PocketPad: Using Handhelds and Digital Pens to Manage Data in Mobile Contexts

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Abstract— **PocketPad is an information management system geared toward university students. The system is designed to support the capture, storage, browsing, editing and organization of handwritten notes via the complementary use of digital pens to capture information, handheld computers to browse and store prior information, and digital pens and handheld computers in combination to edit and organize information. Desktop computer software synchronizes the information from the digital pen and Pocket PC during editing and reorganization. Through the combined use of different hardware components supported by our software, we describe a system that bridges the paper-electronic information divide in mobile contexts. The system relies on human-in-the-loop techniques coupled with stroke timing to simplify coordination of content from different sources, rather than resorting to complex and often error-prone computer document recognition algorithms.**

I. INTRODUCTION

While notebook and tablet computers have many mobility advantages over their desktop counterparts, they are still awkward to use while moving from classroom to classroom on university campuses. Students use cell phones and occasionally handheld computers for communication and scheduling and pen and paper for brainstorming, note taking, problem solving, and other time sensitive or creative processes in the mobile contexts typical of university campuses.

While portable and physically robust, paper does suffer from drawbacks. First, the amount of information that can be carried around simultaneously on paper is limited to between tens of and a few hundred documents. As well, reorganization of captured information is a complex, lengthy process, particularly for informal pen and paper documents such as classroom notes. Finally, wide-spread sharing of paper-based content is time-consuming and limited in scalability.

The goal of our research is to preserve paper-based interaction specifically in mobile contexts, and to augment pen and paper interaction through the design of complimentary computer software. To this end, we describe PocketPad, a mobile information management system for university students. The PocketPad system allows the capture of handwritten notes using an Anoto digital pen, the storage and browsing of pre-existing handwritten notes using a handheld computer, and the editing and reinterpretation of pre-existing handwritten notes through simultaneous use of the Anoto pen and handheld computer.
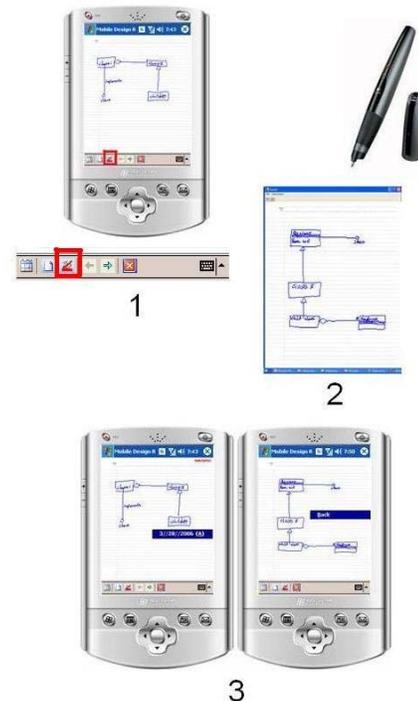

Fig. 1. Annotation serves to reinterpret or comment on existing information. By clicking on the Annotate button (1), the canvas is timestamped. A user creates an annotation using the Anoto pen on paper, and the annotation is captured by the computer (2). When uploaded onto the Pocket PC, the annotation is associated with the annotated document via hyperlink activated by press-and-hold (3). A red label in the top right corner of the annotated document indicates the presence of annotation.

While capture is trivially supported by the digital pen, and storage and browsing are typical of many software applications, the simultaneous and complimentary use of digital pens and handheld computers for editing and reinterpretation demonstrates that, by combining the strengths of different technologies, an improvement in how technology supports people's tasks can result. Digital pens present a highly effective input device for computers, but are limited in output. Pocket PC devices are effective for output, especially due to the advent of VGA resolution screens, but are still small and awkward for input. Through the combined use of these

devices, the disadvantages and advantages of each trade-off to produce a system that more effectively supports capture, storage, and reuse of information captured by university students in classroom environments.

