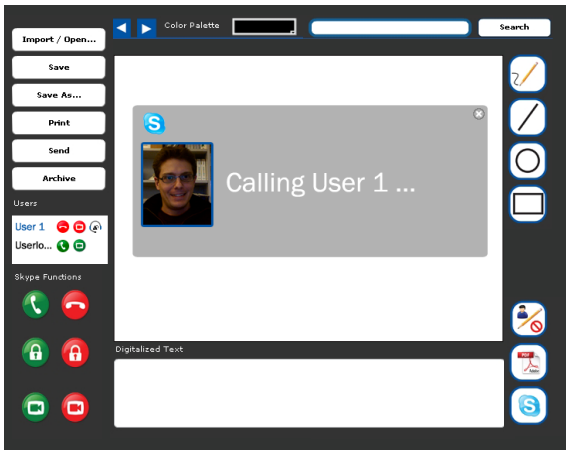


Figure 6. Digital PaperSketch GUI

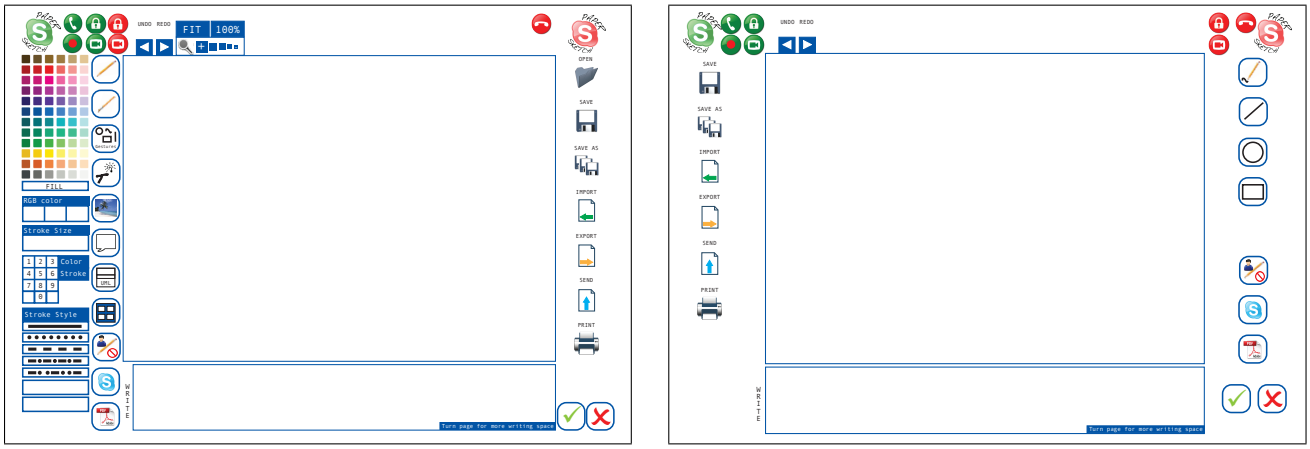
This resulted in an overloaded design which did not conform to our easy-to-learn, efficient-to-use and safe-to-use usability goals. The initial design had too many sketching and application control functions which could confuse the user, slow them down and result in a less natural design process.

In the final prototype shown in Figure 7(b), we removed all unnecessary buttons and we only represented the functionality that would make sense to have on paper. For example, while within the GUI users select the colour from the usual colour picker pop-up, in the physical world this does not make sense. We solved this problem by allowing users to choose different pens which have been filled with differently coloured ink. Based on the different IDs assigned to the pens, the digital application automatically selects the correct colour for the screen rendering. Because most people are right-handed, we positioned the drawing tools on the right-hand side avoiding thus users to cross the paper sketch with the arm or hand in order to pick them up with the pen. Since the interface is based on paper, it would however be easy to define a left-handed paper interface working exactly in the same way. Our paper prototype also complies to the concepts of proximity (grouping similar interactive buttons), symmetry (central sketching area with two sets of buttons on both its right- and left-hand side) and continuity (linear design of the interface).

Interaction and Functionality

The online survey presented in the previous section drove the definition of different functionality to be implemented as part of both the paper interface and the digital GUI. Functionality and related interactions are summarised in Figure 8 where we also highlight on which interface (paper or digital) they have been deployed. Please note that some of the functionality that can be triggered via the paper interface requires some additional user intervention with the digital GUI.

