Penbook: Bringing Pen+Paper Interaction to a Tablet Device to Facilitate Paper-Based Workflows in the Hospital Domain

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ABSTRACT
In many contexts, pen and paper are the ideal option for collecting information despite the pervasiveness of mobile devices. Reasons include the unconstrained nature of sketching or handwriting, as well as the tactility of moving a pen over a paper that supports very fine granular control of the pen. In particular in the context of hospitals, many writing and note taking tasks are still performed using pen and paper. However, often this requires time-consuming transcription into digital form for the sake of documentation. We present Penbook – a system providing a touch screen together with a built-in projector integrated with a wireless pen and a projection screen augmented with Anoto paper. This allows using the pen to write or sketch digital information with light on the projection surface while having the distinct tactility of a pen moving over paper. The touch screen can be used in parallel with the projected information turning the tablet into a dual-display device. In this paper, we present the Penbook concept, detail specific applications in a hospital context, and present a prototype implementation of Penbook.

Author Keywords
hospital; pen input; projection; multi-display device

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation: User interfaces. - Haptic I/O.

INTRODUCTION
Handwriting using pen and paper is one of the most natural ways to interact with documents. Especially in the hospital domain, the low cost and flexibility of paper-based forms helped them to impressively withstand the digital revolution to the greatest extent. Their low cost is the most prominent of reasons for their persistence, i.e. they can be developed much cheaper than software. They also provide greater flexibility, i.e. forms can be altered and unplanned annotations can be added, and accomodate an innate legal bindingness when patients fill and sign these forms. For instance, patient registration, patient anamnesis, or the signing of prescriptions are just a few use cases that rely on the flexibility and ease of use of pen-based input. However, information written on paper

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Figure 1. The Penbook setup: a mounted tablet computer with an integrated projector augments a paper screen that supports digital handwritten input transformed to projected light.

documents needs to be transcribed into a digital form for further storage and quick access. This process is expensive and time consuming. In addition, paper-based forms are highly limited in terms of supporting users interactively to fill in the required information in each field. Yet this is easily possible with digital devices that can display additional help instructions in any circumstances. Hence, this raises the challenge of how to bridge the physical and the digital world while preserving the benefits of both.

In this paper, we contribute to the field by presenting Penbook, a novel multi-display device that supports hand-written input using a digital pen on real paper that is augmented with a projection screen, as well as an additional touch screen allowing for touch-based input. The device is the result of several interviews and discussions we undertook with nurses and doctors within the project *Hospital Engineering* that involves more than 50 German hospitals and companies working in the domain. We present the assessed requirements and how Penbook addresses these in the context of three real-world application scenarios. We present a first fully functional prototype which shows that interaction with Penbook is fast and easy and allows for diverse original interaction techniques. Results from an initial usability study indicate that users appreciate the gained flexibility provided through different input modalities.

We analyzed and identified the requirements for three typical scenarios: patient registration, patient anamnesis, and prescription signing.

In the context of *patient registration*, experts told us that, for instance, surgery forms can become very long and complex and many patients need help at least once while filling them out. Often, input space is too small for more difficult portrayals and together with the lacking support to undo written text, the final appearance of these forms often becomes unaesthetic and therefore hard to read for employees. Digital forms have the potential to resolve all these issues, but would imply that patients receive digital devices with e.g., soft keyboards that not all patients know to handle and could thus demand time-consuming support by the staff and lack support for signature. To combine the advantages of both worlds, we assessed that the registration form should still behave and feel like real paper, but with the added possibilities of undoing actions, optional space enlargement, and in-situ help through a connected device.

Patient anamnesis is in principal well suited for digitalization. Many parts of anamnesis forms carry simple information, e.g. aching in left knee, and can hence be mapped to check- and radio-boxes. However, they usually require the doctor to mark impairments or changes on x-rays or organ schemata. This demands very precise and flexible handwriting which cannot be supported on digital mobile devices as well as on paper. Even devices that support digital pens still suffer from the missing haptics, the optical misalignment, and reflections introduced by the thick screen glass, and usually sensor precision lying much below 600dpi. We assessed that handwriting precision was a critical supporting feature.

