String Figuring: A Story of Reflection, Material Inquiry, and a Novel Sensor

Josephine Klefeker
ATLAS Institute
University of Colorado Boulder
Boulder, CO 80305, USA
josephine.klefeker@colorado.edu

Laura Devendorf
ATLAS Institute
& Dept. of Information Science
University of Colorado Boulder
Boulder, CO 80305, USA
laura.devendorf@colorado.edu

CHI'18 Extended Abstracts, April 21–26, 2018, Montreal, QC, Canada

ACM ISBN 978-1-4503-5621-3/18/04.
https://doi.org/10.1145/3170427.3188570

Abstract
We describe a process of materials inquiry that gave rise to a new kind of sensor: a string figure sensor that correlates resistance changes with the topology of a closed loop of string. We describe the critical and reflective process from which our string figure sensor emerged, how the sensor works, and the future applications we envision our sensor supporting.

Author Keywords
Sensing; Critical making; Reflective design; Feminist Technoscience; Material Correspondence;

ACM Classification Keywords. K4.0 Computers in Society: General.

Introduction
This is a story of a design project that wanders: starting from a motivation to explore fiber-arts for feminist retaliation and culminating in the design and development of a novel soft sensor. Perhaps best characterized as an act of reflective design or critical making, the story of design that we will tell ties together feminist theory, material studies, and cultural reflection to suggest a novel form of sensing - a string figure sensor. The string figure sensor is a concept or early prototype for a string-based sensor that can know something of its own shape. We created a proof of

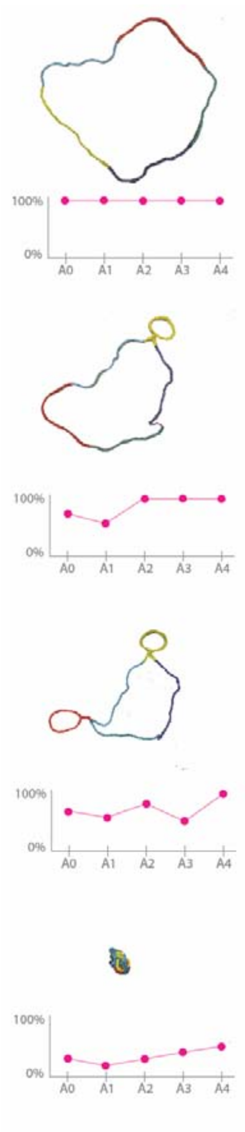

Figure 1: Shapes and corresponding resistance signatures (shown as % = measured resistance over max resistance).

concept by knitting conductive thread and wool around a wire core, resulting in a semi-rigid loop that feels similar to a pipe cleaner in one's hands. When someone plays with the loop, the crosses and knots created in it result in measurable changes in resistance. We take resistance measurements at five points along the length of the loop to create a resistance "signature" that correlates to various shapes or figures created with the string.

The following paper describes our process, the resulting sensor, and the future interactions we envision around this sensor. As we do so, we hope to articulate how the cultural, material, and political dimensions that informed our design were useful in pushing us to consider new kinds of interactions with familiar materials.

Related Work

Our process is inspired by a growing body of materials-led research taking place within CHI (e.g. [9]). These approaches often draw from craft and look to the qualities of the materials themselves to inform the design process. As such, design becomes a dialog or a form of "correspondence" [6] between the designer and the materials. The particular materials we were playing with are often characterized as "e-textiles," a mix of conductive yarns, copper tape, and traditional yarns. Hannah Perner-Wilson and Leah Buechley are perhaps best known within HCI for their experimentations with e-textile materials [1,13]. They have developed a suite of novel sensors using techniques of sewing, weaving, crochet, and knitting for others to replicate. More recently, a growing number of researchers are looking to textiles to create novel body-worn sensors and displays (e.g. [3,7,10]). The sensor we describe in this paper most similar to other forms of soft-potentiometers and self aware string-like sensors [2,8]. Yet, our design is unique in its attempt to capture meaningful information about knotting along a long piece of string. By describing our sensor, we look to add another idea to the suite of techniques available for soft sensing—a technique that uniquely leverages the properties of its materials and histories of playing games with string. String figure games have been discussed within CHI as both novel interaction techniques (for light painting [11] or remote play [12]) as well as a metaphor relating to the relationship between things in a design process [4]). We were most inspired by the latter, exploring the metaphor figuratively and literally throughout our process.

