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BETWEEN YARNS AND ELECTRONS: A METHOD FOR DESIGNING TEXTURAL EXPRESSIONS IN ELECTROMAGNETIC SMART TEXTILES

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ABSTRACT

The design of smart textiles presents a discrepancy of scale where the designer works at the level of structural textile design while facets of the material express at scales beyond one's senses. Without methods to narrow this gap, certain expressional domains of the textile are closed off from design possibilities. The aim of the research has been to design a method for observing, visualizing, and describing expressions of electromagnetism in textiles. Through a method of textile surface scanning, one can produce a visualization of its electromagnetic field. Woven textile samples observed through this method reveal a textural quality that exists within the electron flow – an *electromagnetic texture*, which emerges at the intersection of woven design and electromagnetic domain variables. The design variables field strength, diffusion, and field shape contribute in narrowing the gap that presents when one designs simultaneously at the scale of textile structure and electron flow in yarns.

INTRODUCTION

In artistic fields such as media art, sound art, and installation art, the use of electromagnetism as a material has been widely demonstrated, for example by conceptual artist Robert Barry's interactive electronic objects (MOMA, n.d.) in the 1960's, Joyce Hinterding's room-scale antenna installations in the 1990's to current day (Joyce Hinterding, n.d), and Christina Kubisch's electrical sound walks and electromagnetic installations in the 1980's to current day (Kubisch, n.d.). These and other artists have shown that engagement with this intangible material reveals to us qualities of a world that we are immersed in and yet cannot sense; that there is an "abstract everywhere" (Milutis, 2006) that can be drawn on for artistic purposes. This suggests that conductive textiles might serve to express more than simply power and signal transmission, and that with further exploration new electromagnetic smart textile expressions can be designed.

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Yet, the use of electromagnetism as a material in the smart textile design field is under-represented, in part due to a lack of methods for how to access and design with its extra-sensory and intangible qualities. While methods of sensing are available within practices of science and engineering, they often involve specialized laboratory tools and, further, the skills of how to use them and interpret their outputs (Dunne, 2005, p.7). These tools and skills can be beyond the reach of the textile designer working in the area of smart textiles. There is therefore a need for sensing methods that are "agile, visual, and adaptable" (Mikkonen and Townsend, 2019) for designers to be able to engage directly with the properties of the phenomenon.

This paper proposes an experimental method that has been developed for textile designers, and which can be used within their design process to enable the exploration of the electromagnetic qualities of conductive structural textiles. This method, called *textile surface scanning* visually communicates the presence and form resulting from the electromagnetic field generated by current carrying yarns in a structure. The method outputs a graphical plot that illustrates a textural quality derived from the placement of conductive yarns in a textile structure. It has accessible tool requirements and does not demand specialized knowledge or skills to interpret the results. It is conducted using a smartphone, a smartphone app, and a DC (direct-current) power supply. Multiple sensor readings can be taken and joined together in software to produce a visualization of the textile's electromagnetic expression. Further, it introduces the textile design notion of *electromagnetic texture*. That electromagnetic expressions reside within a textile at the yarn level suggests that decisions regarding textile design variables for example technique, structure, density, scale, and overall formal qualities, will subsequently affect the electromagnetic textural quality. As a sensing method, it opens a space for textile designers to design with electromagnetic textures by exploring the relationship of material, structure, and dynamic expressions, thereby broadening the range of design possibilities of smart textiles.