Finally, the process of *signing prescription forms* depicts a big disadvantage of the physicality of paper. In hospitals, patients often have to wait a long time for their prescription because the doctor does not have time to retrieve the prescription forms from the printer and sign them. A personal digital device of the doctor could address this problem by alerting to and presenting prescription forms to be signed. But as the unique signature of the doctor is key to prevent malicious usage of prescription forms, support for precise handwritten input is indispensable.

CONCEPT OF PENBOOK

From the requirements assessed with experts, we developed the Penbook. It consists of two main components: an upright standing touch-screen slate with a mounting support and an integrated pico projector at its top, and a paper canvas, layered by an Anoto pattern and attached to the Penbook's cover that is used as a projection screen and for input via a digital pen (see Figure 1). This setup retains the mobility of a slate device, yet enables different new options for interaction. In the following, we detail interaction techniques and illustrate their application using the aforementioned application scenarios.

Options for Interacting with Penbook

Penbook enables user input in four different configurations:

1. *Pen-based handwriting*. Unlike conventional digital pens that write with ink and additionally store a digital version of the user's handwriting, Penbook's pen leverages the projection to *write with light* instead of ink (see Figure 1). That is, the pen does not create permanent drawings on the paper canvas; rather the system traces the pen's movements and projects the paths onto the paper canvas. It is thereby not bound to conventional limitations of digital paper pens. For instance, drawing parameters such as color and stroke thickness can be changed. Also, the user can scroll within the drawing area by moving the pen over a scrollbar at the side of the paper, and further, drawings can be undone. At the same time, it keeps the haptic affordances of working with real pen and paper. For instance, this interaction is well suited for annotating content on the paper or the touch-screen (trough annotation links) with hand-written notes. When real ink is desired, techniques such as PhotoScription [2] could be added in the future to make drawings permanent.
2. *Touch-based input*. The touch screen allows users to perform multi-touch operations (see Figure 2 (left)).
3. *Pen-touch input*. The rear side of the pen allows for touch input on the upright touch screen (see Figure 2 (middle)). Hence, users are not obligated to put aside the pen when operating the system with only one hand available.
4. Bi-manual input. When using Penbook while sitting, users can interact bi-manually with the system. That is, while using the pen for input on the projected screen, the other hand is available for touch-based input on the touch screen (see Figure 2 (right)).

Figure 2. Interacting with the Penbook: (left) touch on the upright screen as well as pen-based input on the paper-based projection screen; (middle) pen-based input by using the rear side of the pen; (right) bi-manual interaction enables interaction with pen and touch simultaneously.

The flexible coupling of the displays allows for seamlessly transitioning the Penbook between a dual-display laptop-like posture and a standard single-display touch screen posture by folding the cover behind the device. These distinct postures cover a large amount of interactions and usage scenarios.

Application Scenarios

In the following, we describe how Penbook solves many issues of the analog workflows in the aforementioned hospital scenarios without constricting their flexibility.

Patient Registration

Penbook presents patients with a paper-like form on the projected screen which does not look much different from traditional paper forms. Therefore, patients should know how to fill in the form without prior training, as the changing of colors and tip sizes is not required in this scenario. Deleting strokes by crossing them out is detected by the system automatically. The touch screen further informs the user about an available interactive help feature which is triggered by touching information circles next to the corresponding input field. Touching the information circle brings up a large and thorough explanation regarding the corresponding input field and possible input examples on the touchscreen (see Figure 3 (left)). Further, the digital input allows for optical character recognition (OCR) and digital storage in the background,

