Felted Paper Circuits Using Joomchi

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Abstract

The integration of electronics and paper is a burgeoning
topic for tangible interaction. Here we show how to use the
Korean technique of hand-felting paper known as *joomchi*
to embed electronics in paper after the sheet forming process.
This method requires the use of specialized papers that are
amenable to joomchi. We present embedded LEDs, multi-
layer circuit "sheets", and speakers. While labor-intensive,
joomchi both enables one to completely integrate paper
and electronics, while also making tangible connections
between ancient and modern craft.

Author Keywords

paper circuits; hanji; joomchi; craft

ACM Classification Keywords

J.5 [Arts and Humanities]: Arts, fine and performing

Introduction

The deep integration of paper and electronics is a growing
area of interest for human-computer interaction researchers
[7]. Given thousands of years of experience with different
forms of paper around the world, paper provides a versa-
tile material for new forms of tangible interaction due to its
affordances of ubiquity, familiarity, and ease of modification.

Recent work surrounding the integration of paper and electronics has followed a number of different trajectories. Researchers have shown how to embed electronic components during the forming of individual sheets of paper, developing what they call "pulp-based computing" [3]. The combination of thermochromic inks and layers of paper have enabled artists and designers to create works that change color in response to touch and heat [6, 23, 24]. New developments in inexpensive conductive ink and paint have allowed for the printing and/or drawing of circuits on the surface of paper [9, 20, 21]. Shape-memory alloys have provided for novel movement mechanisms [14, 22, 19]. Copper tape has enabled the construction of "circuit stickers" that can be used to teach the basics of electronics [15, 16]. Various forms of cutting and depositing copper traces on the surface of paper have allowed for new kinds of flexible speakers [10, 18, 17]. Combinations of some or all of these techniques have suggested new ways to think about the intersection of electronics and books [4, 13, 12]. In sum, there is now a vibrant community of researchers tracing out various potentialities for paper computing.

We contribute to this body of work by showing how to use the Korean method of hand-felting paper called *joomchi* to embed electronic components into the paper after the sheets have been formed. Joomchi requires specialized papers with particular material qualities such as the Korean paper called *hanji*, a long-fibered paper made from parts of the paper mulberry tree [8]. Hanji has recently become more well-known in the West through the dedicated advocacy of the artist and researcher Aimee Lee. Joomchi enables one to take a stack of multiple sheets of paper and, through repeated hand agitation with water, felt the individual sheets into a single sheet, with the electronic components embedded *within* the paper itself. This creates a seamless integration of paper and electronics without the complication and difficulty of processing fibers and forming paper by hand.

Paper Characteristics

While there is a large amount of research into the integration of paper and electronics, few of these projects have addressed the specific *materiality* of particular kinds of paper, although the pulp-based computing research of Coelho *et al.* is a notable exception [3]. We think this is a significant oversight, as different types of paper have unique characteristics depending on the choice of fiber, method of separating fibers, and sheet-forming process, amongst other considerations. Here we give a brief overview of why we are working with hanji and why such paper is necessary for joomchi, illustrating how long-fibered papers like hanji could be of interest to the TEI community.

Papermaking is an ancient craft, and all manner of plant fibers have been used to make paper, such as cotton, wood pulp, or the leaves of invasive weeds [5]. Here we are interested in the particular qualities of the inner bark or "bast" of paper mulberry trees, known as *dak* in Korea or *kozo* in Japan (hanji is almost exclusively made of *dak*, while Japanese paper, known as washi, can be made from *kozo* or other plant fibers) [1, 8]. *Dak* fibers are rather long in comparison to other plant fibers (on the order of 12mm, in comparison with 4mm for Western-style pulp), and the process of hand-beating *dak* in order to make pulp does not chop up these fibers but allows them to retain their length [1, 8]. The particularities of the hanji sheet-forming process also allows for an incredibly strong sheet, so much so that hanji has been used for windows, floors, shoes, teapots, umbrellas, and armor, amongst many other objects [8].

