DRAFT VERSION

Computationally-Enhanced Books: Blending Sensor-Based Interaction with Traditional Craft

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ABSTRACT
Books are an important part of early childhood. Pop-up and movable books add a touch of magic to the experience. Believing that the magic comes from the process of the craftsperson, we describe two computationally-enhanced books that blend traditional and digital craft to add the magic of sensor-based interaction to the experience. The first book explores the process of making handmade paper and takes advantage of embedded bend sensors and the flex of the page as an interface. The second book explores the use of pop-up elements as an interface to a set of video segments that help tell a story.

Keywords
Tangible, Ubiquitous, Craft, Physical Computing, Interactive Books, Paper-based Interface, Children's Technology

INTRODUCTION
The children's sections of bookstores contain an impressive array of creative/ inventive approaches to bookmaking and storytelling. Shelves are filled with paper-based interactive books. These books are also known as Harlequinades (or lift-a-flap books) whose movable paper flaps expose new images, Movable books that employ paper mechanisms to add interactivity, and Pop-up books with images that stand up and add physical depth to the depicted scenes. These books have captured the hearts of children and adults alike. And, through embedded sensors, this traditional media offers opportunities for rich computationally-enhanced interactive experiences.

There is a long standing craft to the making of paper-based interactive books. The iterative design process involves the regular handmade prototyping of mechanisms and the refinement of the related graphic elements. Although the printing and die cutting for mass production titles has now been automated, the complexity of pop-up and movable books still requires them to be assembled by hand [1]. It is in this spirit of hands-on crafting that this paper explores the blending of sensor-based interaction with traditional paper-based craft.

The value of traditional craftsmanship lies in a process of making that is steeped in history and has evolved through time. In contrast, the craft of digital technology is young and in a constant state of reinvention. As the interface evolves, researchers have recognized the potential benefits of combining aspects of physical items and technology [2]. In other words, the affordances of, and our interactions with, physical artifacts can be leveraged to create rich interactive experiences and intuitive interfaces. When approaching this blending from a traditional craft point of view, the craftsperson must understand the processes involved in both media, the values by which they are judged, and then use them to reinforce each other.

The relationship between the media must be carefully designed. As designers explore the intersection between physical and digital media they often fall into the pit of simply adding technology on top of traditional crafts. As a result, the rich tradition of the craft is overpowered and neglected. By carefully evaluating the strengths of the traditional and digital crafts, the roles of each can be defined and the two can be successfully blended.

The separation between traditional craft and technology is eroding. McCullough [3] argues for a new definition of craft, one that shifts the focus from requiring the hand and instead emphasizes the specialized skills involved in the individual processes. Meanwhile, researchers such as those at the Craft Technology Group at the University of Colorado seek to find ways of interweaving craft and technology [4]. With Moore's continuing trend for hardware to become smaller, more powerful, and less expensive, the erosion of the boundaries between

traditional craft and digital craft will continue as computation is embedded in everyday objects.

In this paper we describe the design and construction of two computationally-enhanced books. We begin by introducing some related work. Then we describe the design of both books and their implementation. Finally, we discuss some future directions for this work.

RELATED WORK

As popular media has evolved from print to electronic, interactive books and stories have followed suit. Emphasizing this evolution, the related work has been placed in three categories: paper, electronic, and (representing a blending of the two) computationally-enhanced.

Paper

The domain of interactive paper books does not entirely rely on books that are physically manipulated. The Choose Your Own Adventure series, starting in 1979 with Edward Packard's "The Cave of Time", spawned a whole genre of storytelling [5]. Choose Your Own Adventure books allow the reader to make decisions for the story's characters. As a result, a single book can be read several times, each with a different outcome. Although this series of books was discontinued in 1998, a quick web search shows that the genre not only still exists, but because of hyperlinks it has easily been adapted to the internet.

The Choose Your Own Adventure format doesn't currently lend itself to sensor-based enhancement. However, as progress is made with digital paper, this type of interactive book could become computationally-enhanced. Then, we could easily imagine that as the reader makes decisions, the new portion of text and images could be added to the page building a seemingly linear story.

Electronic

Interactive stories on cd-rom are a growing domain. Rebecca James identified two –"Payuta and the Ice God" and "Lulu's Enchanted Book" – as being of high quality in her study of how multimedia affects the reader's experience [6]. James concludes that they are successful because they follow a clear structure that allows the reader the freedom to explore the content within the boundaries of the narrative. And, the carefully crafted relationship between the images, text, music, and sound effects draw the person through the stories. This seamless collaboration between the parts is similar to the careful consideration that we emphasize when blending traditional and digital craft.

Computationally-Enhanced

The commercially available LeapPad is sold as an educational children's system that computationally-enhances paper-based books [7]. The system uses a tethered pen as a selection device that triggers related audio content and eases navigation. Unfortunately, the system cannot recognize pen strokes so its paper and pen metaphor is limited.