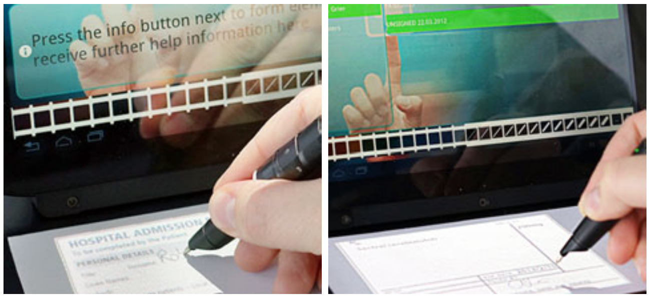

Figure 3. Penbook supporting diverse tasks in the hospital context: interactive patient registration (left); the issuing of prescriptions (right).

without the user noticing it or having to deal with its implications, e.g. correcting writing errors. The patient's signature whose penmanship fits the rest of the form's content assures the same legal bindingness as traditional paper forms. Thus, Penbook does not constrain the existing advantages of patient registration forms, but augments the experience with useful features such as undo, interactive help, and additional space because forms can also be scrolled horizontally to reveal space beside the paper boundaries.

Patient Anamnesis

Penbook offers a digital version of typical anamnesis forms. Instead of shuffling paper stacks to find the correct form, doctors choose from a list of available forms. Most parts of the form consist of check- or select-boxes. But as in traditional paper forms, every digital form also has a schematic organ view that is shown on the projected screen when a form is selected (see Figure 1 (right)). Doctors use it to precisely annotate impairments or changes to the medical condition on the paper, also using different colors and brush sizes. Here, the process is changed more radically, but retains and surmounts the level of precision and flexibility provided by paper, as required in the annotation context.

Issuing Prescriptions

Prescription signing requires a hand-written signature for authorization purposes. Using the Penbook enables natural signing of prescriptions as the prescription form and area for signing can be projected onto the paper (see Figure 3 (right)). When finished, the complete signed form is digitally available and can be encrypted and transmitted to the front desk to be printed automatically. As the Penbook is highly mobile, doctors can sign prescriptions directly after treatment.

IMPLEMENTATION

In the following, we first introduce the custom-built hardware setup and its components. Second, we detail the software architecture and integrated components. As there is currently no available slate device which features a built-in projector and paper-like cover, we designed and built such a system consisting of four main components which are described in the following.

1. A tablet computer (Motorola Zoom 2) that serves as the upright touch screen.
2. A smartphone (Samsung Galaxy SII) connected to a laser pico projector (Microvision SHOWWX+ HDMI) in order to control the projected screen and its content. The optical path of the projection passes two mirrors in order to increase its overall length. Despite the low brightness of the projector, the projection can be seen very well in standard indoor lighting due to the short distance to the projection surface and the innate sharp focus of the laser projector.
3. An Anoto pen, which supports hand-written input on paper equipped with a specific pattern. The pen does not dispense ink; instead, strokes made with the pen are projected onto the paper. The pen tracks the Anoto pattern on the paper to track its position on the projection screen using a built-in infrared camera. The information is sent via Bluetooth to the mobile phone. We reverse-engineered the communication protocol of the pen and wrote a driver to connect the digital pen to Android that allows fine-grained control over its features. Additionally, a capacitive cap was added to the tail of the pen and the pen wrapped with capacitive seam to enable pen-touch input on the touch screen. The abovementioned components are integrated into an aluminum case with a flexible stand and a foldable cover that contains the projection screen.

The commercial availability of projector phones (e.g. Samsung Galaxy Beam) indicates that the device could be built in a form factor similar to standard slate devices. The Penbook software components are jointly distributed between the devices.

The server component executed on the mobile phone is connected to the digital pen. As soon as the pen is activated (by taking it out of its holder that is fixed to the case), the connection is initialized and the pen continuously sends location data. Depending on the current setting for pen color and stroke thickness, new strokes are added to the projected image. The image is pre-warped to appear correctly on the projection screen (which is not orthogonal to the projector) after passing through the optical path that includes two mirrors. The necessary onetime calibration is facilitated by an interactive application that defines pre-warping and mapping of the reference system/position of the pen to the projection area. Pre-warping consists of mapping the projection corners to the corners of the paper's surface, and correcting the lens and perspective distortion of the projector. All algorithms are implemented as OpenGLES shaders, thus do not introduce noticeable delay.