No matter the source fiber, "pulp" generally refers to these processed plant fibers suspended in water. This pulp be-

comes *paper* through hydrogen bonding of cellulose between the fibers themselves as the water evaporates from the pulp after a sheet has been formed [1, pg. 290]. Hanji's strength comes primarily from this hydrogen bonding of its long fibers. Because of this strength, the fibers between two or more sheets of hanji can be "felted" together through joomchi, a craft that has existed for hundreds of years and has recently become well-known amongst papermakers due to the teaching of workshops by artists such as Jiyoung Chung and Aimee Lee [2, 8]. Joomchi involves wetting sheets of hanji (or washi made of kozo) and, through various forms of hand agitation and manipulation, melding multiple sheets into one through the formation of new hydrogen bonds between fibers of the original sheets.

Because of the merging of multiple layers of hanji into a single sheet through joomchi, any inclusions (for example, electronic components) that we place on interior sheets become a part of the new single sheet of hanji. This allows us to take advantage of the characteristics of hanji without having to embed the electronics as inclusions at the time of sheet formation, an option unavailable to most given the specialized equipment and training necessary to make hanji or other types of specialized paper. We are also able to draw upon the wide variety of dyed papers available on the market. While labor intensive, joomchi therefore enables anyone to embed electronics into paper (rather than placing them on the surface, as in many other paper electronics projects), while at the same time extending an ancient craft into new directions.

Example Joomchi Procedure

We use a slightly modified form of joomchi from that described by Jiyoung Chung in her book *Joomchi & Beyond* [2]. Credit goes to Chung for creating easy-to-follow recipes for different types of joomchi; we nevertheless outline the most basic steps here, as well as provide visual documentation in Figure 1. Joomchi has many variations that could be of use to the paper computing designer, and we encourage those interested to examine Chung's book.

1. On a single sheet of hanji (Japanese washi made from kozo can also be used), sew the electrical circuit desired (Figure 1a).

2. Place additional sheets of hanji above and below the sewn sheet(s) from Step 1 (Figure 1b).

3. Thoroughly wet with a spray bottle all sheets of hanji. It is helpful to wet each sheet individually, building up the stack sheet by sheet, and ensuring that there are few to no air bubbles between the sheets (Figure 1c).

4. For the first "round" of joomchi, accordion fold along the horizontal edge, then roll into a cylinder. Agitate the cylinder by compressing it evenly in your hand, ensuring that all parts of the cylinder receive equal agitation. The cylinder needs to remain wet throughout this process, so spray with additional water as needed. Agitate for ten minutes (Figures 1d and 1e).

