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Frequency-Based Design of Smart Textiles

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Figure 1: Using Teksig to reliably identify pinching on a wrinkled textile.

ABSTRACT

Despite the increasing amount of smart textile design practitioners, the methods and tools commonly available have not progressed to the same scale. Most smart textile interaction designs today rely on detecting changes in resistance. The tools and sensors for this are generally limited to DC-voltage-divider based sensors and multimeters. Furthermore, the textiles and the materials used in smart textile design can exhibit behaviour making it difficult to identify even simple interactions using those means. For instance, steel-based textiles exhibit intrinsic semiconductive properties that are difficult to identify with current methods. In this paper, we show an alternative way to measure interaction with smart textiles. By relying on visualisation known as Lissajous-figures and frequency-based signals, we can detect even subtle and varied forms of interaction with smart textiles. We also show an approach to measuring frequency-based signals and present an Arduino-based system called Teksig to support this type of textile practice.

CCS CONCEPTS

• **Human-centered computing → Systems and tools for interaction design**.

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KEYWORDS

Lissajous; Smart Textile Design Practice; Arduino; Frequency.

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1 INTRODUCTION

Even though there are an increasing amount of smart textile design practitioners globally, the methods and tools commonly available for creating a textile with sensing capabilities have not progressed or evolved in the same scale [26]. In practice, a typical smart textile sensing circuit is resistance-based. It is developed with sensors that only measure the resistance changes due to deformation of the textile (e.g. bending [5], pressing [13], or stretching [32]), or using conductive yarn to make switch-like connections. The interactions built on these inputs are thus equally limited and error-prone as, for instance, a stretch creates the same effect as a squeeze.

An alternative to a resistance-based sensing circuit, are smart textiles design that uses capacitive touch sensing. This enables interactions without the need for direct physical human-material contact but are based on proximity, for example, hovering, swiping, in addition to more direct forms of touching (i.e. tapping, pressing [12]) [9]. However, while capacitive sensing enables a broader range of interactions, its sensitivity to surrounding electricity, and the need for a program to calculate the capacitance, create technical challenges. Evidently, this makes it challenging to determine whether the input is coming from the intended source through a specific interaction, or as a result of electrical noise from surrounding humans, objects or devices, or even from nearby mains power.

In both approaches, separately and in their combined use, the interaction relies on the assumption that the signal originates from the interaction detected by the sensor. As there is no reference signal or source to compare it to, the cause of the possible signal change may become difficult to verify or determine. This is the reason why both of these approaches are used in conditions that: 1) are predominantly used on a surface with constrained movement to limit non-interaction signals (e.g. [23]), 2) require several sensors to determine the use conditions (e.g. [11]), or 3) require additional protection from the influence of surrounding conditions, which cause signal disruption (e.g. [17]). Therefore, the values and signals given by resistive and capacitive measurements have limited expression towards the out-of-the-lab use in smart textile interactions. This limitation tends to direct smart textile interfaces towards flat textile surfaces which cannot be manipulated as a textile while being functional as an interface. Being unable to determine the cause of the non-functioning interaction is an issue in itself. However, this may be the result of a measurement approach that is not suited for smart textile development. This unsuitable approach can be seen limiting the scope of the textile designers' expertise in smart textile interaction design.

To address these limitations, we present Teksig, a system that measures how a textile sensor effects a change to a known electrical signal and visualises this change. The system is built in a design setting and only utilises off-the-shelf basic components available in most design labs — building on a visualisation approach for measuring frequency-based signals and utilising them for detecting interactions which would not be detectable with existing measurement approaches. We show how Teksig can be used as a tool or as a material in smart textile development, to cope with real-world deformations exemplified in Figure 1. Finally, we conclude with implications for HCI and design research practice in smart textile development.

2 BACKGROUND

Working with smart textiles is an interdisciplinary endeavour encompassing several academic fields, each with their own approach in developing interactions. Smart textile interactions can be a product of an artistic research journey [25] or explored using extreme engineering methods [21]. Nonetheless, to make a smart textile interactive, practitioners have to utilise some form of electronic sensing. Which begs the questions "What is being sensed exactly? How accurate is it? What does it actually mean?" [16](p.109). Textile on-off switches and sensors detecting connections give clear results (i.e., 0 or 1). Where analogue sensors like sliders, pressure sensors, stretch sensors, flex-sensors and so forth, typically give a number on a range. How this numerical range is determined, depends on the measurement approach, connected electronics, the software, and the textile itself. These are critical to designing interactions in smart textiles and emphasises the need for the textile designers to have means to measure and understand electrical signals: sensors and the technical requirements for signal quality influence the placement and the movement of a sensor. The inability to manage the combination of textile and signal requirements restricts or limits the usability of the design in real-world [17]; a stage costume with smart textile sensors was improved by involving textile design to the sensor development. However, the sensors still suffered from the moisture resulting from skin-contact.

When an interaction is performed, the sensors that read this interaction should give numbers which behave in an expected and stable way. However, the laboratory measurements may not be reflective of the use conditions in practice. Unexpected behaviour in the smart textile sensor will lead to unreliable or non-functioning interactions, which sometimes results from unforeseen real-world use conditions [17] or the dynamic nature of the textile itself [6].

Current smart textile tools

The tools to develop smart textiles reflects the measurement approaches used in the smart textile sensors themselves. The most common tool is the multimeter, which is used to measure resistance, voltage, and continuity [16]. The tools specifically for smart textile development, however, have not evolved on par with smart textiles [26]; with only few tools specific to electronic textile crafts. These tools aim to make the function of a multimeter more accessible, by offering a simplified function measuring resistance, or conductivity, i.e. a low resistance. Simultaneously, they also function as a tool for textile craft practice, i.e. as a seam-ripper [24], as a tape-measure or as pins [26].