Editing and reinterpretation require simultaneous use of handheld and digital pen. PocketPad supports editing and reinterpretation via two processes: annotation and repurposing. Annotation is the process of adding interpretive comments to pre-existing content to elaborate on or extend previously captured information. On PocketPad, annotation of a page of notes is explicitly supported via a hyperlinking feature of the system. Users browsing documents can click on an Annotate button, highlighted in Figure 1. This timestamps the electronic canvas on the Pocket PC. Users can then add interpretive comments with their Anoto pen on augmented paper. Computer desktop software coordinates the data from the Pocket PC with data from the digital pen, and creates a two-way link between annotated page and annotation, as shown in Figure 1. Repurposing is the process of recombining information. This process is supported via hybrid electronic-paper documents, as depicted by Figure 2. A user can select a portion of one or more digital documents on the Pocket PC and arrange them on a new electronic canvas, creating a new electronic document on the Pocket PC. The user can also write using the Anoto pen on digital paper. When synchronized, the strokes from the Anoto pen and from the handheld's canvas are merged. In this way, users can combine into a new document repurposed content from the handheld with optional additional content from pen and paper.

This paper is organized as follows. We first outline related work on pen computing and pen-based information capture. We also highlight work on handheld computing, specifically in education settings. Next, we outline the components of our system and describe testing done with university students at our institution.

II. RELATED WORK

A. Preserving Pen-Based Interaction

Many authors have noted the value of pen and paper-based notes and drawings in support of problem solving [12], [4]. Due to this value, and to overcome some challenges associated with reproduction, editing, and portability of large paper-based repositories, researchers have explored the design of systems for pen-based computing devices such as Tablet PCs. Pen-based systems exist that support software engineering [10], architecture [4], user interface design [12], engineering design [18], and military strategizing [2]. Computer systems offer numerous advantages, including the ability to share information more easily than photocopying, to edit more easily than with white-out, and to augment the depicted information with AI processes that reason about the drawings. However, computers with displays that offer paper-quality resolution are still not available, and high resolution computers with sufficiently large displays also often tend to be both more bulky and fragile than a pad of paper, making these pen-computer systems less portable than pen and paper. Even
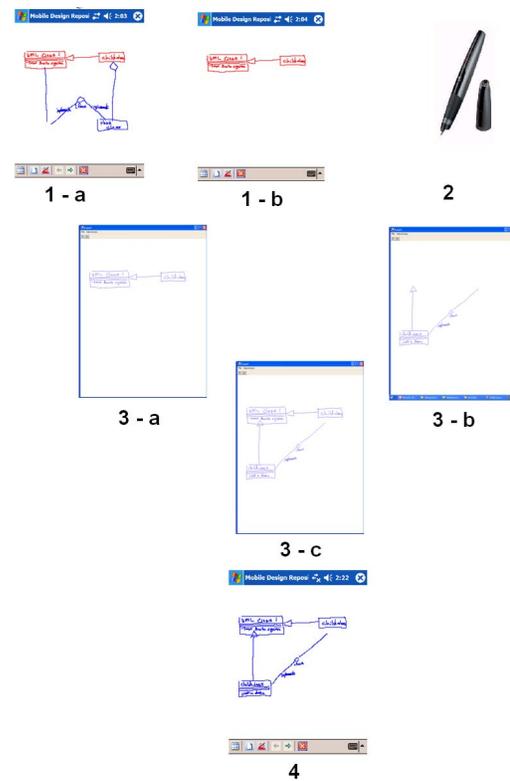

Fig. 2.   Users can select strokes on the Pocket PC (1a) and paste them onto a new canvas (1b). Users can also draw on Anoto paper with an anoto pen (2). A desktop computer application captures information from the Pocket PC (3a) and the Anoto pen (3b) and combines this information into a new hybrid document (3c), here a UML diagram, which is then uploaded to the handheld computer (4).

with a highly portable computer, the need to interact with application logic while drawing has hindered the usability of computer sketching systems [15], [16].

