Hello World: A Children's Touch and Feel Books enhanced with DIY Electronics

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Figure 1: Our textile touch-and-feel book enhanced with DIY electronics.

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Abstract
A variety of interactive books, including 'touch and feel books', enable children to physically learn and develop knowledge. We developed an interactive touch and feel book for children that integrates sound and LED light to enhance the child's interaction. Our project explores the development of textile-based electronic touch and feel books, integrating textiles with ready-made and self-made sensors and actuators in a book format. It is called 'Hello World' as this is the common name of the very first program by someone new to software or hardware development, and thought ta good metaphor for children exploring their very first touch-and-feel book enhanced with interactive features.

Author Keywords
E-textiles, Crafting, DIY electronics, Arduino, Children.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

Introduction
The integration of technology in learning environments is most constructive to young children's lives when it supports childhood activities and development of abilities, such as talking, manipulating, pretend play,

Visual Design of the Pages

Figure 2: The Fish page with water bubbles.

Figure 3: The Bear page with flowers on the adjacent page.

Figure 3: The Firefly page (light sensor visible as two dots on the belly, LEDs in the stars on the adjacent page).

reading, constructing, exploration, and reflecting. Introduction to technology begins when children play with electronic toys and digital games that provide opportunity to learn about and *with* technology [13].

The aim of our project was to develop an interactive textile touch-and-feel book for small children, using e-textiles with embedded electronics for the book's construction components, with haptic, audio and visual feedback on the children's actions. This feedback motivates children to explore and use their senses actively. Our prototype book addresses the senses of seeing, hearing and feeling/touch. We here provide an overview of our system design, focusing on technical implementation. We build on traditional touch-and-feel books (available in bookstores or done by crafters, labelled quilt books) for toddlers that aim to help children develop knowledge involving all their senses, in particular fostering tactile recognition of materials and texture and triggering imagination. Many books include tasks for children, such as the texture of depicted animals, or train precise finger movement, e.g. tying a shoelace. We argue that traditional touch-and-feel books do not activate all senses, being limited to touching and feeling objects and textures. Via technical manipulation of sensors and actuators we can provoke the other senses, which allows learning not just by touching and seeing, but also hearing and further activities that train the child's motor skills.

Using e-textiles as components for construction enabled us to embed electronics into the book. Fabric-based touch, pressure, stretch sensors provided opportunity to combine these with textiles without having to use additional electronic components. We report on lessons learned, which include construction approaches that accommodate and safeguard components and overall circuitry, and addresses the need of proving access for repair. We discuss our solution for a soft yet stable support system for pages that holds electronics in place and still feels soft on the hands of children.

Related Work

Learning through and with technology comes in many ways, for example, books, toys, games, smart devices. Various projects [3, 7, 11, 12] showed the potential of interactive surfaces to support of children in their early developmental stages. Moreover, multi-sensory activities and feedback cultivate the attention span of young children. Augmenting books and reading has a tradition in HCI. Various kinds of interactive books have been developed, such as electronic paper-based pop-up books [10], Augmented Reality books [1, 4, 5] or gamebooks [9] which offer readers various options to choose from and may even change the storyline as they read. Most interactive paper interfaces are based on the properties and tradition of traditional paper books, thus, so far there has been no demonstration of how to build or construct a textile-based interactive book.

The Rewear' project [8] explores modular 'plug-and-play' construction kits for re-constructing existing textiles (e.g., hats, scarfs, shirts) with interactive electronic and computational behaviors without sewing or coding. It mainly aims at engaging younger children (ages 4-12) in creative design, play, and customization of e-textiles/wearables. Plushbot [6] enables children to plan and design their own computationally-enhanced stuffed toys. This system works with the LilyPad Arduino [2], a toolkit that enables novice textile designers, engineers along with a collection of

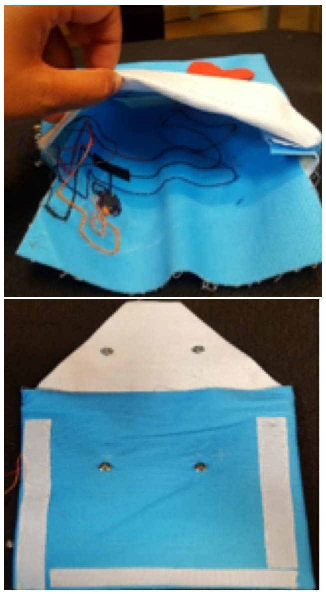

Figure 5. Electronic Pocket template with flexible cables, the back flap with snap fasteners and the Velcro sewed on the edges of the page