Using resistance and capacitance

While interacting with the textile form, the movement causes changes to the contact resistance between the conductive elements, in addition to changes in the deformation of the yarn fibres [33]. Making these changes readable by an electronics platform requires only one resistor and a voltage source; a circuit known as voltage divider[1]. It creates a voltage output that can be read by the electronics platform. The book on smart textile design [16] specifically mentions these resistance-based sensors to be used with 'direct current', meaning that the smart textile sensors are connected to a stable, unchanging voltage. These 'direct current' (DC)– sensors

[1]https://en.wikipedia.org/wiki/Voltage_divider

can be powered using batteries or voltage-pins of the electronics platform; both are readily available and do not require anything beyond a connection to the conductive yarn. Thus, the interaction creates a change in the resistance, and when the unchanging voltage powers this changing resistance, it creates a readable voltage signal.

While there are several increasingly elaborate ways to create and use a capacitance sensor [9], the simplest capacitance measuring smart textile sensor is similar to resistance-based sensors in two aspects; they utilise direct current voltage and a resistor [1]. This type of capacitance measuring circuits also produces a voltage that the electronics platform can read, and the actual sensor value is based on how quickly the voltage on the pin changes. Capacitive sensing has been mentioned as problematic when developing smart textiles, being prone to the surrounding conditions [9]. Resistive sensing can be augmented with capacitive measurements. This hybrid sensing has been utilised in zPatch, where these two approaches are combined by alternating between capacitive sensing and resistance measurement [29]. zPatch also sets the reference for comparison; the ability to detect hover, and different strength touch by pressing a textile against a flat surface.

Frequency-based signals

The capacitive and resistive smart textile sensors require a direct current voltage or complex electronics. The latter limits the usage in a design environment, finding more use in an electronics lab. The former relies on the voltage to be extremely stable; if these sensors are powered from a source that changes randomly, then the sensor signal changes randomly as well. With an unstable or 'noisy' voltage, there would be no way to know if the signal change was due to movement, interaction, or some other reason.

However, creating an intentionally alternating signal can be useful, as it introduces frequency, and provides more information from the sensor. There is an apparent lack of utilising frequency-based signals for interactions, in practice all of the functional prototypes and methodology exist in engineering, such as the woven touchpad [7]. While the survey [9] addresses capacitive smart textile solutions, they do not indicate practical means for the development of smart textiles in a design setting.

The effect of frequency in a knit textile structure has been evaluated using frequency-based signals, towards their utilisation in human-computer interaction [30, 31]: our prior research describes how Lissajous-figures can be used to measure different types of touch (see the explanation of a Lissajous-figure below). We evaluated signals in the range of 1kHz – 500kHz [31], and discussed the interdisciplinary research, giving an example of how designers perceive the use of Lissajous-figures [30]. However, we identified the lack of methods available for textile design in this respect.

Standards, Laboratory and Real-World

Decaens and Vermeersch summarise several standards for measuring smart textiles, which are all from the resistive perspective [3]. These include static and dynamic conditions in laboratory conditions, such as how to evaluate electrical resistance changes due to specific mechanical action. Although these measurements are not frequency-based, they discuss the utilisation of frequency with respect to skin-contact using a specific lab-apparatus and electrolyte. Here, all measurements assume that the smart textiles consist only of discrete components and ignore the signal shape-change. Furthermore, current standards and laboratory measurements avoid the issues caused by wearing and ageing, i.e. the real-world use. In contrast to laboratory conditions, in real-world conditions, the textile is subject to user whims and influences beyond the control of the user. This contrast imposes limitations to interaction design. For example, to identify the intended interaction from other movement-based signals, the sensor might need to be specifically tailored for a body location (e.g. [23]), or utilise multiple sensors (e.g. [11]). Alternatively, the sensor might require a flat surface to function (e.g. [22, 29]), or the interaction would require a specific textile deformation (e.g. [15]). While in some cases they show that the textile can be deformed (e.g. [22]), it is unclear how much additional work would be needed to identify the interaction from the deformation. The cases hint of fundamental design issues, which inhibit the possibilities provided by textile design. Thus, the interaction design could benefit from the affordances of complex 3D textiles, and textile deformability could be better designed for.

Electronics Platform

Perhaps the most often used microcomputer platform for smart textile development is Lilypad Arduino [2], which has been the basis for numerous projects in eTextiles. It is also used in programming-based approaches, such as with Modkit [20] for eTextiles [28]. It is also used as a basis for developing environments, to visually form electrical connections of a smart garment [10], and in the other case, to also create textile patterns [14]. There is a flourishing smart textile- and crafts-community around Arduino, however, they rely on DC-based resistive measurements. Extending Arduino with frequency-based measurements would benefit these practitioners.

To summarise, it is apparent that while the capacitive and frequency-based measurements are well known, they are not well used in smart textiles. This is evident from the standards, which do not discuss frequency-based capacitive systems.

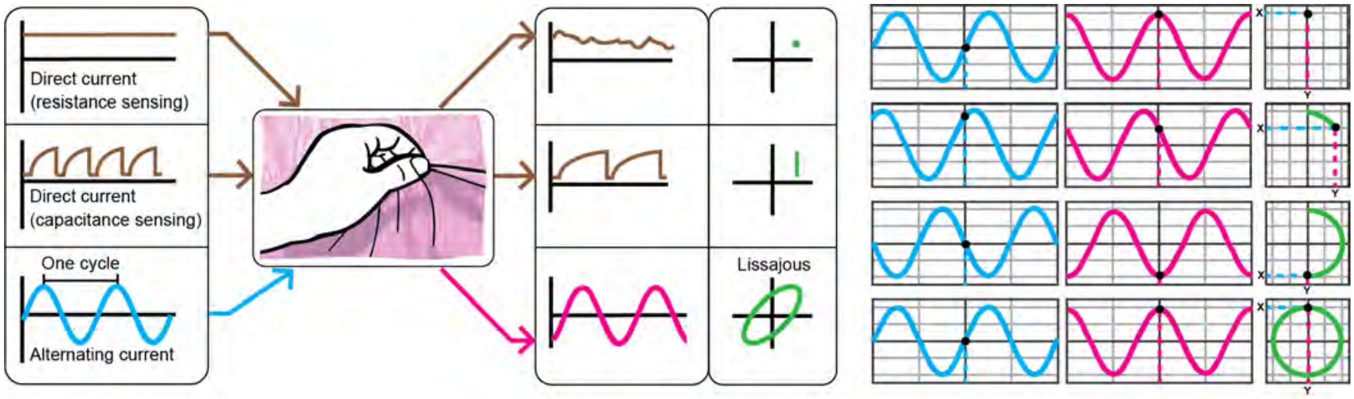

Figure 2: Different measurement approaches compared and shown using Lissajous-figures. Input-output relation is shown on right. Direct-current based signals always create either a dot or a line. The blue alternating signal on the left-hand side is different to the red signal coming out of the pinched textile. Thus, the red signal is delayed, and the resulting green Lissajous-figure is slightly round. The right-hand side shows how a Lissajous-figure is drawn, in four steps.