Listen Reader [8], an exploration similar to ours, focused on enhancing the immersive reading experience by providing an optional interactive soundtrack for the story being read. Designed for an exhibition, capacitance sensors embedded in the table under the book allow the users hands to trigger the story's audio sound effects. Observing that most interactive methods seem to distract the reader, our books instead focus on expressing the story through the interaction. Simply put, the interaction is integral to the experience.

BOOKS

The book is a powerful medium that has had a tremendous impact on society and culture. The book has become synonymous with knowledge. From monks' hand copying early religious texts to Gutenberg's experiments with the printing press and movable type, books have documented our thoughts, actions, and experiences. With the advent of the internet and electronic documents, the format has shifted from paper to the screen and the dissemination of information has become seemingly instantaneous. However, there is still a quality to the physical document that surpasses our experiences with screen-based media. The following two projects seek to bridge that gap through careful consideration of the affordances of the physical page as an interface for digital media.

THE HANDMADE PAPER BOOK

During a four-day workshop at the Haystack School of Art, one of us (Camarata) collaborated with two paper makers to make a computationally-enhanced book that focuses on the relationship between new computational technology and the age old craft of handmade paper.

Handmade Paper

As early as 4000 B.C. Egyptians were creating a paper substance out of papyrus. However, the "modern" process of making handmade paper was invented in approximately 105 A.D. by a Chinese court official named Ts'ai Lun. [9] Through time the art evolved, the skills spread to other countries, and the knowledge base grew to include an understanding of cellulose fibers and their effect on the paper being made. Just as people learned to work with fibers for making paper, today we are learning about

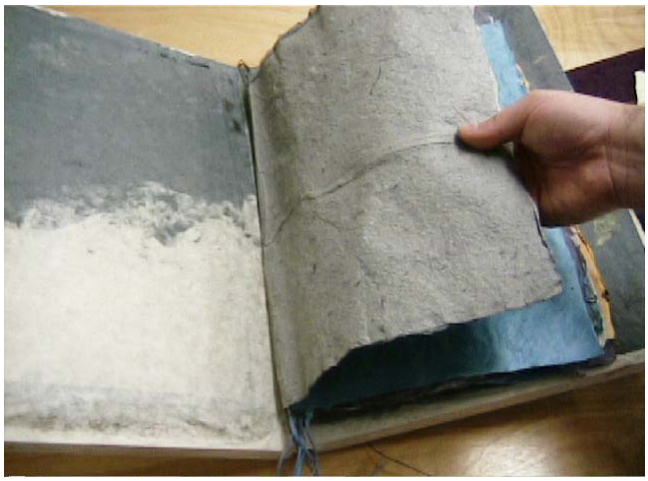

Figure 1 Flexing a page in the book of handmade paper triggers the playback of a soundbyte from the process of making the paper.

embedding computation. Artists who work with handmade paper delight in its subtle characteristics. A paper-maker expresses her connection to the craft and the value she places on it like this: "I value the time it takes to work with handmade paper because it gives me the chance to forge an energy and character from these materials, crafting each sheet as the artwork requires." [10] Although digital technology is relatively young, digital craftspeople express similar affinities toward their work.

Project Overview and Discussion

After a day of exchanging an understanding of the process of papermaking with an exploration of the realm of computationally-enhanced artifacts, we began embedding bend sensors into the sheets of paper that would eventually become a book. The flat profile of bend sensors and their subtle flexing interaction made them an ideal choice for use in paper-based media. Recording the sounds of the paper making process, we created digital content to attach to the physical book. Composed of six responsive pages, each with different visual character, the book invites visual inspection. Similar to lifting a flap to expose a new image in a harlequinade, flexing the handmade pages of the book (Fig 1) triggers the playback of sounds expressing the process of making the handmade paper.

In the handmade paper book, technology has taken the role of reinforcing the paper craft by providing an experience (sound) that focuses the user's attention onto the craft object itself. The subtle and intuitive action of flexing the pages brings the users visual attention onto the page where the fleck of the fiber and the texture of the page is the focus. Meanwhile, the audio feedback reveals clues to the process behind their creation. The story told is of the making of handmade paper. Through physical and visual interaction the "reader" gains subtle detail about the process. The topic of handmade paper obviously lends itself to the use of a book to tell the story and the affordances of the book as an interface easily support the digital / physical relationship.

The simplicity of using a book is carried over to its use as a computational interface. This gives the user a sense of control over the media. Our tendency to naturally flex the pages as we turn them offers an ease of use through simple manual interaction. And finally, though difficult to measure, the concept of using a traditional medium for transferring knowledge as a computational interface resonates with a wide range of users.