Another approach to overcoming paper's drawbacks while preserving its use in the physical world has been to explore mechanisms for moving seamlessly between the physical and paper world. The Digital Desk project [21] projected information onto paper and captured information from paper using complex vision algorithms, and the Paper PDA project of Heiner et al. [7] used document recognition algorithms and a document scanner to support information movement between the physical and electronic domains.

More recently, researchers have explored digital pen and paper technology such as Anoto's enabled paper and pens to transition between paper and electronic formats [22] [13]. Anoto-enabled pens contain a digital camera. When used on paper printed with a special dot pattern, the pen both writes on the paper and simultaneously captures stroke coordinates and timing information (based on the unix clock). By interpreting the underlying dot pattern on the Anoto paper, the pen can locate itself at specific (x,y) coordinates on a specific page in a specific notebook, and can indicate the time, in milliseconds, of each (x,y) point along the pen stroke. Two recent projects

of note have explored the use of Anoto digital pens coupled with computers to support more enhanced interaction. One project, ButterflyNet, explored the use of the Anoto pen (and digital cameras, GPS data, and other information sources) for information capture for field biologists, and a browsable digital repository of information on a desktop or laptop computer as a vehicle for browsing the information [22]. A second project, the Paper Augmented Digital Documents system, or PADD, used a laser printer to print documents on Anoto paper [5]. By using an Anoto pen to annotate electronic content, the documents could be augmented with useful notes and sketches, enabling "active reading." A gesture-based mechanism in PADD allowed pasting of prior paper content using specialized gestures activated by a foot pedal [11].

B. Student Information Capture and Management

Student information capture was studied as a component of the Classroom 2000 project, a smart classroom installation at Georgia Tech [20]. One key observation made during the study of student behaviour in lectures and while studying was the separation of capture and access into two distinct tasks with unique challenges. Capture challenges included making public streams available, supporting individual pacing, and the distinction between public and private, while access challenges included access to timestamps, support for browsing, and support for editing. The classroom 2000 project was a fixed installation, and did not explore the role that mobility plays in student information capture and management.

Other studies of tablet applications in education include the ChemPad, *Pad, MathPad, and related applications from Brown University, and the Livenotes application [9]. These special purpose applications take advantage of the affordances of the tablet computer, aiming to replace pen and paper with a computer.

One drawback of tablet computers is their size. Griswold et al. [3] note that handheld devices such as personal digital assistants are more ideally suited to the mobility of typical students. As a result, researchers have introduced handheld computers as educational appliances for students in both grade school classrooms and in university settings. In grade schools, Cole and Stanton describe a series of applications developed specifically for children [1], including a drawing application (Kidstory), and data display application (the Hunting of Snarf), and a data collection application (Ambient Wood). Sharples et al. describe an 'experience capture' application for handheld computers that teaches lifelong learning by allowing archiving of and reflection on everyday experiences [17]. On university campuses, handhelds have been explored as an information appliance, and as a reading appliance in courses. In the ActiveClass project [3], handheld devices on a wireless network allow students to note questions for the entire class, and to vote on questions. During breaks, professors can examine voted questions and answer those that have the highest priority to the largest number of students, preserving group anonymity in posing questions. As well, the ActiveCampus project [3] explores the use of handhelds to inform individuals on the current location of other individuals or of campus happenings. In both projects handheld computers are limited to posing questions, scheduling, other trivial data entry tasks, or to providing generic information rather than to comprehensive information management.

Marshall et al. studied the broader use of handheld computers for course readings, and noted some of the challenges associated with reading on small form factor devices [14]. Although it was rare for students in the study to read long passages on handheld devices, rereading passages and locating pre-existing information were both common activities. These are tasks which students often perform on their classroom notes, supporting the idea of a handheld device as a storage platform for classroom notes. Marshall et al. also note the need for some form of information capture and annotation on the handheld device to better support the information needs of students.