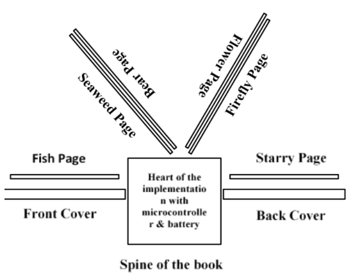

Figure 6. System architecture of the book

computational devices suitable for use with fabrics and conductive thread.

Concept Design

The core concept was to develop a textile touch-and-feel book for toddlers, enhanced with electronic interactivity. While many toys that children use during playtime are made of plastic or wood, they also enjoy fabric toys that are soft, gentle and comfortable when holding or playing with them. Textile books for toddlers tend to not have a traditional storyline; instead, each page constitutes a story or activity that children can engage with independently.

Our prototype book shows three separate characters – Fish, Bear and Firefly (see figures 1, 2, 3). For our implementation, the feedback given to children's interactions was selected based on the primary senses - seeing, feeling and hearing. When the fish's tail is pulled, it activates a buzzer to play a tune. For the bear, touching or pressing softly on its furry belly gives vibration feedback. The firefly's interaction is to turn on and off LEDs on the page when covering an integrated light sensor. A small LED next to the sensor is intended to attract the child's attention, and dims when covered.

Hardware Implementation

We constructed the book in a modular way by sewing individual pages and connecting them with Velcro to form a book (figure 6). This design keeps the circuit of each page separate and enables easy access for repair (by opening the Velcro). Each user-facing page has its circuitry and electronics on the backside (figure 8). Backsides of adjoining pages are attached to each other, hiding the electronics (see figure 6). The pages for the final book are 20cm by 20cm.

To better accommodate the electronics and attach them to a suitable surface for each page, an L-shaped cutting pattern was cut from the selected fabric of each page, with a width of 55cm (see figure 4). This L-shape was sewn to form an 'electronic pocket-template' to hold the sensors and actuators inside (figure 5). The creation of each circuit begins by sewing the electronic components on extra fabric along with flexible wires, which then is inserted into the electronic pocket template (see figure 5). To close the 'pocket', snap fasteners are sewn on. This extra layer of fabric, that electronic components are sewn onto, ensures precise positioning of cables with respect to position of sensors and actuators inside and outside the pocket. To support each page for stability and protect the circuits, the pocket was padded with foam. All electronics connect into the book's spine, which further holds the central intelligence (microprocessor) and batteries and will be described in a follow-up section.

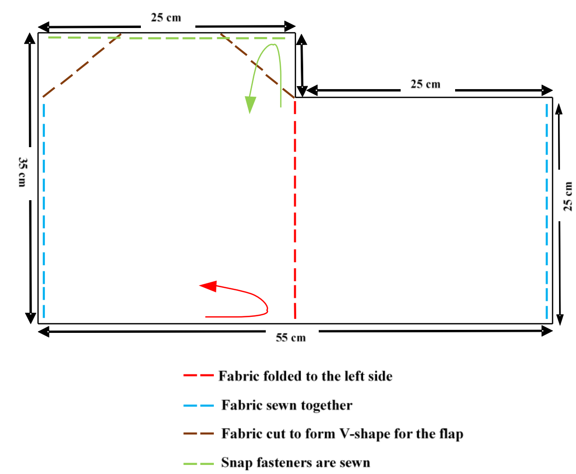

Figure 4: L-shaped cutting pattern of the electronic pocket template.

The page circuits

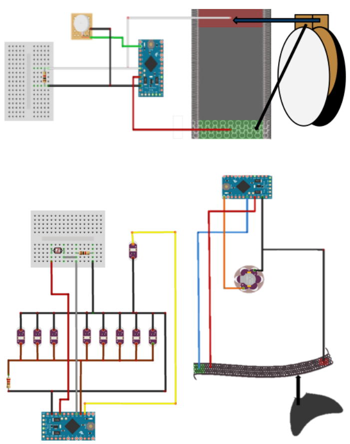

Figure 7: Circuits for bear, firefly and fish

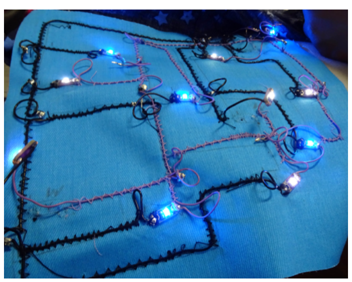

Figure 8. Flexible cables and Lilypad LEDs sewn on extra fabric.