Therefore, there is a need to move beyond using a multimeter and direct current-based measurements, to show a way of tackling the increasingly complex possibilities emerging from the development of active yarns, materials and the combination of textile-interaction. To this end, we developed Teksig, a system, which addresses frequency-specific sensing, while keeping the simplicity of use at the forefront.

3 TEKSIG

Teksig is an Arduino-based measurement system, which can be seen as a first attempt of utilising frequency-specific sensing in a smart textile design practice. The work builds on our prior work by making smart textile sensing understandable by replacing sensed values with visual patterns [30, 31]; using Lissajous-based figures is suitable for visualising textile-interactions.

Lissajous as base

We base our system on the use of Lissajous-figures. These figures are traditionally visualised with an oscilloscope, and they show how the sensor modifies a known signal (see Figure 2). This behaviour is somewhat similar to how an echo works: when a person yells at a mountain, an echo can be heard after a while. The yell can be identified from, for instance, the sounds of the wind. The mountain is probably near if the echo returns immediately. However, if there is a considerable delay, the mountain might be far away. In electronics, this delay can be negative or positive and is called a phase. A change in this delay suggests a change in capacitance or inductance, and could, e.g. be seen as a change to the proximity to the conductive yarns. In a Lissajous-figure, this delay is represented by the emerging circle. If there is no delay, the result is a straight line. A short piece of conductive silver yarn should be visible as a straight diagonal line, as it has very low resistance. A steel-yarn with higher resistance and smaller fibre, such as the Bekinox we used in our second knit, might create a slightly round and tilted figure if the conditions are otherwise similar. The final form of the Lissajous-figure depends on the chosen yarns, textile pattern, and other conditions, and thus varies case-by-case.

Lissajous-figures provide information as a single continuous shape that is either a line or a loop. It is effective as it combines a known signal (sent) to a modified (received), giving a visual reference for evaluating all parts of the shape. This visual combination helps to identify the cause of the shape, and therefore sensor and interaction details. The Lissajous-figures are only perceivable in alternative current (AC), i.e. with frequency-based signals. If we compare the signals and their possible changes in DC with AC, as seen on an oscilloscope, the usefulness is apparent through additional visual information, as shown in Figure 2.

Functional description

Our system is built using Arduino Uno, with only capacitors and resistors as additional components (See Figure 3. The Arduino sends a sine-wave as an input signal to a smart textile sensor, while simultaneously reading the returning modified sine-wave. From the technical perspective, by generating a signal in the same device where the modified signal is measured, changes can be calculated by focusing primarily on the characteristics of the modified signal, without having to measure also the original signal.

Coming from design practice, we base our approach on the assumption that the signal is stable enough to perform several successive measurements, and that the signal does not vary wildly during the measurement. This assumption is

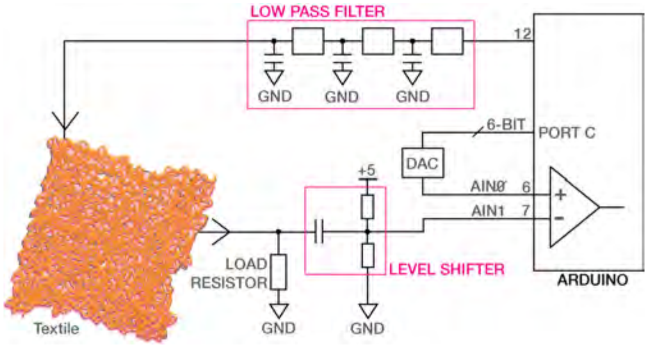

Figure 3: The simplified schematic of Teksig.

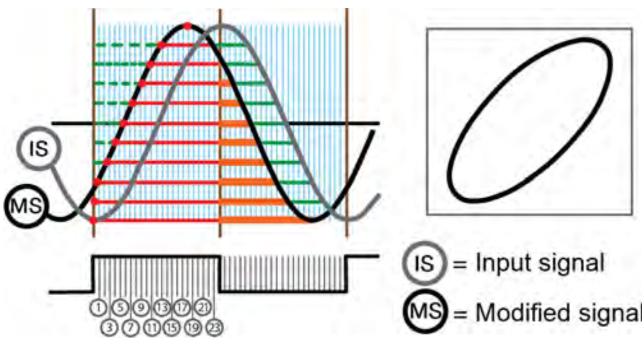

Figure 4: Measuring Sine-wave. The wave is 'sliced' in horizontal and vertical, to count amplitude, delay and shape. The number of horizontal slices indicate the amplitude, and the vertical slices are used to calculate the delay and the duration of each horizontal slice.

enabled by using a high frequency (100kHz) and by limiting the detection to low-resolution in both amplitude and delay. These fast measurements would also help to neglect the micro-movements within the textile. Indeed, by producing these higher frequency sine-waves for successive measurements, we can assume all of the measurements within the same set to be of static conditions.

Figure 4 depicts how the sine-wave is measured. In order to analyse the signal coming back from the smart textile sensor, it is compared against different voltage-levels, which create 'slices' of the modified sine-wave. In order to calculate the changes, each slice is analysed to identify the time for reaching the sine-wave edge and the sine-wave width. The former directly indicates the delay, and both together are used to estimate the shape of the signal. Amount of these horizontal slices indicates the amplitude.