C. Summary and Research Direction

Rather than replacing pen and paper with tablet computers, our research aim has been to augment paper by designing technologies that incorporate paper and computers in complimentary roles. Past experience (e.g. the 'Paperless Office') suggests that attempting to remove paper from a work practice is unlikely to be successful. In designing augmented paper systems, our research extends the work of the ButterflyNet project [22], where suitable information management technologies are needed to compliment augmented paper. As well, rather than focus on one device, as in the PADD project, we explore the synergies that can exist through the use of multiple mobile computing devices, in our case handheld computers and Anoto digital pens.

III. SYSTEM DESIGN

Two software components have been designed to support the transition from electronic information to paper-based content in mobile contexts. These two components are a Pocket PC based application, PocketPad, and personal computer based software that supports the sharing of information between the handheld computer and the digital pen. In this section we describe each of the software applications and their role.

A. PocketPad: Storage, Access, and Reuse of HandDrawn Content

The primary component in our system is a Pocket PC based application pictured in Figure 3. Initially a repository view is presented to the user. This view is organized as a calendar, with dates containing content highlighted for the user. An arabic numeral in the bottom left hand corner of highlighted dates indicates the number of pages of hand drawn content associated with a specific day. The user can navigate by date to information contained in the repository. By clicking on a date with content, the content for that date becomes available, shown on the second screen, a drawing viewer screen.

On the drawing viewer screen, a user can navigate through drawings the current day's using Next and Previous toolbar

Fig. 3.   Interface screens for PocketPad

buttons located at the bottom of the screen. On a drawing of interest, the user can perform three tasks. First, trivially, he or she can reread the handwritten notes on the handheld screen. Second, he or she can annotate the drawing to create interpretive information associated with the content by pressing the button depicting a stylus. Finally, he or she can edit a drawing through selective re-use of pre-existing content by selecting content and then pressing the 'New Document' button. Buttons are shown on the enlarged toobar in Figure 1.

If a user selects the Annotate operation, the name of the drawing and time annotation started are stored by the Pocket PC. The user then creates a drawing on paper using the Anoto pen. When drawing with the Anoto pen, each physical ink stroke is also captured and time-stamped by the pen. Using the time-stamped pen stroke data and the stored time that the annotation operation was selected, association of pen drawing with a Pocket PC based repository document is performed. Annotation and source document are linked, and the annotated document contains a small label in it's upper right corner indicating that annotations exist, shown in Figure 4. A press-and-hold operation (analogous to right click) in the background allows navigation to and from annotation and source document.

Fig. 4.   Accessing annotations associated with a current drawing.

The user can also select a subset of strokes in the drawing using lasso-based selection, shown in Figure 5. De-selection is supported either by clicking on the display (de-select all) or by re-encircling previously selected content (selective de-selection). The user can continue to browse other drawings, identifying additional useful information that he or she may

wish to include in a new document. Eventually, the user can click on the "New Document" button, a dog-eared sheet of paper, to create a new electronic canvas. The user is prompted with a dialog which asks whether all selected strokes or only strokes from the current drawing should be incorporated into the new document. Selected strokes, either from the current document or from a number of documents, are cloned and placed on a new electronic canvas. The new electronic canvas is time-stamped by the Pocket PC application.

A number of editing tools are made available to the user when he or she creates a new document. While prior content may be relevant, its placement on a new electronic canvas may not be ideal. The user can move content around on the display by selecting content from the screen using the same lasso-based selection technique as above. As well, the user can select groups of strokes for translation using the Cycle-Selections button (centre panel in Figure 5). Strokes from a common source document constitute a group, as well as prior strokes previously selected and manipulated together. Handles, pictured as small, black squares in Figure 5 at right, allow resizing (the four corner handles) and translation (the central handle) of content. To improve rendering speed and responsiveness during translation and scaling operations, only the active handle is repositioned. At the end of the operation (on the pen up event) the translation or scaling operation is applied to the selected content.
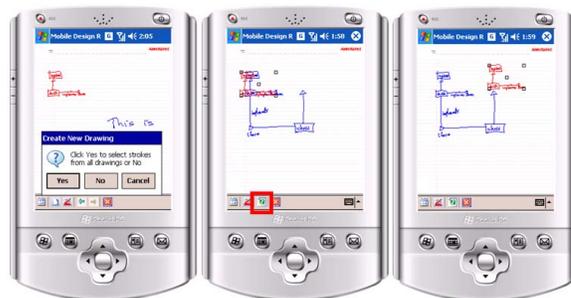

Fig. 5.   Creating a new drawing and editing stroke placement.