SCALES OF SMART TEXTILE DESIGN: FROM TEXTILES TO YARNS TO ELECTRONS

In structural textile design, designers must simultaneously regard the broader expression of the textile while addressing nuances at the scale of yarns. Expressions of texture, surface, and visual aesthetics (e.g. colour and patterning) are determined by yarn properties such as fibre type, yarn thickness, yarn number, and twist. For smart textile designers, the design variables increase. While the focus on structure, material, and expression are maintained, further variables are introduced: time-based, state-changing, and recurrent behaviours (Worbin, 2010; Kettley, 2016; Heinzel and Hinestroza, 2020). These active and dynamic qualities in smart textiles move towards Ishii's vision of "radical atoms": physical materials that "*transform* [their] shape to reflect underlying computational states and user input; *conform* to constraints imposed by environment and user input; *Inform* users of its transformational capabilities (as dynamic affordances)" (Ishii, Lakatos, Bonanni and Labrune, 2012, p.45). Electromagnetic smart textiles can be seen as radical materials given that they *transform* in multidimensional ways, yet they are *conformed* to the physics of their textile structure. Through observation methods such as the visualizations illustrated in this paper, they *inform* users of their transformation. Smart textile designers manage these multi-layered and multi-scaled approaches to design, and therefore work in a highly complex and "entangled" space with "technological compositions", and must do so "without ever losing sight of the expressive potential of the work" (Kettley, ibid., p.145).

Designers working with electromagnetic expressions in textiles are few, and works produced have been mainly focused on frequency-based electromagnetism (e.g. sound and radio-based works). However, design researchers Ebru Kurbak and Irene Posch have designed a non-frequency embroidered electromagnetic textile that functions as an 8-bit computer (Kurbak and Posch in Kurbak, 2018). The textile contains a matrix of magnetite beads encircled by the ornate stitches of embroidered conductive thread. A gold coil relay switch is attached to the magnetite bead, and when an electromagnetic field is generated in the yarns, the relay coil flips its position, thereby expressing different logic structures. Participants are invited to program this textile computer and witness the different logic structures expressed through the textile materials. In this work, the two have greatly enlarged the scale of matrixial computational logic gates, visually revealing the basic material interactions that are normally intangible, miniaturized, and embedded within integrated circuits.

Kurbak has also worked with So Kanno to design a magnetic yarn voice recorder (Kanno and Kurbak in Kurbak, ibid.). Using this recorder, a participant is able to record their voice on a single thread of conductive yarn. Soundwaves of one's voice are passed to the yarn while turning a spindle. The yarn is guided through a recording head where the yarn is magnetized with the magnetic order of the voice recording. The yarn can then be played back by winding the yarn spindle to listen to the recording. This work uses the effect of mechanical magnetic recording as used in cassette players of previous decades. Here, the pair reveal an overlooked quality of conductive yarns: their ability to store and transmit data in their magnetic field. Across both examples, the two work closely with the material properties of electromagnetism and invite participants to engage with their works and bear witness to the secret properties of conductive yarns.

Working with frequency-based electromagnetic expressions, Afroditi Psarra explores satellite transmission data as a material for textile design. In *Listening Space* (2019), Psarra uses software-defined radio (SDR) to record satellite positions in proximity to her listening station. These transmissions are translated to audio waveforms that then become patterns for machine knitting. Electromagnetic waves are represented through changes in textile structure, material and patterning, using symbolism to balance the scales of design between yarns and electrons. In addition, she uses "low-cost methodologies" and "digital crafting" combined with textile design processes (Psarra, ibid.). This assists in opening textile designers to electromagnetism as material, particularly where it can be accessed through materials that textile designers are already engaged with, and are intimately familiar with.

Yet thinking at the scale of electrons is not commonplace in design, and is an issue that Dunne attributes in part to the obscuring and miniaturization of electronic components, making them increasingly out of reach from designers (Dunne, 2005). He identifies the lack of methods and tools as a contributing factor, resulting in a missed opportunity for designers: "[electromagnetism's] modernist poetry, based on truth to materials, is lost" (Dunne, ibid., p.9). However, in smart textiles, conductive yarns are no longer a novelty. Accessing the electromagnetic domain that is already within the textiles being designed simply requires methods and tools to open smart textile designers to the expressive potential of the material. Smart textile designers balance a vast array of design variables when in the forming process, zooming between the scales of yarns and textile. Perhaps to design between scales of textiles, yarns, *and electrons*, is not at all farfetched.

METHOD

The example of experimental design research presented here explores electromagnetic textile expressions through a smart textile design practice. To observe the formation of electromagnetic fields, digital sensing tools were used. The use of a magnetometer as sensor provided a high resolution of sensor data wherein nuances of the electromagnetic fields could be observed. A decision was made to use the magnetometer contained within a smartphone. This was based on designer's anticipated ease of access for tools to conduct technical measurements, where most designers would conceivably be in possession of this tool already. Further, the processing power of a smartphone greatly outweighs that of common microcontrollers such as Arduino. As a result, the read-rate of the sensor is higher, and therefore provides greater resolution of data, allowing one to observe the electromagnetic fields with greater detail.