5. Unroll the cylinder, and roll it up in the opposite direction. Agitate for 10 minutes.

6. Unroll and unfold the sheet, then accordion fold in the vertical direction. Repeat steps 4 and 5.

Unroll and unfold the sheet. At this point you will have agitated for around 40 minutes (Figure 1f). The next step can be repeated *ad infinitum*, but should be done at least four to five times.
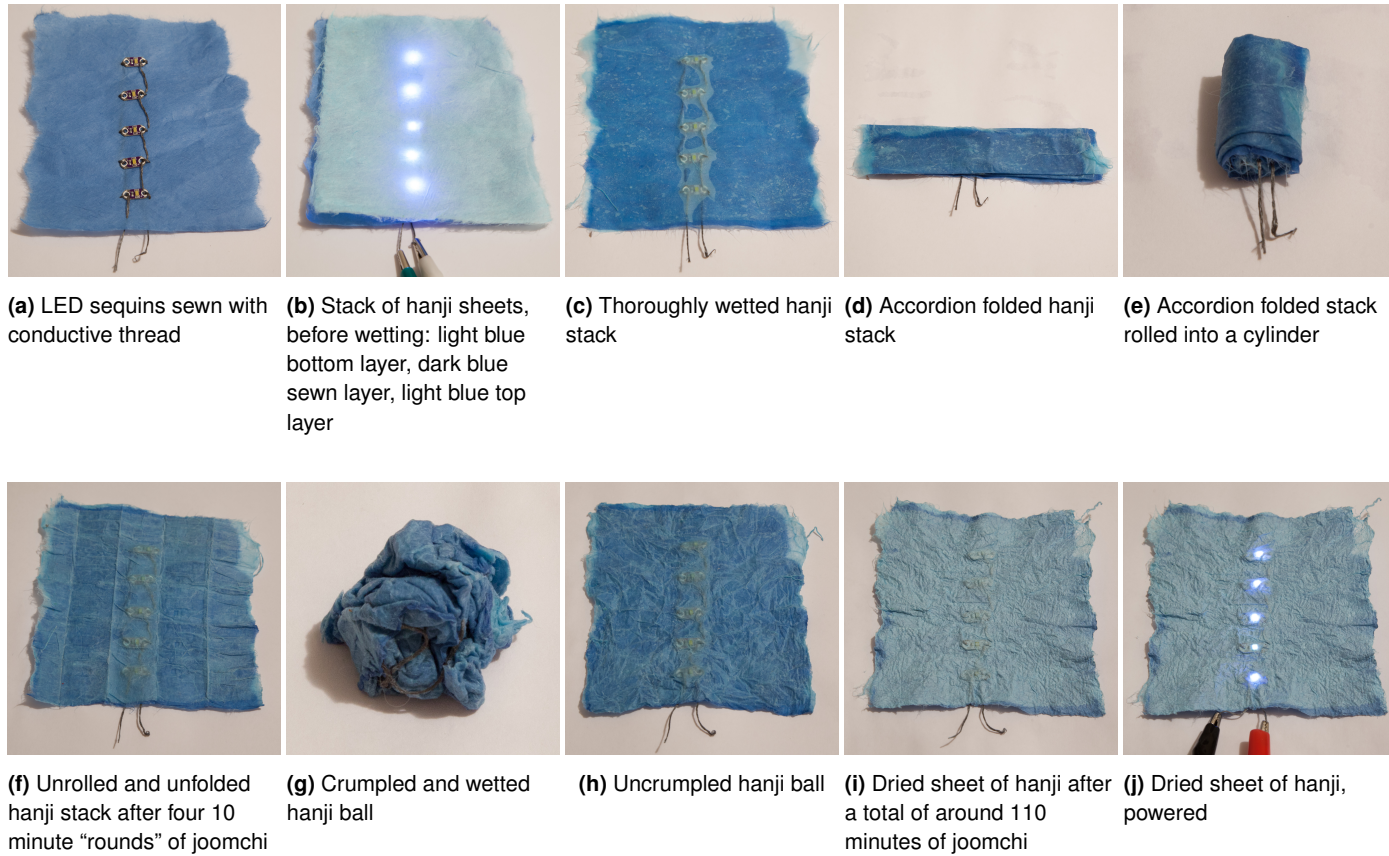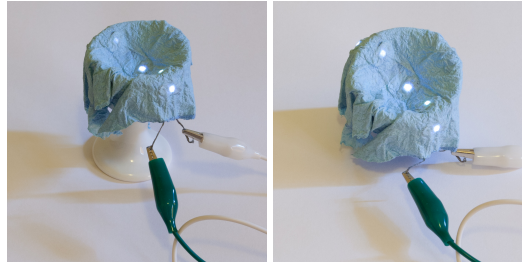
(a) LED sequins sewn with conductive thread

(b) Stack of hanji sheets, before wetting: light blue bottom layer, dark blue sewn layer, light blue top layer

(c) Thoroughly wetted hanji stack

(d) Accordion folded hanji stack

(e) Accordion folded stack rolled into a cylinder

(f) Unrolled and unfolded hanji stack after four 10 minute "rounds" of joomchi

(g) Crumpled and wetted hanji ball

(h) Uncrumpled hanji ball

(i) Dried sheet of hanji after a total of around 110 minutes of joomchi

(j) Dried sheet of hanji, powered

Figure 1: Illustration of joomchi steps

(a) Hanji sheet from Figure 1 that has been re-wetted, draped over an object, and left to dry.

(b) Draped circuit without underlying object, showing how the sheet retains its form.

Figure 2: Draping circuits made of hanji after joomchi.

7. Re-wet the sheet and crumple it into a ball. Agitate by squeezing the ball evenly for 10 minutes (Figures 1g and 1h).

A properly felted sheet of hanji will take at least 80 minutes of hand agitation, and likely upwards of 120 minutes (Figures 1i and 1j). The amount of agitation needed is dependent on the original size of the sheet (in this example the sheet was around 5" on a side) as well as the number of sheets in the stack[1]. As is clear from the figures and the list of steps, joomchi is likely not amenable to the embedding of large, inflexible components, although new techniques might make this possible. For now, inclusions need to be small and/or malleable, such as small LED sequins and conductive thread. As well, inclusions need to be able to withstand being soaked in water, at least for the duration of the joomchi and drying processes. So far standard LED

sequins have continued to work even after being continually soaked in water during joomchi, but their long-term viability is an open question. Conductive threads will likely move around somewhat during joomchi, thus threads carrying differing signals need to be separated by a reasonable distance at the time of sewing.