Initially, we intended to use conductive thread from 100% polyamid material with a silver coating. But this turned out not to be reliable enough. Consequently, for stable connection, while maintaining flexibility of the circuit, plastic coated flexible cables were used, which were sewn on in a zig-zag pattern with a wide stitch. The cables that are connected to the microcontroller via the book spine are attached to conductive snap fasteners.

The individual pages

For the fish, a Lilypad Buzzer and stretch sensor were used to trigger a sound (see Figure 7). The fish's tail is made from resistive fabric. There are different variants of stretch sensors made from knitted fabrics integrating conductive yarns to pre-fabricated conductive/resistive fabrics [15]. We used a ready-made resistive fabric for the tail. Even though the fabric can be stretched to its maximum length, it goes back to its original length. Using fabric as stretch sensor does have limitations, such as influence of environmental conditions (e.g. air humidity) and long-time usage decay.

Touching the bear's belly activates vibration feedback from a small disk motor (see Figure 7). Due to budget reasons, we constructed the vibration board manually. The board along with a coin type vibration motor were sewn on the extra fabric along with flexible wires. Beneath the bear belly fur, conductive fabric is glued on. This is separated with Velostat from another layer of conductive fabric. When the belly is pressed, the two layers come in contact, pressure resulting in change of resistance in the.

As for the firefly, a photo resistor and multiple LEDs were deployed. When the photo resistor in the firefly's tail is half or fully covered (in darkness), this turns on the LEDs placed on the adjoining page among the stars (see Figure 3). To avoid draining energy by activating the LEDs when this last page is closed (so the sensor would detect darkness), two patches of conductive fabric on opposite corners detect opening. Here, Lilypad LEDs were the ideal option because they can be directly sewn onto fabric.

Design Challenges

One of the major challenges encountered during the design and construction of the book was the integration of components and connections from the individual pages to the microcontroller.

For traditional books, the spine acts as a backbone that supports stability, compactness, durability and anchors pages. Fabric-based electronic books also require a spine to hold the book together. Moreover, the spine can form the central infrastructure for connecting the electronics of individual pages and to the core intelligence, the Arduino Pro Mini microprocessor and batteries. Here we explain the building technique used to form a spine for the fabric book by adding electronics to traditional binding.

The spine must accommodate electronic parts, the microcontroller, batteries, etc., and must also provide access to these components in case of replacement of electronic components due to malfunction. The idea was first sketched on paper (figure 10), to understand the design, the spaces required for components and how connections to the microcontroller should be located on the spine. The paper sketch was then transferred to a sample fabric to further test this idea before implementing it in the final book. A length of

Figure 9: Book spine with micro-controller and connections from individual pages.

around ten cm was measured between the front and back cover of the page. This space, acting as spine, accommodates the connection from all pages to the grid with conductive fabrics and snap fasteners, microcontroller and battery (figure 9).

For the final execution, individual pages were sewn together on their edges closest to the spine on an extra fabric, through which the connections were extended out to the spine of the book (figure 11, 12). In principle, each page's circuit of sensors and actuators can be directly connected to the microcontroller. However, a direct connection can create issues as cables are long and wobbly, which would not hold components securely in place. Since the book is constantly opened and closed, unstable connections and constant shuffling of cables can result in cables detaching from respective components. Loose cables also do not provide easy access for replacing electronic components. For these reasons, a connecting layer from the pages to the microcontroller is needed that secures connections and renders them accessible. To form this connecting layer, a bridge using conductive fabric along with snap fasteners (adapted from e.g. [14]), where cables can flexibly adjust with the movement of the page and extend the connection from the sensors and actuators to the microcontroller in a secure and stable manner.