In Teksig, we represent this modified signal using three values; Amplitude, Start-phase, and Width/Amplitude. We note that these are simplified values, which are sent to a computer for reproducing the Lissajous-figure. These values can also be used independently from Lissajous-generation. However, at this stage, we are satisfied first with phase (as Start-phase) and Amplitude. Since the system (for now) is very coarse, the current maximum Amplitude is 11. Similarly, the width of the sine-wave is limited to two 24-measurement sets, with a maximum of 47. These numbers indicate how the textile sensor alters the signal. If there is no sensor, the values are all zero. If there is a short circuit, then the Amplitude is 10. The delay and shape depend on the small differences of the components used with Arduino, e.g. for our system these values were Start-phase 21,1 and Width/Amp as 2,8.

Setting up

Teksig is intended to be an independent tool for smart textile design practice. Thus it is using components that can be found in most design schools, which have rudimentary electronics facilities. Even though our design used surface mounted components, they can be replaced with more traditional through-hole resistors. The system was developed using what discrete components were available on a component kit, and we followed an experimental approach. Thus, we stayed away from complex maths and approached the problem using visual means.

The files and the schematic needed to build Teksig are available on the GitHub repository[2], where details on the sample knits can also be found. Once the system is built, the usage is straightforward. Teksig provides two signal wires. One wire sends the signal to the smart textile, and the other receives the modified signal; the smart textile sensor is connected between the wires. Once Arduino is connected to the computer, the visual figure can be seen using the visualisation program available from the GitHub repository. Alternatively, the numbers can be read from the Arduino system monitor. While the schematic should be followed, the load resistor can be changed to explore sensitivity. For our measurements, we utilised 1MΩ load resistor. All values are thus measured as the voltage over load-resistor.

4 VERIFYING FUNCTIONALITY

We evaluated Teksig in two phases. First, in order to verify the technical functionality, we ran a test set with different known capacitive and resistive components to produce a systematic signal change. Second, by interaction tests using knit samples. These results are used to explore smart textile interaction possibilities.

Measurements to verify the functionality are performed through continuous reading, using 200 successive measurements for calculating a rolling average. The purpose is to use known capacitances and resistances, to verify that these basic electrical parameters can be identified.

[2]https://github.com/kryt/teksig

Table 1: Verification by identifying discrete components

Test condition	Amp	Start-delay	W/Amp
Open	0	0	0
22pF	5	16,7	4,8
47pF	6	17,8	3,9
100pF	8	18,5	3,2
22nF	11	20,2	2,4
0Ω	10	21,1	2,8
2k2Ω	10	21,5	2,8
22kΩ	5	26,2	5,1
47kΩ	4	27,7	7,6
220kΩ	1	30	30
250kΩ	1	30	33
500kΩ	0	5	5,3
1MΩ	0	0	0
LED, cathode/input	5	16,8	4,7
LED, anode/input	6	18,9	4

Note: Amp = Amplitude, W = Signal Width

The components were chosen to increase the resistance and capacitance systematically. The measured capacitances behave as expected, increasing capacitance increases the delay. Increasing capacitance also increases the voltage, i.e. there is less voltage over the capacitance. Similarly, increasing resistance reduces the amplitude of the load resistor, so there is a larger voltage over a larger test resistor. Resistor values also change the delay, which we assume to be due to the resistor acting together with the capacitors to form a filter. In order to evaluate if the waveform could be used for rudimentary detection of distortion, we also calculated Width/Amplitude. Being able to differentiate these conditions also shows a basic ability towards identifying the shape, providing information beyond the current state of the art [29]. Thus, we determine that our proof of concept identifies basic electrical components.

Test of Teksig with smart textile interactions

We have developed a series of knit samples which we test for interactions like hover, touch-strength [29], and touch with a metallic object [31]. Where previous work [29, 31] test interactions by identifying them with a non-deformed textile against a flat surface, we have chosen to test interactions in conditions similar to actual usage; stretched, wrinkled, folded and rolled (see Figure 1, 7, 8, 9).

A knit is a commonly used smart textile for interaction as it allows for various degrees of stretch as well as for the designer to specify where exactly the conductive patches should go. Here we work with two knits, details of which can also be found in the GitHub repository. The first knit sample is a weft-knitted plain structure with alternating cable stitches, shown in Figures 5 and 6. The conductive knit patterns were knitted with Shieldex 117/17 dtext 2-ply yarn. The second knit sample has five different sections designed across the width of the sample. These sections were knitted with a combination of two conductive yarns: Karl Grimm High-Flex 3981 7 x 1 fach verselit Silber 14/ooo and Bekaert Bekinox 50/2 Co 20% Bekinox 80%, in a different order (for more details see our prior work [30]). The first knit sample has stronger three-dimensionality in the surface structure, as well as being more accommodating to stretching. Due to the knit structure, it has naturally occurring pleats on the surface, which bring the conductive yarns to the surface. The second knit sample has an overall even surface, with no discernible surface texture. In this knit, the conductive yarns are at the same level as the non-conductive cotton, either on the

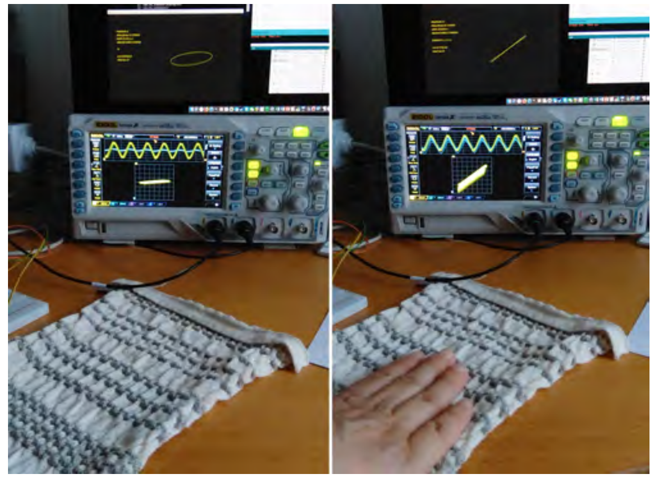

Figure 5: No touch (l) and strong touch (r)