Design Process

As we suggest in the introduction, this process was open-ended and improvisational - combining theoretical reflections with material practice. As such, we describe our process by briefly describing the key points of insight that occurred along this journey that we think helped us see new uses for yarn in sensing.

Engaging Yarn on its own Terms

The project began with an idea to combine knitting and technology to further or embolden knitting as an act of feminist retaliation. Take the Women's March and "pussy hats" where some participants utilized knitting, a skill often associated with women, and embraced it to make a statement about women's bodies and rights [13]. This movement seemed to live on beyond the hats themselves because knitting and yarn were forever imprinted. Our intention was to push this relationship, to analyze yarn and why it was affected in such a way. We also sought to further politicize yarn

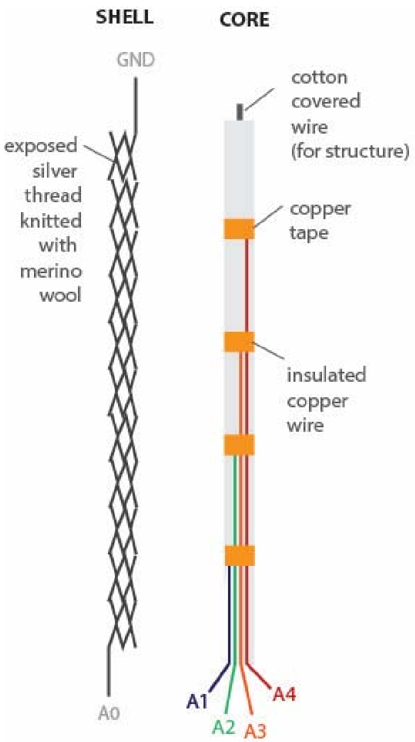

Figure 2: A structural diagram of the string figure sensor

and investigate acts of feminist fiber arts through a material perspective. Initially we wanted to explore a yarn-based input to an interactive system for reflecting on women's issues, experiences, and rights. We started by knitting with conductive and non-conductive yarns, with the intent to discover a new way to map the act of knitting to sound (perhaps a politicized version of [7]). At the same time, we reflected on the varying social connotations of yarn, rope, and string. However, it quickly became evident that our early attempts to politicize the gendered connotations found within yarn ran the risk of further enforcing these connotations rather than provoking reflection around them. It was at this point that we decided to move away from our political inspirations and focus on creating something open-ended, creative, and not intentionally provocative as a way to explore the material qualities that our feminist perspective brought us without asserting more about gender identity than we were currently capable of.

Our next endeavor was to aimlessly make with yarn in order to bring out diverse connotations. However, it felt impossible to disentangle our personal assumptions about yarn. All of the assumptions we had about knitting had carried over to the speculations we were making about yarn as a material. Moving forward we felt a need to disrupt our habitual ways of making. And hopefully, return with a wider understanding of the material and knitting as well.

Moving from Knitting to String Figures

Heading forward, we brainstormed other methods of aimless making, considering ideas around unraveling, other fiber arts, and eventually string figures. Because string figures are different from other uses of yarn that we were familiar with, we had fewer preconceived ideas about what they ought to be What interests us in string figures was the idea of being the tool yourself, no needles, hooks, or hoops, just your hands. It's tactile and immobilizing. With yourself being what is keeping your string figure alive, there's suspense and attachment. These restrictive and bodily aspects were interesting to us because they forced a direct contact with the material. String figures invite an uninhibited exchange between the player and the string being played.