While most of the functionality such as freehand sketching, file management and Skype-related functions should be relatively straightforward to understand, other interactions require some explanation. For example, the 'Line', 'Circle' and 'Rectangle' functions grouped within the 'Tools Picker' functionality provide a way to draw precise geometrical shapes by means of an automatic beautification of the freehand drawings that matches the collected strokes to the shape previously selected. The 'Open' and 'New' functions, which are available in the digital interface only, have been implemented for the paper interface through a natural interaction based on normal user behaviour. Instead of drawing directly within the sketching area in order to create a new sketch, users place an empty A4 paper sheet on top of the paper interface and start sketching. As described earlier, the A3 paper-based interface has been designed in order to have an A4 sheet that perfectly fits in landscape mode within the sketching area and PaperSketch is able to track the starting of a new sketch based on the unique Anoto pattern that has been printed on the different empty paper sheets. If a user invokes the 'Open' or 'New' command from the digital GUI without using a new paper sheet, the system detects the invalid state by checking the pattern of the page



(a) Initial paper interface (b) Final paper interface

Figure 7. PaperSketch paper interfaces

currently being used and issues visual and audio warnings. In order to open an existing sketch, a similar interaction pattern is required where users just have to place an existing paper sketch into the sketching area and tap on it with the pen. The digital sketch will automatically be visualised on the screen. Text input is supported from the paper interface by providing a writing box positioned below the sketching area. Users first specify the target area for the textual input on the sketch itself by touching the paper in the desired position and subsequently write with the digital pen. The entered text is analysed by Intelligent Character Recognition (ICR) software and rendered at the corresponding position within the sketch.

Even though our aim was to realise as many interactions as possible closely related to the natural use of pen and paper, in order to cope with the lack of feedback on the paper interface

Functionality	Description	Paper	Digital
Sketching Area	The core element for capturing the sketch, placed in the center of the application	✓	✓
Start/Close	Start or close the digital application if not running	✓	✗
Contact List	Show on-line users and open a new connection	✗	✓
Color Picker	Select the colour to be used for sketching	✓	✓
Search Field	Search and open a stored sketches	✗	✓
Tools Picker	Select different tools for drawing such as free sketch, line, circle or rectangle	✓	✓
Text Input	Input field for inserting text (hand-writing recognition or typed text respectively)	✓	✓
Skype Comm	Bridge to Skype functions (start/end call, start/end video, private communication)	✓	✓
Record Session	Record sketching session combining text input with voice and video communication	✓	✓
Undo/Redo	Update the sketch by undoing the last changes or redoing the last undone changes	✓	✓
New	Create a new sketch	✓	✓
Open	Open existing sketch and render it on the screen	✓	✓
Save / Save As...	Store the sketch and the recorded session	✓	✓
Export	Export sketch to different formats (e.g. PDF, SVG)	✓	✓
Import	Import external images within the sketch	✓	✓
Send	Open the default email client and attach the sketch	✓	✓
Print	Print the current sketch on the default printer	✓	✓
Block/Unblock	Manage exclusive use of the sketching area	✓	✓
Show Skype	Bring up the Skype window	✓	✓
Ok/Cancel	Confirm/cancel the current action as shown in the highlighted dialogue	✓	✗

Figure 8. PaperSketch functionality

also some less-natural interactions had to be implemented. As we outline in the discussion, this is an important issue that we tried to overcome with the introduction of artificial interactions such as the 'Ok/Cancel' buttons that have been added to allow users to quickly react to dialogues appearing in the digital application without having to switch to the digital application. Due to the same limitation, other features such as 'Undo/Redo' and the exclusive usage of the sketching area by means of the 'Block/Unblock' buttons, affect only the digital UI, even if they can be executed from the paper interface. Finally, even if a number of features do not have to be represented on paper (e.g. for the file management), we decided to add the corresponding paper buttons to offer an alternative to mouse and keyboard interactions.

EVALUATION

In order to evaluate the functionality and new interaction patterns offered by PaperSketch, we conducted a small usability study with 6 participants. Even if small-scale, this study allows us to outline some interesting issues that could lead to novel design and implementation patterns for future paper-digital applications. The major goal of the study was to find out how well the application can be used for sketching and collaboration, as well as to see how easy it is to learn to use the system. Moreover, we wanted to investigate whether the nature of sketching is preserved, the functions and icons on the paper prototype are self-explanatory and what could be improved in future versions of the application.

Participants

The study took place at the usability lab of the University of Konstanz during two days. Altogether, there were three sessions with two users in each session who were collaborating from two separate rooms. Five users were team members of the Human Computer Interaction Group of the University and another user was a researcher in a different subject. Users were filmed during the tests and informal interviews took place right after the completion of the tasks.