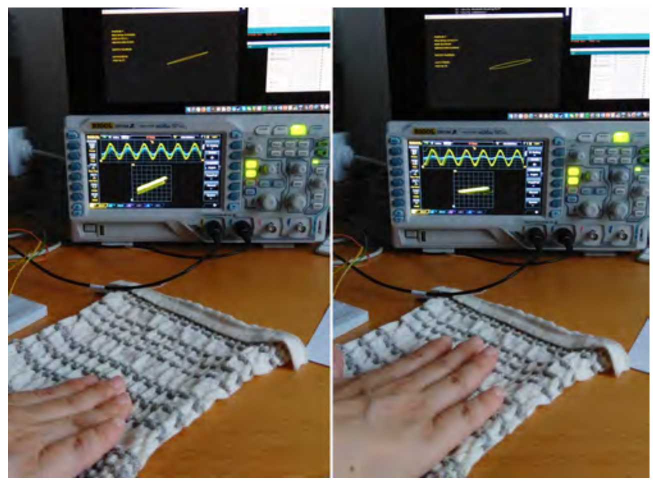

Figure 6: Light touch (l) and resting hand (r)

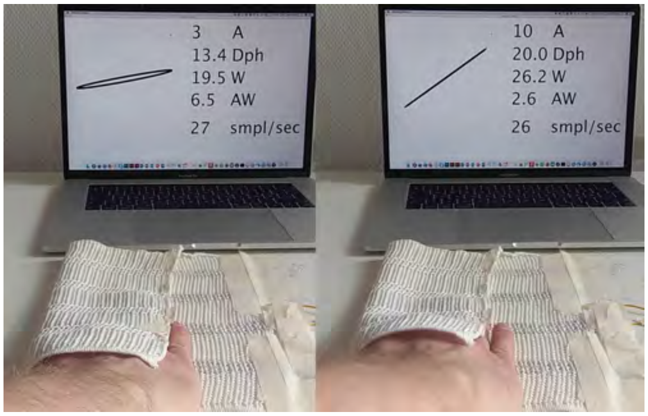

Figure 7: Folded over hand (l) and pressed while inside (r)

surface or embedded into the structure. The structure of the second knit keeps both the cotton and the conductive yarns in similar internal forms during deformations (Figures 1, 7, 8 and 9).

Testing the Knits. The first knit was tested with a touch using three different touch strengths and without touch. Three conditions for touch and one for not touched were successfully identified during the continuous evaluation. Screen-captures from a test-video are shown in Figures 5 and 6. The oscilloscope shows both the sine-waves and the Lissajous-figures, and the visualisation program shows an estimate of what figure was detected. The first knit had base values of Amplitude 2, Start-phase 12,4 and Width/Amp 7,3: this means the textile itself was first detected, i.e. the textile modifies the signal before any interaction. Strong and light touch both produced a straight line with the Lissajous-figure, indicating contact with the textile. Resting hand sees the Lissajous with a small ellipse, suggesting that the hand might not touch the textile very well.

Teksig was tested using the second knit by placing it on a flat surface, as well as deforming it. Both the flat and the deformed textile conditions were then evaluated using textile interactions. In addition to using the textile flat, we deformed it by wrinkling, stretching, rolling, or folding it. In all cases, the interactions were identified from the deformation. We also utilised interactions that we saw appropriate for that deformation, such as pinching a wrinkle. Finally, we used a brass object and verified that its location on top of the textile could be identified with all five areas. When left untouched, the second knit had base values of Amplitude 3, Start-phase 13,4 and Width/Amp 6,6.

For testing touch only, the second knit was placed on a flat surface. We evaluated it by pressing the textile at different locations. This evaluation was repeated with the same textile while it was being stretched. These results were compared

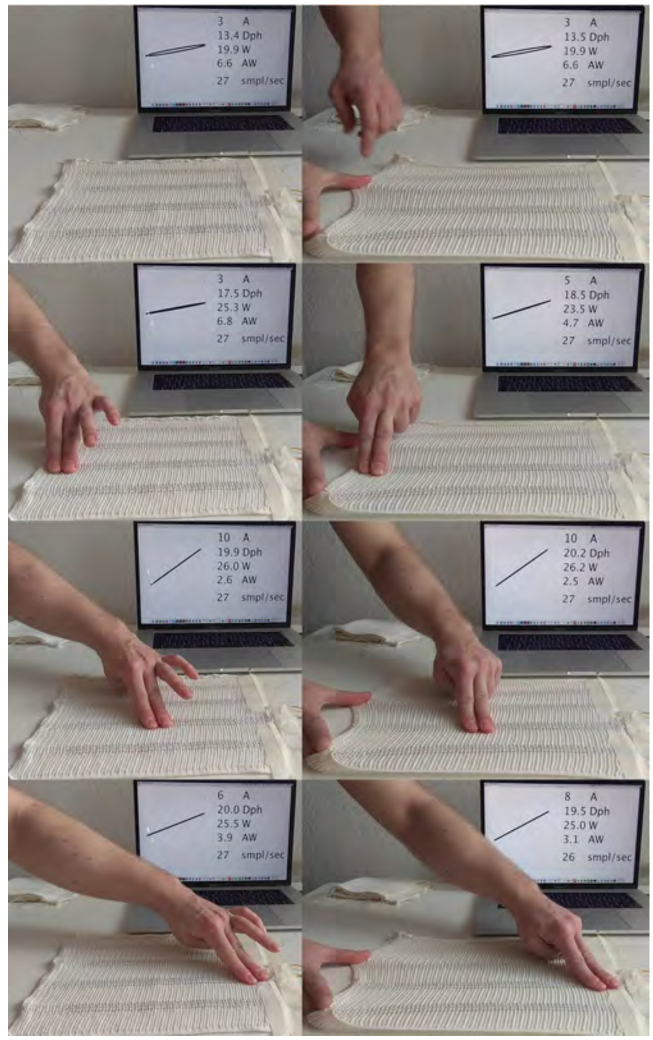

Figure 8: Interactions with stretched textile

between each other to identify the differences, with results from three textile locations shown in Figure 8. Each press could be seen from the Lissajous-figure, as it tilted to an angle. Pressing from the centre of the textile has a strong response in both cases. Stretching made the textile slightly more sensitive, increasing the tilt and making the Lissajous more line-like.