String figures also create interesting links to historical forms of play as well as contemporary feminist critique. Specifically, Donna Haraway used the metaphor of string figures and cat's cradle to describe interrelationships between people, things, and environments, emphasizing the processional, contingent, and tangled nature of relationships [5].

The String Figure Sensor

Our playful material engagements and ongoing reflection culminated in a proof-of-concept prototype that we call the "String Figure Sensor." Our string figure sensor can be understood as a potentiometer with multiple output readings. It measures resistance changes caused when the string figure sensor makes contact with itself, for instance, through crossing or knotting. The problem with only having only one conductive loop within the string was that after the circuit was "shorted" or made contact occurring along the rest of the string, it limited the shapes the sensor could potentially identify (for example, a loop crossed at the ends would have the same resistance as a knotted ball). Our approach was to measure resistance changes along multiple lengths of the sensor. This allows us to gather more information about the

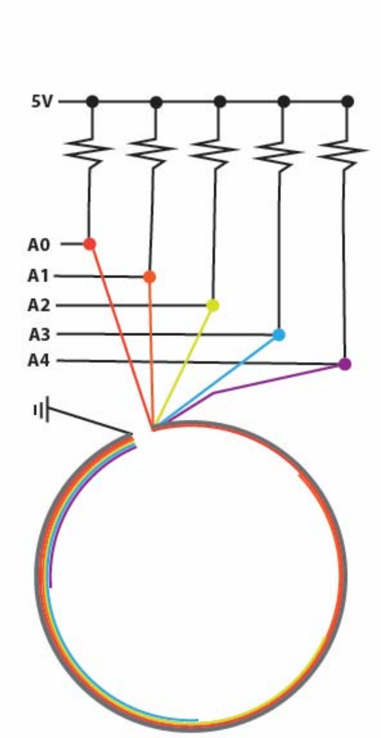

Figure 3: Schematic diagram for obtaining resistance measurements with an Arduino

topology of the sensor, for instance, which sections are crossing as well as a relative measure of how complexly knotted the sensor may be. Structurally, we accomplished this by making the sensor from a core and a shell that encases the core.

Shell Structure & Construction

We created the shell by knitting merino wool with uninsulated silver thread in the shape of a hollow tube. Thus, when the length of yarn makes any sort of contact with itself, it "shorts" the circuit, or lessens the path of resistance. We produced the shell by feeding one strand of thin, conductive silver yarn and one strand of merino wool yarn, together, into a small knitting machine (Figure 3). The knitting machine we used was an Embellish-Knit! spool loom, which allowed us to turn a crank to produce a hollow knitted tube. The resulting tube is roughly a centimeter in diameter. We alternated the color of the merino wool along the length to visually indicate the various regions of sensing. While we experimented with stainless steel thread as well, it was ultimately wasn't smooth enough to be fed through the knitting machine.

Core Structure & Construction

The core consists of a long cotton-wrapped wire with varying lengths of very thin (32AWG) insulated copper magnet wire attached to it with copper tape. The cotton wrapped wire is not used for sensing, but only to give the sensor a semi-rigid feel and the ability to hold a shape, much like a pipe cleaner. It also keeps the shell from making contact with itself when squished. The sensing occurs on the thin insulated copper wires as well as the silver thread in the shell. We stripped the ends of these wires of their insulation using sandpaper and then attached them to the core using copper tape with conductive adhesive. Thus, when the copper tape makes contact with the silver thread on the shell, it transmits the current from the copper wire to the shell, when it takes the shortest path to reach ground. We integrated the core into the shell during the knitting process: holding the core in the center of the knitting machine and letting the knitting machine knit around the core. Knitting around the core also allowed all the output wires to come out of one end of the string, making it easier to avoid tangles when playing with sensor. We found the knitted tube structure to offer several advantages for sensing string figures. First, it helps the yarn easily make contact with itself by keeping lots of conductive yarn exposed, which ensures that any time the string crosses, there is a measurable point of contact. Secondly, the hollow structure allows the core to be stuffed, in our case with a semi-rigid wire, allowing resistance values to be more stable by preventing the two side of the shell from touching.