This network and layering of conductive fabrics and conductive snap fasteners was first drawn to plan the spine. Based on this sketch, a prototype and then a working network was developed. To avoid accidental connections between conductive fabric strips with multiple connections on a single layer within the limited space of the spine, each electronic circuit was put on one layer. This also make the spine more space-effective. We thus sub-divided the circuit into three different layers (see figure 10 and 11), The first of 3.5cm x 5cm in height and width, the second 7cm x 5cm and the final layer 10.5cm x 6.5cm. To compensate for the limited space available, each layer was placed one on top of the other thereby providing adequate gap to sew snap fasteners.

Issues encountered included difficulties sewing layers on the spine and not having constant and stable connections when the book was opened up. The dimensions of the layers were increased by 0.5cm in length and height to further stabilize connections on the grid. In addition, cardboard pieces spanning a centimetre less than the fabric were adhered on the back of the layer fabrics using hot glue to support and further ensure constant and stable connection through the bridge. The extra fabric on which the individual pages are sewn can be joined to the spine based on the cover of the book with snap fasteners. This modularity of the spine allows for the easy access for the replacement of electronic parts by simply unfastening the snap fasteners (see figure 11).

The modular design of the spine eases replacement of electronic components and provides easy access to change battery or check the connections. We estimate that with our current hardware design, the spine offers enough space for the wiring related to 5-6 interactive pages (each with a separate layer). With more complex books, the need will grow for such 'infrastructure' and modularization components and architectures. Here, we have shown how the book spine can serve to contain core parts of this infrastructure and to connect everything together - extending the traditional 'binding'

The Book Spine as Central Infrastructure

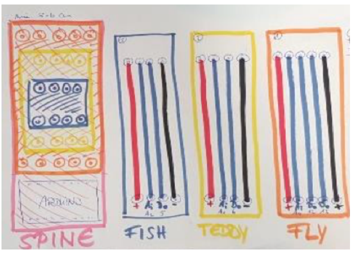

Figure 10: Layer sketch.

Figure 11: Close-up of the three different layers with conductive fabric and snap fasteners for each circuit.

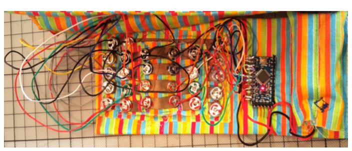

Figure 12: Integrated connections from pages to spine.

and connecting architectonic function of the spine into the digital world.

On completing the pages and assembling the book, we ran into issues pertaining to interaction with the fish tail. Since it is constructed from stretch sensors and stretch fabric, connecting a flexible cable to the fabric was a challenge. However, we could remove the tip of the cable leaving only the copper strands of the cable. These strands were pierced through the resistive fabric and the tip of the copper strands alone were sewn with conductive thread to the fabric. Although there is no easy technique to connect wires with fabric, this method sufficed. Another option for connecting cables and a fabric is to use conductive snap fasteners, where the female part is stitched onto the fabric and the male part has the cable looped through the holes and then soldered. But, in our case, snap fasteners do not fit with the interaction of the tail to be pulled, for which reason we had to select our less 'elegant' solution.

Using the Arduino Pro Mini not only worked well with textiles, but also due to its small size enabled us to reduce the size of the book, making it easy and comfortable for small children to hold and interact with. This formation of the spine for the fabric book in comparison to traditional binding provided sufficient space to sew on an Arduino Pro Mini, whereas a Lilypad as core intelligence would have extended the spine width and occupied larger space, thereby making the book larger and rendering it difficult for small children to interact with the book without assistance of parents.

Conclusion

Our demo shows a textile touch, feel and hear book for children: 'Hello World' promises new ways of interaction for children to support their sensory and motor-skill experiences when 'reading' their first books. Based on DIY knowledge and our e-textile experiences, it is designed modular with integrated electronics consisting of ready-made hardware components and self-made textile sensors.

We have described how we constructed a textile-based interactive book. With the techniques described here, we can proceed to develop more advanced and complex textile-based interactive books. Future work includes scaling the hardware and material design for larger/longer books with more varied interactions, detecting which pages are opened (to simplify electronics), and more complex interactions suitable for older children, as well as making the hardware design smaller and more stable (e.g. waterproofing). We further aim to replace the Velcro connections (that hide the electronics in-between visible pages), as these leave a visible gap, intrigue children to open them up, and increase material volume, with e.g. zippers (inset zippers like those used to hide the opening gap in cushions) that are almost invisible and require manual dexterity to open up while not adding much weight or volume.

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