When the second knit was folded over a hand, sensor values changed slightly. However, pressing the textile with the hand inside the fold was clearly detectable, as seen in Figure 9. When the hand is inside the textile, the Lissajous is almost the same as the base level. This result means that hand that rests under the fold cannot be identified with this textile. On the other hand, the textile retains sensing functionality, as it reacts to applying pressure by producing a sharp and strong line. Textile wrinkling had a tiny measurable effect on the

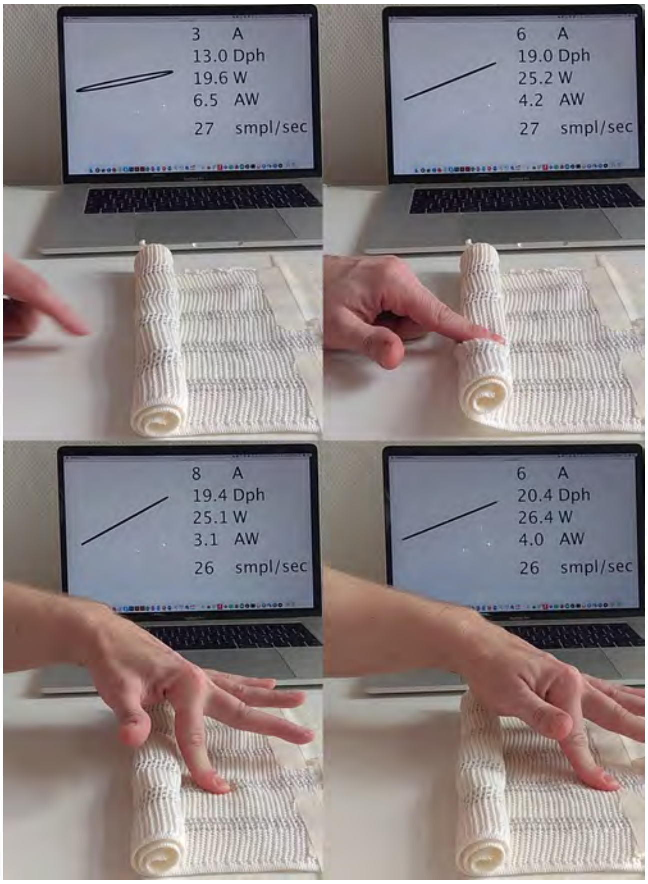

Figure 9: Rolled textile and pressing

sensor values, as shown in Figure 1. Pinching the folds created an increasingly growing signal, with each pinch being stronger as they get closer to the right-hand side. Interestingly, all folds produce slightly different signals and could be identified as separate. Looking at Figure 9., rolling the textile created a slightly more round Lissajous, suggesting that the signal connects without having a physical connection. Curiously, applying pressure to the rolled textile does not create a large signal. This result means that the textile does not have a strong contact inside, but detection is still possible. While the textile is rolled, detecting touch still works in un-rolled parts.

While the interactions shown in Figures 1, 5, 6, 7, 8 and 9 are identifiable from the deformations or the untouched state, the interactions at the end of the textile (e.g. Figure 8) created different Lissajous-figures from those at the other end. With the second knit, we were able to identify several different conditions that can be utilised for developing interactions with smart textiles. Our measurements indicate that Teksig performs as a proof of concept of the Lissajous-based Teksig-approach.

5 DISCUSSION

We have proven that the Lissajous-based measurement approach can be implemented using a single Arduino which generates a high-frequency signal. The system can give a very rough measurement of the amplitude and the phase, as well as notice differences in shape. The signal in Teksig has sufficient stability to reliably detect the three interaction-related conditions found in [31]: no touch, human touch and metallic touch on a flat surface. Furthermore, our system can detect the same interactions as shown in zPatch [29], with limitations towards hovering. As hover detection is heavily dependent on the textile structure, our detection distance extremely low. We utilised two knits with different surface qualities and conductive yarns and successfully tested them for detecting touch. Going beyond prior art, we were able to identify interactions in five real-world use conditions using the same textile; against a flat surface, as well as a stretched-, wrinkled-, folded- and rolled textile. Application-wise, we were able to locate a brass object on a smart textile knit consisting of two different yarns and two different knit structures, in a single sensor configuration. While we acknowledge that our system is not very precise, it is the first utilising Arduino with frequency-based signals. Importantly, it can be constructed and utilised with low effort, to be used in smart textile development. The resolution and the scale of values received from Teksig thus provide a rudimentary design space to begin exploring smart textile interactions.

Implications to Textile Design

Each textile has different properties, which are a result of the different yarns and measurement conditions affecting the textile. It should be noted that the textile movement always creates a signal, even if it is minimal. If there are a lot of bad connections, the Lissajous-figure changes rapidly and does not set. This restlessness means that every textile sensor behaves differently and that the textiles that work in one condition probably do not work exactly the same way in another condition. The Lissajous-figures may simply be different due to the difference in yarns, as both conductive and non-conductive properties vary from batch to batch. Textile structures may have slight differences due to manufacturing, which also contribute small unknown changes to the values. There may also be environmental differences, such as due to absorption of moisture. Therefore, each textile has to be measured, to see what kind of Lissajous-figures they produce. By utilising Teksig, the practitioner can measure these differences between successive samples and develop a smart textile structure which minimises the effect of these variations.