Obtaining a Resistance Signature

To measure the resistance along the varying lengths of our sensor, we wired each segment of the sensor to a unique voltage divider with a source voltage of 5V. Each unique segment is connected to an analog port on an Arduino, allowing us to measure resistance as the string takes on various shapes. We call the collection of measurements across the string a "resistance signature" and through testing, we are able to make some claims about the shape of the sensor based on the resistance signatures (Figure 1). The resistance of the longest segment in our sensor was 585 Ohms. The complexity of knots makes it challenging to determine the exact shape from the resistance alone but we intend to explore the following two strategies in future technical work: First, since a string figure is created

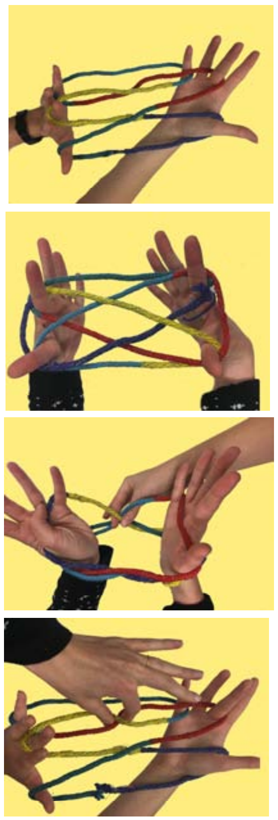

Figure 4: Narrative Cat's Cradle

through a series of steps and crossings, we are curious to experiment with machine learning to see if we can determine the shape of the string figure by mapping its resistance changes over time. Second, rather than using the sensor to determine any arbitrary shape, we are experimenting with the ability to see if we can determine which of a discrete set of shapes the string might be in. To aid in both these efforts, we have been developing software that simulates knotting patterns and calculates the resistance signature for any given shape. The software allows a user to input a resistance signature and generate a set of possible shapes that are capable of producing that signature. (https://github.com/Devendork/stringfigures)

Envisioned Interactions

Our sensor invites tactile interaction because it's curious looking, soft, and sculptural. It asks to be understood through play. We found it enjoyable to manipulate, coil and uncoil, wrap around our fingers, arrange into shapes, or even just squish. All of the following future visions we propose aim to embrace this quality and attempt to use it as a way to bring attention to the cultural assumptions of the objects with which we interact.

Narrative Cat's Cradle

One of our earliest inspirations was Donna Haraway's consideration of string figures as having the capability to make tangible the ever-evolving connections that occur between beings [5]. In string figure games, stories aren't limited to the literal forms that string figures might embody but are also told through shapes, angles, points, hands, and textures. The motions inherent to cat's cradle for example—passing, pinching, pulling, crossing—can often generate points of self-contact on the length of yarn, subsequently creating changes in resistance (Figure 5). We envision leveraging these moments to link certain traits of the string figures to specific sounds in a library such as correlating length, density, or number of twists with specific sounds or spoken narratives. We could also and correlate other attributes like speed and passing to qualities like volume, pitch, or distortion. Thus, the player of the string could utilize the string figure form almost like a puppet, enabling them to physically craft an abstract narrative.

Reflective Headphones

A significant portion of the interactions we have with headphones go unnoticed: untangling, wrapping, fidgeting with them while waiting. We envision combining our sensor and headphone wire (Figure 6) so we can monitor knots that occur on the headphone wire and convey these moments to the wearer. For instance, the pitch of the audio could be adjusted by how "knotted" the sensor has become. With pitch being suggestive of a male or female voice—there is potential for introspection pertaining to these movements and the materials they're being made with. The ability to distort audio through gesture entangles the user in this audio-yarn web, interrelating themselves with the movement/pitch connection, in turn opening a forum for reflection and storytelling.