Methods

After a short introduction about the application, users had to complete five exercises to get used to the system. They

were first asked to have a look at the paper interface and describe the functionality of the different buttons (E1). Afterwards, they had to sketch a house and a car (E2) and try to use as many of the available tools as possible. Users were then asked to use the *undo* function (E3) and the *redo* function (E4). Finally they were asked to save the sketch as a JPEG on the file system (E5). After these exercises, users were asked to start working on a collaborative sketch and to collaboratively accomplish seven specific tasks. The general scenario was the collaborative design of a GUI for a novel personal information management application. After connecting with the remote user through the integrated Skype functionality, participants were able to collaboratively work on the given task by possibly managing the exclusive use of the sketching area. One of the users was responsible for the design of a calendar tool while the other participant worked on a new email client. After completing the sketches, they had to close the connection, store the current sketch and reopen the first sketch to add a new component.

Results

All users followed a similar path for solving the task that they have been assigned to. All of them naturally placed the A4 paper sheet within the A3 control panel and touched the paper sheet with the pen to start a new drawing. Afterwards, users initiated a Skype-based communication channel, exploiting both voice and video to discuss about their design task and to coordinate their sketches. While sketching, users continuously kept changing their gaze from the paper to the digital interface to always have a complete understanding about the shared sketch. When sketching synchronously, users exploited different parts of the sketching area, while they naturally introduced turn-taking when sketching on the same area. Users made use of both the freehand tool and the shape tools to create a mix of rough and more precise sketching. All users successfully perceived and reacted (e.g. by looking at the screen) to audio feedback from the system informing them about changes in the application.

The first and most important outcome of this small usability study is that all users enjoyed working with the paper-based drawing tool (*"Funny... I like it"*) and stated that sketching with the interactive paper interface is much better than using a mouse or any other input device (*"I like that it is pen and paper and I don't have to use some other non-natural tool"*). Moreover the interaction with Skype did not create any problems since users were familiar with this type of tool. Most of them preferred to access functions directly from paper instead of a digital GUI-based selection. We further observed how the nature of sketching is preserved both when users want to start a new sketch or if they want to open an existing one. The usage of the tangible paper sheet to start a new or open an existing sketch worked and was well accepted. Handwriting recognition was not completely integrated in PaperSketch but users were keen to have it so they could combine text entries with their sketches. However, the option to use a keyboard and mouse should also be provided because of personal preferences and in order to deal with incorrectly recognised text entries. Since one of the users was left-handed, we realised that the application also works quite well in this situation. Participants suggested to use PaperSketch as a classic drawing tool for freehand drawing in collaborative and stand-alone situations, but also in a range of different scenarios like brainstorming sessions, creative collaborative sessions and remote focus groups.

Users generally had difficulties to understand the meaning of the 'Block/Unblock' and the 'Skype' icons. Looking at the usage of these tools, we could observe how the management of exclusive access to the sketching area was coordinated through voice rather than by using the designated functionality and how the Skype application was directly selected from the application bar if there was a need to bring it to the foreground. Therefore, their presence in a final paper version is questionable. As we outlined in the previous section, the icons of the currently selected tool were represented on the screen by an orange border. This kind of feedback was not enough for some users who started drawing in the wrong mode. A possible solution could be to improve the highlighting by providing, for example, a blinking state to be activated when a tool is selected.

Due to the missing possibility of the static paper interface to interactively change its status and be synchronised with the digital drawing on the screen, remote sketches could not be represented on the local paper interface. Therefore, users generally used pen and paper to create different local sketches–one for each participant, in a different part of the sketching area–and the digital GUI for collaborating on a remote sketch. This interaction pattern highlights how work surface territoriality in collaborative settings [26] is an important factor also for a paper-digital collaborative remote sketching tool. In order to better support this natural response of users to a limitation of the current technology, the digital sketchpad could be split into different parts, one for every participant. As a final remark, users generally stated that PaperSketch preserves the nature of sketching and that the interaction with it was natural and straightforward.

DISCUSSION, LIMITATIONS AND IMPLICATIONS

Our prototype allows paper sketches to be transmitted in parallel to voice or video communication in mobile, desk and meeting environments. The well-known Skype application supports the remote synchronous collaboration and works as a bridge between the digital and the paper interfaces, supporting sketching on paper in both synchronous and asynchronous situations. Furthermore, natural paper-based interactions have been implemented: the creation or retrieval of a sketch by means of simply positioning the pen over a paper sheet and the colour and style functionality bound to the selection of different physical devices. These kind of interactions maintain the nature, simplicity and spontaneity of sketching, even if users are digitising their work and collaborating with people over the Internet.