The analysis of the sensor data was conducted with the textile design expression in focus rather than the numeric values. The sensor data was evaluated for the overall field shape expressed across the surface of the textile, and was further examined for its likeness to the structural qualities of the textile design. This analysis required knowledge of the direction of current flow, where conductive yarns were positioned in the textile structure, and whether dielectric yarns (conventional textile yarns e.g. cotton, linen, wool) interlace on the surface of the textile between conductive yarns and the sensor. Correlation could then be made between the peaks and valleys of the graphical plot, the areas within the textile structure where field strength was increased or decreased due to proximity of conductive yarns to one another, and the vertical layering of yarns in the woven construction.

The basic structures of twill, waffle, and honeycomb were selected for their clarity in illustrating the electromagnetic field shape in relation to the textile structure. The textile samples used a conductive enameled copper yarn (0.16mm) with an electrical resistance of 0.89 Ohms per meter. This yarn is ideal for weaving as it is fine and flexible, yet strong, and not subject to breaking under tension. The dielectric warp materials were cotton yarns (30/2). All samples were woven on 24-shaft computerized ARM looms. The warp density on these looms were 24 EPC (ends-per centimeter) for the twill and honeycomb samples, and 12 EPC for the waffle weave sample. Each sample was woven with conductive yarn ends exiting the textile on left and right selvedge at intervals of 1cm to provide access points to electrical connections.

TEXTILE SURFACE SCANNING METHOD

The *textile surface scanning* method provides a way for smart textile designers to observe the electromagnetic field expression of a current-carrying textile. It produces a visualization of the electromagnetic field shape expressed on one surface of the textile. The method is comprised of a smartphone app, a physical setup, a sliding technique, and visualization approach. The sensor data output contains magnitude readings as Teslas (μT) expressed by the textile. The textile samples were placed antiparallel to the Earth to avoid sensor data being affected by the earth's electromagnetic field.

MAGNETOMETER SMARTPHONE APP

The Android smartphone app "Magnetic Field Sensor" by SMF Apps GbR was used. Through this app one can access the data from the magnetometer sensor in the smartphone. The app formats the output data as a 2D graphical plot of magnetic field strength (as Teslas) mapped over time. It stores within the smartphone memory as a text file that contains XYZ positional data, Teslas, timestamps. This allows the text file to be imported into a variety of software capable of plotting and visualizing data sets.

PHYSICAL SETUP

Figure 1 Full setup, sensing position (top left); Detail sensing position (top right); Textile suspension (bottom left); two tripods separated (bottom right)

The physical setup of smartphone holder, tripods, and a plastic planar surface (Figure 1, top left and bottom right). A sliding camera mount was modified by attaching a smartphone holder (Figure 1, top right). This allowing one to smoothly move the smartphone vertically over the surface of the textile during sensor reading. The slider was placed vertical to the Earth. A textile sample was positioned vertically a plastic board facing the smartphone (Figure 1, bottom left). Power and ground electrical connections were made to the textile via conductive yarns at the selvedge, and 1A of electrical current was applied. Variation to this physical setup is possible based on the tools and materials one has available to them, however a key parameter is that the sliding movement must be made antiparallel to the Earth.

The sensing technique is the physical motion of vertically sliding the smartphone across the surface of the textile sample. The textile sample was placed vertically on the plastic board and the smartphone scanned the surface over 10 seconds moving from top to bottom, selvedge to selvedge. This duration provided the clearest visual impression of the field shape. The use of an external timer assisted in timing the movement. The sensor reads an approximate 1cm wide band of the textile. Multiple readings across the textile surface then need to be shifted by 1cm to the left or right in order to make additional readings across the textile surface.