Following joomchi, the sheet is by default relatively stiff, with the feeling of leathery skin. This can be modified by gently rubbing the sheet in one's hands to soften the paper [2]. With enough time, the paper takes on the characteristics of cloth, with all of the draping possibilities that implies.
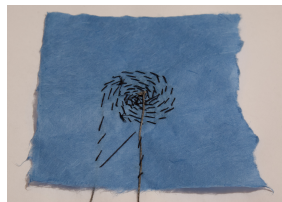
Further examples

The example shown in Figure 1 involved sewing five LilyPad LED sequins[2] to a sheet of hanji using conductive thread. We show here other examples of felted paper electronics made through joomchi.

- It is possible to take a sheet of hanji after joomchi and, by re-wetting it, allow it to drape and take the form of an underlying object. We took the sheet shown in Figure 1 and draped it over an egg cup and let it dry. The resulting sheet retains its shape even without the underlying object (see Figure 2).

- Because of hanji's strength, we can have electronic inclusions that can be seen from the front and back of the sheet, creating what we could call a "sheet circuit". By using layers of hanji as insulators *between* two individual layers that have electronic inclusions, we can replicate the insulating material of printed circuit boards (see Figure 3).
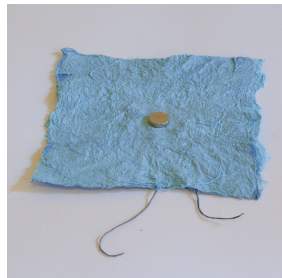
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[1]There is often some shrinkage in both horizontal and vertical dimensions after joomchi.

[2]https://www.sparkfun.com/products/10081

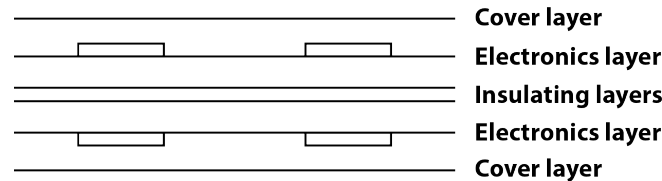**(a)** Embroidered speaker made from conductive thread, front.

(b) Embroidered speaker made from conductive thread, back.
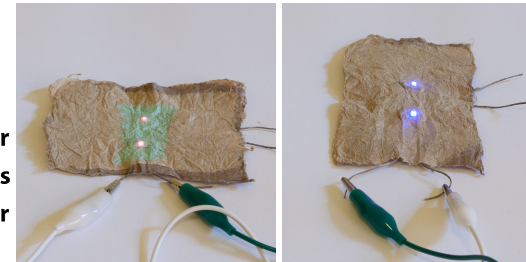

(c) Embroidered speaker after joomchi, showing placement of neodymium magnet.

Figure 4: Creating a paper speaker through joomchi.

(a) Diagram of a hanji stack forming a "sheet circuit", shown end-on before the individual sheets have been felted together through joomchi.

(b) Front side of a hanji "sheet circuit" after joomchi.

(c) Back side of a hanji "sheet circuit" after joomchi.

Figure 3: Creating a "sheet circuit".

- We can also create paper speakers by sewing conductive thread in a spiral pattern and attaching a powerful neodymium magnet, drawing upon the work of Hannah Perner-Wilson (see Figure 4) [10, 11].

These examples act as proofs of concept that show some of the potential for the embedding of electronics in paper through joomchi.

Future Work
The examples of paper circuits in this paper are the beginning of our research into the intersection of hanji, electronics, and joomchi. We intend to further refine our procedure to make the sewing more resilient to joomchi, as well as considering other methods of joomchi besides the basic one used in this paper. We will also explore the possibility of using conductive inks or paints to create bend and capacitive sensors, as well as the embedding of NFC tags for the storage of small amounts of data *within* the paper itself. The purpose of our investigations is to weave together the most appropriate affordances of paper and electronics. In sum, we hope that others consider how the specific material qualities of different types of paper could be useful in creating novel paper circuits, while at the same time enabling one to extend old forms of craft into new directions.

Acknowledgements

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