Figure 2 Pulling the tab on this page of the book "launches" the paper rocket and, by exposing an embedded photocell, plays a video depicting a rocket launch.

THE POP-UP BOOK

Pop-ups offer an interesting opportunity to build a relationship between this traditional interactive media and digital media. Pop-up books, through their direct manipulation (Fig 2), support a level of playful discovery often not found in other media. Referred to as "paper engineers", pop-up designers explore the use of physical actions (pulling, pushing, twisting, opening) to create these interactive experiences [11]. These physical interactions naturally lend the pages of a pop-up book to being used as input devices.

Pop-ups and Movable Books

Elements of pop-up books can be traced back to the 13th century and the "*success of a [mechanical book] is to be measured by the ingenuity with which their bookish format conceals unbookish characteristics*." [12] Prior to the 18th century the methods used in pop-ups to take books beyond

their typical text and graphic based expression were employed mainly for scholarly work.

Project Overview and Discussion

Our pop-up book was designed by a group of students in our physical computing course [13] and sits on a podium with an embedded flatscreen monitor. As visitors interact with the book's pop-up elements, videos that reinforce the story play on the monitor. The pop-up elements, graphics, and video segments were each carefully crafted and selected to reinforce each other and the story being told. For the purposes of prototyping the idea, students chose to depict a common urban legend that relates the width of the space shuttles booster rocket to the width of two horses. Each page depicts a segment of the story and each segment has a video that is triggered through a pop-up interface.

In this example the user's visual attention shifts from the book and its pop-up elements to the monitor and back again. This scenario is less than ideal. Embedding a display into the book itself, designing a new visual display, or focusing on audio enhancement, could have reduced the cognitive load associated with this shift and strengthened the relationship between the physical object and the digital media. Wanting to focus on video enhancement while maintaining the format of the traditional book the designers opted to minimize the shift by carefully scaling and positioning the book relative to the monitor. The resulting relationship, while not ideal, is nonetheless successful and is similar to the shift between the keyboard and the screen on a laptop computer. The playful, natural interaction of the pop-up book touches on the characteristics described by Alan Kay [14] and his desire to create a computer that would resonate with children.

IMPLEMENTATION

While the two books each take on a different character, their design and construction relies on the same two key components: embedded sensors, and the desktop/ microcontroller system that drives the interaction.

Embedding the Sensors in Handmade Paper

The process of embedding sensors into the pages is one of carefully applied skill and attention to detail. Pulling a sheet of paper involves submerging a deckle (frame) and mold into a vat of pulp and slowly pulling it up until it's above the water level. Once the excess water has drained, the deckle is removed and the mold (now covered in pulp) is turned over onto a felt pad (couched) to release the sheet of paper. A bend sensor is then carefully placed on the still wet sheet of paper. Taking advantage of the fold to be created when binding the book, we ran the wires from the bend sensor to the midpoint of the page, and then down the centerline so that they will exit the book at its spine. Preparing for the binding process, we also ran string down the centerline, leaving slack above and below the page. To finish the page, we carefully aligned and couched a second sheet of paper over the top of the first one. After pressing the sheets, the fibers bond the two sheets together, leaving the sensor embedded inside a sheet of handmade paper (Fig 3) that is ready to be folded and bound. This process not only erodes the distinction between the traditional craft and digital technology, but shows a balance being reached between understanding the process involved in the craft of papermaking and the process of creating an input device.

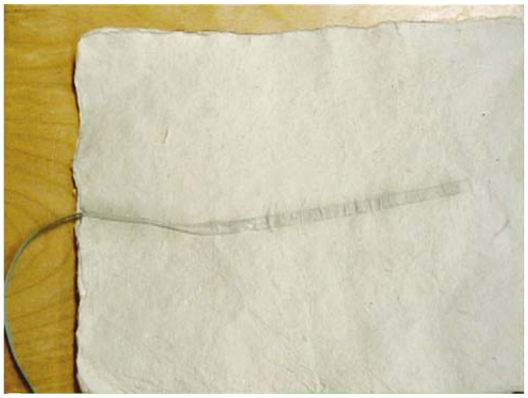

Figure 3 Test sheet of paper with the form of the bend sensor digitally highlighted

Embedding the Sensors in a Pop-Up Book

Using foamcore as the core of the pages and wrapping them in carefully crafted pop-up veneers, the student designers embedded CdS (cadmium sulfide) photocells into the pages to sense the shift in the movable pieces (Fig 4). The first prototype used magnetic reed switches and small rare earth magnets to detect the shifts. However, the sensitivity of the switches and the sloppy nature of paper parts made this scheme unreliable. Using an approach that is similar to the handmade paper book, the wires were run to the binding and out the spine of the book. The simple lesson learned was to choose the right technology for the craft. Without recognizing the sloppy nature of the paper interface it would be easy to design a project that is unreliable and frustrating to use. The realization that opening a book to a specific page results in adding light to the page's surface led the student design team to create an engaging experience.