Smart textiles developed using the frequency-based approach can be simpler, as there is no need for direct skin

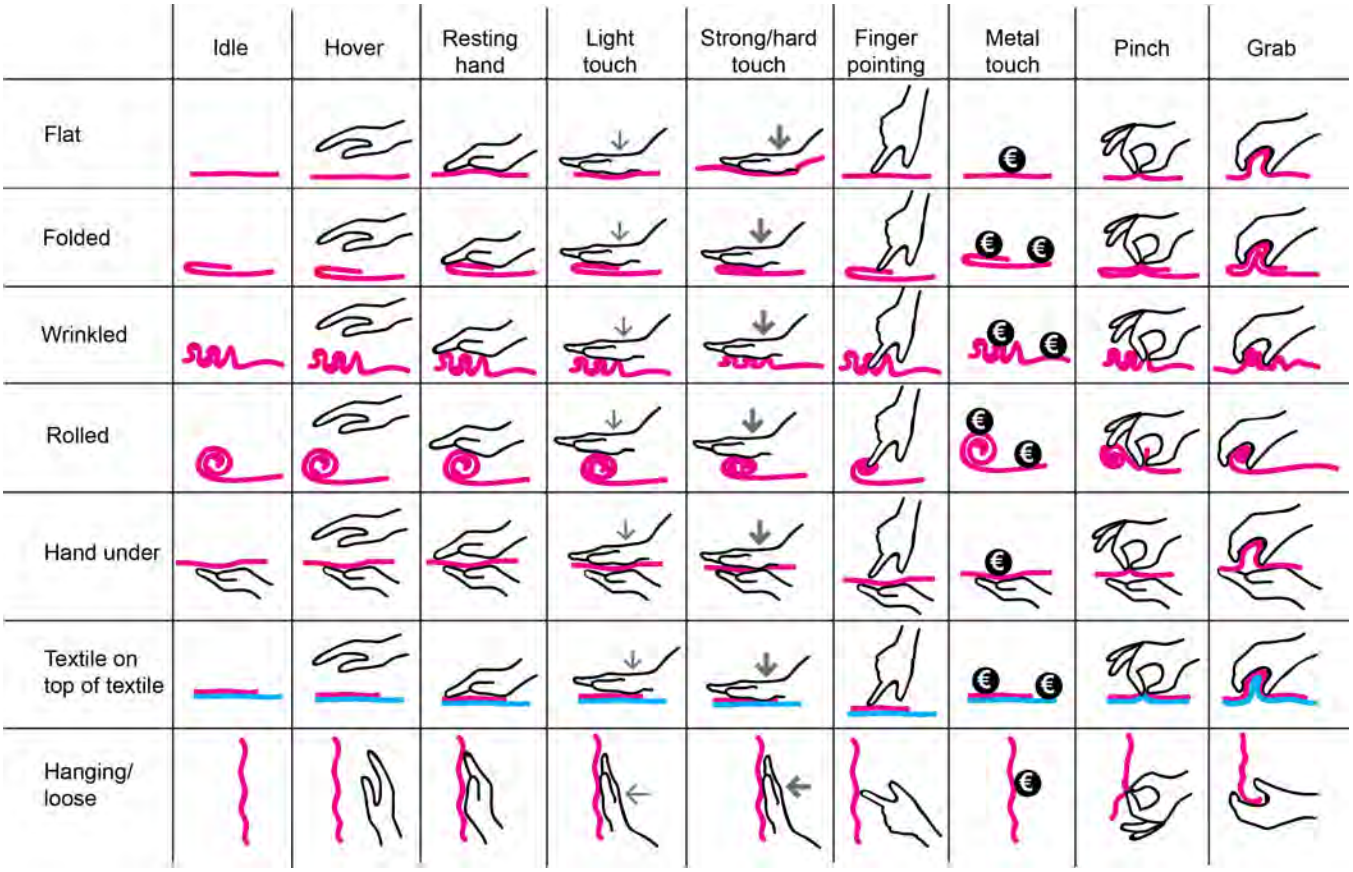

Figure 10: Smart Textile interactions derived using frequency-based measurement

contact. Conductive yarns can be fully or partially hidden inside the textile structure. Importantly, the textile practitioners and designers can develop textiles that go beyond flat structures. The freedom towards the textile structure facilitates a better combination of textile design and HCI. Thus, the smart textile can be better designed for a given interaction, and the textile practitioner can be involved in the design process. The system uses two wires, similar to a multimeter. As the signals given by the system are visualised, the practitioner can utilise either the numbers or the visual figure. Thus, the textile can be independently designed using different conductive yarns and textile patterns, to develop a sensor for a location best suited for the interaction. This ability could empower smart textile practitioners to be less dependent on electronics facilities, a problem that has been identified in prior research [17].

Implications to Smart Textile Interactions

The measured smart textile interactions suggest use situations, which are possible using textile design and the frequency-based approach. These are summarised in Figure 10. Each interaction creates a Lissajous-figure, which can be identified from the leftmost, idle state. While we presented a limited interaction set in Figures 1, 5, 6, 7, 8 and 9, they show interactions which can be identified using Lissajous-based signals. However, they require a well-designed textile, i.e. a textile designer to be equally involved in the interaction design process.

The second knit had five different sections, producing different Lissajous-figures. The distinct figures imply that using different conductive yarns can be used to create a whole new dimension to designing textile interactions: different yarns can be used to create Lissajous-figures unique to touch, location or interaction. The ability to discern these variations allows the smart textile to be designed in different colours, patterns, tactility and now, for more elaborate electric behaviours. Based on the interactions, we derive three areas of interest, which could be improved with frequency-based signals. Textile design expertise is needed for the smart textile to go beyond the lab, and into the real world where Teksig could be integrated into the smart textile as a material.

Two Sides of a Surface. We see Teksig open up three areas for combining textile-design and HCI, as shown in Figure 11. The first area, Two-sides of a surface, combines our practical findings with prior research [8], showing it can be meaningful and beneficial to design the textile from both its face and back. The textile can have qualities and characteristics that feed interests of both textile designers and HCI-practitioners. The implications of these textile structures can be better developed when the designer can have a direct interpretation of the electrical signals.

Textile-like vs device-like. The second area, textile-like vs device-like, identifies that it is common practice to design a textile with both tactile and sensorial properties in mind. However, HCI tends to approach textile as a device of a more specific focus. Thus, by augmenting the development capabilities, new opportunities for bridging these two can arise. Textile surface qualities concerning conductive qualities can be explored, as the system can be utilised between each textile sample. As rudimentary frequency-characteristics can be explored without an electronics facility, Teksig could be utilised directly with looms or knitting machines, taking the work to the practitioner. This opportunity will open up new possibilities for realistic and robust smart textile interactions.