Further, the mobile phone runs a Wi-Fi hotspot which allows the tablet computer to connect and communicate via an API to set or get various parameters of the current system state. These include changing pen features, setting or getting the projected image, attaching or deleting meta-information from any place on the projection screen, and storing and loading calibration data.

The client component running on the tablet computer controls the user applications. It leverages the API of the server to trigger the calibration procedure, change pen or paper (such as graph and ruled paper) properties, set or retrieve the projected output. The client is written as an Android fragment view that can be added to any Android application. It adds an expandable control bar at the bottom of the application that provides access to all system features.

INITIAL USER FEEDBACK

Before the hardware is going to be studied in a longer field trial (see Conclusion), we conducted an initial usability study with 10 non-professional participants (5 female) of average an age of 29 years (25-33 years). The objective was to understand how users interact with the device when coping with a task requiring parallel usage of touchscreen and pen for creating annotations.

Initially, we demonstrated all interaction features of the Penbook to participants and they had the opportunity to make themselves familiar with the prototype. Then we introduced them to a task, which was to browse a website and search for items (i.e., products) matching specific criteria (e.g., price). The goal was to decide which is the best available option. Participants could take notes using the pen and create annotations alongside the browsed website. Finally, clicking on notes with the pen brought users back to the corresponding websites to help them with their final decision.

After the practical part, we interviewed participants about their usage experiences. 9 of 10 participants emphasized that they would buy and use the Penbook if it was commercially available. One stated that he did not like his handwriting and that he was much faster with a hardware keyboard. 5 participants highlighted the interconnection between slate and projection, i.e. the backlink feature, as useful. 9 participants expressed that they very much appreciate the haptic affordance of real paper for writing (including one person who owns a high-class convertible laptop with a digital pen).

These results show a generally very positive opinion of participants towards the Penbook, and most participants cherished the benefits of the Penbook over traditional tablet computers.

RELATED WORK

In the medical domain, many systems employed pen interaction to provide intuitive interaction to physicians [6], but did not try to mimic real paper and did not employ multiple displays. Research prototypes such as Hinckley et al.'s Codex explored the design space of mobile dual-screen devices with pen and touch input [4], yet without including real paper or a projected display that benefits haptics and the device's form factor. Research on pen and touch modalities was extended by Hinckley et al. by considering the combination of both modalities which yields new interaction techniques [5]. Combining pen input with projected light has been demonstrated by Cao et al. [1] and further explored by Song et al. [7,8] using the architectural domain and uni- or bi-manual input. Here, users can explore different information layers and menus using the pen control. In these works, writing with light alone has not been explored, neither has the dual-screen context. Also, digital pens for input on tablet computers are commercially available, such as the APen [9]. However, the thick protective glass of the tablet computer results in an offset between the touch point and the displayed pixel. Further, they lack the natural haptic feeling of paper and can often not support a comparable input precision. In addition, they do not double the display area. Many works have further dealt with the support of information gathering e.g. [3], while our work focused on the support of existing paper-based workflows.

DISCUSSION AND CONCLUSION

The hospital domain still relies heavily on paper-based records and documentation, and the shift towards digital devices is slow. In this work, we presented the Penbook, a system that bridges the gap between the digital world and paper-based workflows as it combines the benefits of both characteristics in one device. Based on a domain-specific design process, we presented a first hardware and software solution with example applications that augment patient application forms with interactive guides, help the physician during anamnesis by supporting precise handwriting where required, and further, supporting trustworthy digital signatures. Results of a first qualitative user study indicate that users highly appreciate the concept and find it easy to understand and use. As part of the *Hospital Engineering* project, the Penbook will be used in a model hospital in a real world setting over a period of several years, and we hope to gain in-depth insights to how patients and physicians take advantage of such a multi-modal device. Further, as the tablet's built-in camera watches the projection area through the second mirror, we are going to further explore use cases that include object and paper tracking above the projection area.

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