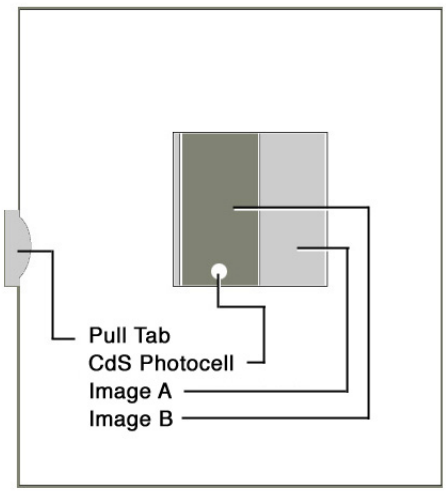

Figure 4 Diagram of a pop-up page that includes a pull-tab with a sliding image that trips an embedded sensor by covering and uncovering it

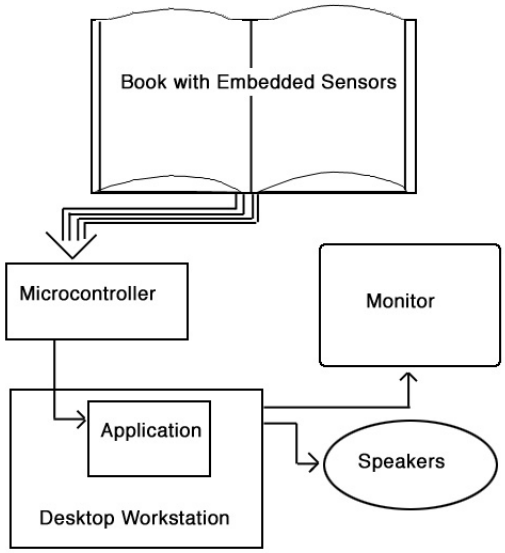

Figure 5 System Diagram

System Overview

Both of these books are currently tethered: wires lead from the book to an ensemble of analog and digital electronics. We expect that as trends of hardware to decrease in size continue, these books will become portable like traditional physical books. The technology that drives the interaction of these prototypes consists of a desktop computer and a microcontroller. The microcontroller reads the sensors in the book to determine the page the user is on. Based on the value it receives from the embedded sensors, it transmits a value to the desktop machine that represents the action that needs to be taken. On the desktop computer an application reads the incoming serial data and processes it. The processing includes determining what file should be played and if the file is already being played so that it can cancel repeated calls. Finally, it plays the appropriate audio or video file (Fig 5) until either another file is selected or the clip comes to an end.

FUTURE WORK

The pop-up book offers an interesting opportunity for future exploration. The creation of a pop-up tangible toolkit could explore the range of pop-up / movable parts and define uses for each element. This merger between inexpensive paper-based media and low cost easily embedded sensors expresses an interface solution that could easily become ubiquitous.

There is a rich body of literature that describes the benefits of engaging children in the process of making. There is also a growing body of literature that engages children in computational, robotic, and sensor-based learning activities. The pop-up tangible toolkit could act as the foundation for a computational construction kit that allows children to author, design and build their own interactive books.

The current version of the handmade paper book maintains an artistic presence and purposefully avoids using text and images. It is easy to imagine a new version that is more educational. With the addition of video, images, and text, the "reader" could learn how to make handmade paper and the pages of the book could act as a visual example of the characteristics and qualities that are valued within the craft.

Continuing to explore paper-based media, we can imagine constructing a physical book that can be used to explore a dynamically changing electronic resource such as a web site. Bridging the gap between a static object and a dynamic resource would mediate the relationship between well established and documented information that is often found in physical books with the constantly changing and evolving nature of related information that is being created and served to the world through electronic resources.

And finally, in J.K. Rowling's "Harry Potter and the Prisoner of Azkaban" [15], she describes a paper-based media that could soon be a reality. Her vision of the Marauder's Map as a map that tells the current location of the occupants in Hogwarts School of Witchcraft and Wizardry can be thought of as a digital paper output device being used within a sensor-rich environment.

CONCLUSION

This paper has presented two computationally-enhanced books. These projects take advantage of the direct manipulation qualities of pop-up and traditional books to control related multimedia content.

The design of these two books takes the affordances of paper-based media into careful consideration and uses digital media to help tell their stories. As a result, the interfaces are intuitive. The reader simply needs to know how to turn a page or interact with the mechanisms within a pop-up book.

The pop-up book has been exhibited to guests and visitors. All of them responded with enthusiasm. Judging from the smiles on their face and the resulting conversations, the careful blending of paper-based and digital crafts has given these computationally-enhanced books a magical quality that is worthy of continued exploration.

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