Non-Perceivable. Combining all these in the third area, we see it possible to move beyond seeing the textile only as a platform, a circuit board and move closer to the real-life smart textile applications. We see Teksig alleviate non-perceivable design- and use-related challenges, as there is evidence to support that visualising signal behaviour enables understandable discussion on interactions with textile [30]. Furthermore, the robustness to textile deformations supports the usefulness towards developing real-world use cases.

Empowering. Teksig could open up new possibilities to develop while knitting or weaving. In practice, the measurements can be managed throughout the actual knitting or weaving activity, or during the larger scale of the overall textile design process. During weaving, the textile cannot be removed immediately without material loss, in addition to the lost time for setting up the warp again, in both a studio-based and industrial setting. However, the textile can be measured while still on the loom, by releasing the warp tension. While we acknowledge that it is not the same as the intended use situation, it could give a general indication of how a textile sample behaves. How accurate this is, needs to be verified in future research. Teksig would also allow evaluation of successive samples made with the same warp. Knitting, in this respect, is a more agile process for testing smaller, detachable material samples, although, in an industrial setting, material loss is also inevitable.

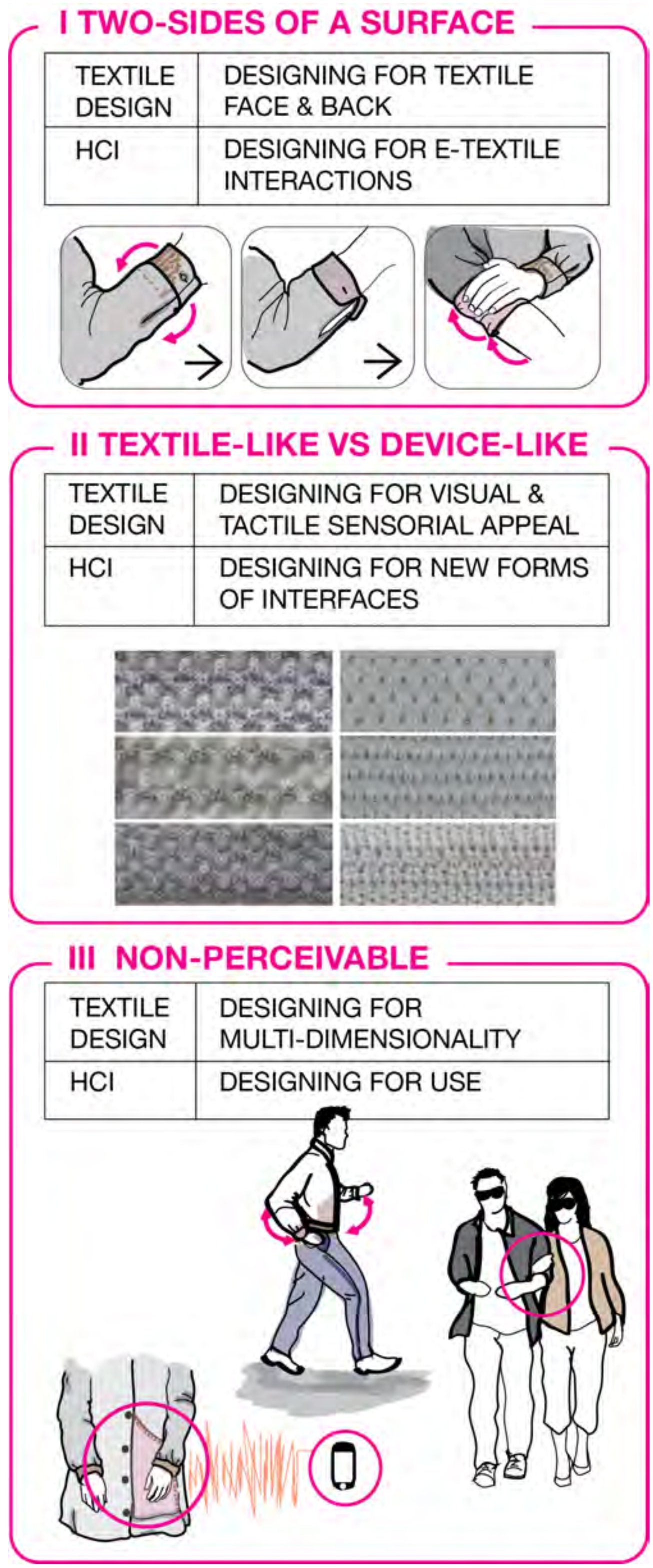

Figure 11: Implications to Textile-design and HCI

Technology development. Technologically, the tool could provide new directions for the development of integrateable textile-components. The designers and HCI-practitioners would benefit greatly from a frequency-based measurement system in the form of a knittable or weaveable processor or a component, or even as an external component [4, 18, 19, 27]. From textile development-perspective, we have found that it is essential to be able to measure amplitude, phase-difference, and signal shape. As semiconductive signal distortions are a reality, they could also be taken as a benefit, with materials research. A woven or knitted textile consists of a system of yarns and could be seen behaving statistically. Therefore, neither the textile nor the electrical signals should lose functionality if few yarns break, or if the textile is worn in whatever way. Thus, we see that the smart textile interactions and smart textile electronics, in general, should conform to the textile qualities, and not the electrical qualities.

6 CONCLUSION

In this paper, we have presented Teksig, a system utilising frequency-based measurement towards smart textile interactions. Through measurements, we conclude that while very low-resolution, the system identifies interactions from deformations. Designed with design-schools in mind, Teksig can be constructed using commonly available components. Thus, the smart textile practitioner can utilise the system as a tool, or as a material: smart textile design practitioners can independently utilise the method in their textile-development. Teksig augments the existing smart textile toolkit, providing information-rich measurements for the smart textile design practice and HCI.

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