While the electronic canvas and paper do vary in size and resolution, the strokes on the Pocket PC, originally created on paper, are stored in full resolution and scaled to display size by the application. Translation and scaling operations appear to manipulate Pocket PC display content. However, the operations are performed on the original stroke data. Pocket PC stroke data (represented as scaled strokes) is recreated from the original full resolution data after each operation, preserving resolution of the original pen and paper content. The process of generating a new set of scaled strokes after each operation occurs in less than 300 ms for typical pen and paper sketches, providing the appearance of real-time rendering. Finally, also note that both the drawing and new document screens, Figures 4 and 5, contain a background image of the notebook page. This visual cue supports more accurate placement of content on the page, replacing specialized gestures used in some other

systems [11].

Once the new drawing canvas has been created, time-stamped by the system, and rearranged by the user, the user now serves as the bridge between the electronic content on the display and new information created on Anoto paper, a human-in-the-loop bridging of the electronic/paper divide. By taking elements from already existing designs in the repository and placing them onto a new time-stamped canvas, a partial drawing has been created. The user can use the Anoto pen to sketch on paper, and these strokes are stored for later inclusion in the new drawing. The Pocket PC display and the paper pad are of very different sizes, and the user must scale the image by visually estimating size and location on the paper surface. However, as shown in Figure 2, users are able to place physical pen strokes with high accuracy for inclusion on the logical canvas displayed on the Pocket PC screen.

B. Coordination of Pen Content and Repository Contents

The second component of our system is software infrastructure, currently a COM automation server in C# on a personal computer. When the user returns to a desktop environment and docks the pen and Pocket PC device, the software is automatically invoked. The software collects data from the pen using tools from the Anoto SDK. Using ActiveSync, the application programmatically synchronises the information from the digital pen with information in the Pocket PC. Due to the time-stamping of the canvas and of the Anoto pen strokes, drawings can be combined without manual intervention.

IV. EVALUATING POCKETPAD

We evaluated the PocketPad application system by conducting structured walkthroughs with 24 participants in small group sessions. Participants were drawn from a computer science class in our institution. The goal of our evaluation was formative assessment, specifically to analyze potential users' overall impressions of the PocketPad system and to determine the usability and usefulness of each feature. Walkthoughs lasted approximately 35 minutes, and a post-walkthough questionnaire collected users' impressions and suggested improvements.

In Figure 6, we see participants impressions of the Pocket-Pad system. Participants in our study rated PocketPad on a -3 = unfavourable to +3 = favourable scale. Shown in the graph is a boxplot. The solid black vertical line represents median response, the shaded box represents the 95% confidence interval for mean response, and the inner fences contain 99% of subject responses. As shown on the graph, participants 5 and 7 are outliers, and participant 9 is considered, by statistical software, an extreme outlier. The full range of data stretched from -1 to +3. Based on the depicted 95% confidence interval, we can conclude that participants have a positive impression of the PocketPad system. We also asked participants whether they thought PocketPad would reduce (-3) or increase (+3) the time associated with managing their handwritten notes (also shown in Figure 6). In this case, negative values indicate a reduction in time, and most participants thought that the system would

reduce the time taken to manage their handwritten notes. One participant, number 6, is an outlier. Analyzing this participant's subsequent responses, it appears that the participant may have inverted the scale, and assumed that +3 indicated that management would take less time.
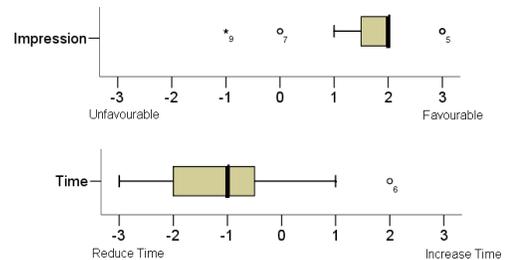

Fig. 6. Participants' response to the question: "What are your impressions of the PocketPad system?" and "How would PocketPad affect the time it takes you to manage your handwritten documents?"