Beyond Paper Feedback

Surprisingly, the fundamental limitation of paper as an interactive interface and its constraints in providing interactive feedback was naturally overcome by our users. Participants defined spatial constraints on the paper interface to provide

separate sketches and to promote discussion and remote brainstorming based on it. This mechanism exploits high-level collaboration, keeping consistency between the paper interface and its digital representation.

Furthermore, multimodal communication and synchronisation of pen-based interactions through Skype audio and video have been exploited to manage access to common areas of the sketch. This interaction pattern highlights how face-to-face communication, even in a remote situation, still plays a fundamental role in collaborative environments.

We believe that a sketching scenario like the one supported by our application, enables the flexible integration of synchronisation and collaboration mechanisms. Human beings are generally good in overcoming limitations in a natural way, exploiting their multimodal capabilities. However, in more complex situations where complete and simultaneous access to the same portion of the drawing is required and where a tangible representation of the remote information is needed, other approaches are required. New technologies, such as organic electronics and active graphic displays [2] or plastic electronics[5] are addressing these limitations and might possibly represent an alternative solution in the future.

Other solutions to this problem could be adopted. For example, one could exploit the combination of the paper interface with a top projection of digital remote information, as already proposed in the early 1990s in Wellner's Digital Desk [36]. However, this approach requires a static environment where the system has to be carefully calibrated and therefore lacks mobility which is an important affordance of paper. Recent developments in the domain of pico projectors offer new forms of flexible feedback projected on top of the paper interface in dynamic and mobile environments and could easily be combined with our interactive paper solution as demonstrated in [29].

Design Guidelines

The development of our paper-digital prototype and the observed user interactions highlight some important issues and ask for solutions that might be adopted in the further development of paper-digital interfaces.

First, the introduction of tangible metaphors based on the natural usage of pen and paper interfaces are highly effective in increasing the interaction with users and should be introduced in paper-digital interfaces, replacing classical digital metaphors like for instance buttons. This has been implemented in our prototype both for the colour picker and the start/opening of new or existing documents. Users seem to generally accept such metaphors very well, exploiting their current experience also in mixed paper-digital interfaces.

Furthermore, since interactive paper is not yet mature enough to present visual feedback, applications should be implemented in a way that minimises the need of such feedback. However, designers should not neglect the intrinsic ability of people to automatically adapt to an unclear or unknown situation and naturally negotiate a solution. We have seen how the lack of paper-based feedback did not affect the effectiveness of our prototype in the collaborative sketching of different components. Collaboration was based on direct visual and audio communication that allowed the different designers to negotiate responsibility for specific aspects of the collaborative tasks.

Finally, we observed that certain functionality might not be realised via a paper-based interface only, but requires some paper-digital interaction. Therefore, care has to be taken in order to define such mixed interactions in a way that minimises user efforts. As a more general remark, we observed how the usage of techniques and systems with which users are familiar, for example Skype, are fundamental in order to minimise the learning efforts. The introduction of a multimodal prototype combining novel interaction techniques and existing tools has demonstrated to be effective in terms of understandability and general usability.

CONCLUSION

In this paper, we presented an analysis of sketching activities in collaborative environments supported by an online survey about user requirements in this setting. We proposed paper as a suitable interface to better support the nature of sketching and presented PaperSketch, a paper-digital prototype that supports paper-based remote sketching. Our prototype revealed that the integration of technologies for interactive paper and standard communication and collaboration technology like Skype can enable an effective collaboration over paper sketches. Finally, we performed an initial evaluation of the developed prototype by means of a small usability study that highlighted the validity of the presented approach. We discussed how current technologies are powerful enough to support complex interaction in a mixed paper-digital environment, but also how important issues in terms of feedback have to be taken into consideration when designing and developing such applications. Our prototype also proves that users can naturally adapt and negotiate effective solutions to overcome specific interface problems. We outlined initial guidelines for the design and development of new applications that integrate paper interfaces with digital tools. These initial findings have to be validated by means of further investigations and more thorough studies and evaluations. In future work, we plan to compare PaperSketch with other sketching modalities and to assess such modalities by measuring interactions with the different channels used for communication and sketching (speech, paper, video, screen, etc.). Moreover, we plan to run a larger scale long-term user study that should highlight when, in which domains and to what extent collaborative paper-based sketching brings additional benefits.

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[5] http://www.plasticlogic.com

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