Understanding and Translating Fabric Motion

The semi-rigid state of the sensor makes for unusually playful applications; It seems that it would have compelling interactions with motion when exposed to forces like wind or gravity (Figure 7). A future use that we brainstormed was to line clothing with a string figure sensor and then track all of the bends and

Figure 5: Reflective Headphones

Figure 6: Example of recording fabric motion

movements that occur to our clothing when we aren't wearing it. This could become particularity interesting when in an environment like the dryer, where movement is especially exaggerated. We could even imagine these movements informing a performance piece such as dance—where a performer recreates the movements of clothing worn apart from the body, physicalizing the autonomous motion of the fabric.

Conclusions and Implications for CHI

Our material inquiry into yarn allowed us to see beyond traditional interactions to generate forms of sensing with yarn that embraced it as a material. Its form allows for playful and interesting non-linear inputs that invite a tactile interaction with the material. Furthermore, the design process itself led to interesting reflections and tensions between what materials "represent" within a particular frame and the multitude of other representations they may embody. Moving forward, we will continue to reflect on the flow of materiality and representations within yarn and how our design can fully embrace the material. Additionally, we plan to investigate the connection between material and gender through further engagements with feminist geography, anthropology, and making.

References

1. Leah Buechley and Hannah Perner-Wilson. 2012. Crafting Technology: Reimagining the Processes, Materials, and Cultures of Electronics. *ACM Trans. Comput.-Hum. Interact.* 19, 3: 21:1–21:21.
2. Artem Dementyev, Hsin-Liu (Cindy) Kao, and Joseph A. Paradiso. 2015. SensorTape: Modular and Programmable 3D-Aware Dense Sensor Network on a Tape. In Proc. UIST '15
3. Laura Devendorf, Joanne Lo, Noura Howell, et al. 2016. "I Don't Want to Wear a Screen": Probing Perceptions of and Possibilities for Dynamic Displays on Clothing. *In Proc. CHI '16*
4. Laura Devendorf and Daniela Rosner. 2016. Beyond Hybrids: Metaphors and Margins in Design. In Proc. DIS '16
5. Donna J. Haraway. 2016. *Staying with the Trouble: Making Kin in the Chthulucene*. Duke University Press Books, Durham.
6. Tim Ingold. 2013. *Making: Anthropology, Archaeology, Art and Architecture*. Routledge, London ; New York.
7. Ivan Poupyrev, Nan-Wei Gong, Shiho Fukuhara, Mustafa Emre Karagozler, Carsten Schwesig, and Karen E. Robinson. 2016. Project Jacquard: Interactive Digital Textiles at Scale. In Proc. *CHI '16*
8. Philipp Schoessler, Sang-won Leigh, Krithika Jagannath, Patrick van Hoof, and Hiroshi Ishii. 2015. Cord UIs: Controlling Devices with Augmented Cables. In Proc. *TEI '15*
9. Vasiliki Tsaknaki, Ylva Fernaeus, Emma Rapp, and Jordi Solsona Belenguer. 2017. Articulating Challenges of Hybrid Crafting for the Case of Interactive Silversmith Practice. In Proc. DIS '17
10. Anita Vogl, Patrick Parzer, Teo Babic, Joanne Leong, Alex Olwal, and Michael Haller. 2017. StretchEBand: Enabling Fabric-based Interactions Through Rapid Fabrication of Textile Stretch Sensors. In Proc. *CHI '17*
11. Marina Wada, Akito Nakano, Yoshifumi Mizuno, and Hisakazu Hada. 2016. The Light Painting by a Fluorescence String Figure. ACM Press, 1–5.
12. Lining Yao, Sayamindu Dasgupta, Nadia Cheng, Jason Spingarn-Koff, Ostap Rudakevych, and Hiroshi Ishii. 2011. RopePlus: Bridging Distances with Social and Kinesthetic Rope Games. *CHI '11 EA*
13. KOBAKANT. http://www.kobakant.at/.