One task that is not well-supported by our current handheld computer interface is searching the repository for information. When we asked participants to rate the features search, browse, create new drawings, and arrange electronic content between difficult and easy on a -3 to +3 scale (Figure 7), we see that search performed poorly in our interface, an expected result due to the lack of metadata associated with the pen-documents. We are exploring alternative repository visualizations based on information clustering approaches (see, for example, [19]) to enhance search. The other feature that presented some challenge for participants was the process of rearranging data on the handheld computer display. Using the black square handles to manipulate content worked well for most participants, but four found it challenging to arrange the content as they wanted. This is reflected by the large range in our box plot for difficulty in arranging content.
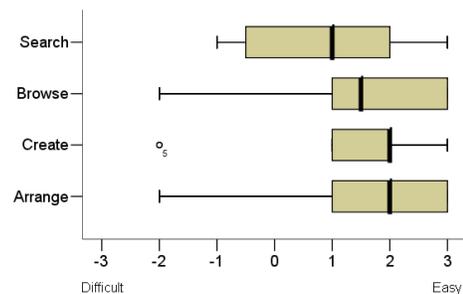

Fig. 7. Participants' response to the question: "Rate your impression of the following tasks in the PocketPad system between difficult and easy."

We also asked participants to comment on how important each feature is (not useful = 0 to useful = 7), and also how frequently they would use features in the PocketPad system (0 = never, 7 = very often). Results are shown in Figure 8. Examining the data, the calendar was the least useful feature, while the repurposing of pre-existing digital strokes

into new hybrid paper-electronic documents was the most useful feature, a surprising result. In terms of frequency of use, we asked our participants, as students, how often they would use the system to store, browse, study from, and edit their paper-based classroom notes, with generally positive results.
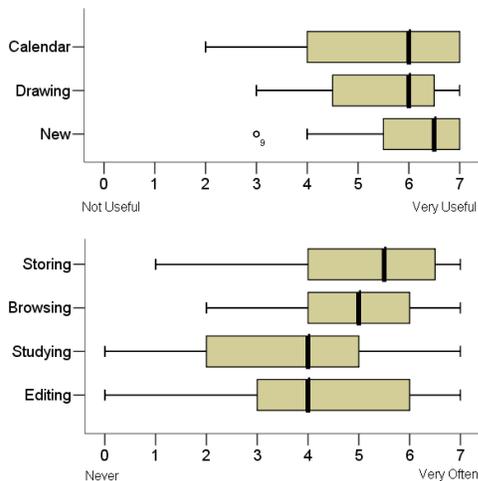

Fig. 8.   Participants' response

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V. Conclusion

This paper describes PocketPad, a software system incorporating digital pens, handheld computers, and desktop coordination software to manage pen and paper documents created during note taking by students in university classrooms. The system uses digital pens to capture handwritten information, handheld computers to store and browse content, and digital pens and handheld computers in concert to support editing and reinterpretation of existing electronic content. In tests conducted with university students, the system was highly rated. In particular, the ability to store and reuse classroom notes in mobile contexts was cited as a high-value contribution of this application.

This research contributes to the understanding of the synergistic use of different devices in mobile contexts. Using digital pens and handheld computers together, we show that the advantages and disadvantages of complimentary devices offset each other, producing a software-hardware system that enhances the usability of the individual devices. While this complimentary use of technology is well-established in other domains, its exploration in mobile contexts has received little treatment in the literature.

Finally, the use of visual spatial placement coupled with simple timing is a novel way to coordinate content from different sources. Using human abilities and timing, we overcome the pitfalls of error-prone recognition algorithms while creating a system for bridging the paper-electronic divide.

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