VISUALIZATION

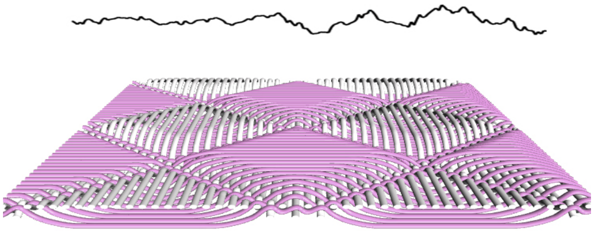

Figure 2 Single line visualization of electromagnetic field expression placed atop of waffle weave structural visualization

The sensor data can be imported for use in a variety of software capable of plotting 2D datasets (e.g. Python, P5.js, Processing, MathWorks, Excel, etc.). The image output from the app can be used in image software (e.g. Photoshop, Illustrator) to isolate the line from its background in order to produce a single line representation of the texture (Figure 2). The image and data can also be imported into 3D software (e.g. Blender, Fusion 360) to construct 3-dimensional surface visualizations, such as the ones in this paper. The openness of the visual representation of the data is a strength in the method, where one is able begin with either the image or the dataset, and within the style and software of one's choosing.

EXPERIMENT 1: STRIPED TWILL

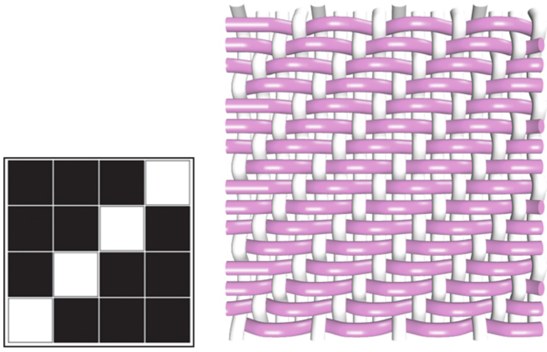

Figure 3 Weft-faced twill weave draft (left) and structural visualization (right)

Figure 4 Striped twill textile

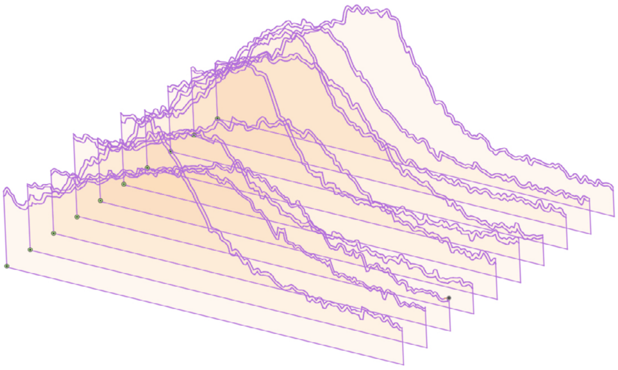

Figure 5 Electromagnetic texture of striped twill textile

Twill is a basic weave structure that involves the weft passing over one and under three warp threads (Figure 3). Each weft pass progresses the interlacement one step, resulting in the diagonal lines that characterize the twill structure (Sinclair, 2014, p.272). Twills are dense textile structures, as the progressive offset of the interlacement allows weft threads to pack more densely together. This allows for the dense placement of conductive and dielectric yarns in a textile structure. The woven textile is a weft-faced twill (6cm x 10cm) with a striped pattern that alternates sections of dielectric cotton weft with conductive copper yarn weft. The conductive stripes become progressively thinner towards the bottom of the textile sample (Figure 4).

Using the *textile surface scanning* method, 10 sequential sensor readings were made and panelized using 3D software. The textile was scanned from top to bottom over the course of 9 seconds. The electromagnetic field extends approximately 3-4mm from the textile surface. The resulting visualization of the electromagnetic texture is presented in Figure 5.

This example illustrates the discrepancy that emerges between the tangible textural qualities of a textile and electromagnetic textural qualities that arise. The visual, tangible surface of the textile in Figure 4 is flat and smooth with minimal textural qualities. However, the field strength is strongest over the widest conductive copper stripe at the top of the textile, resulting in a strong visual peak in the electromagnetic field. The peak tapers off towards the bottom of the textile as the conductive bands get progressively smaller. This resulting in a unique electromagnetic textural expression that appears only within the textile's hidden domain of the electromagnetic field.

EXPERIMENT 2: WAFFLE WEAVE

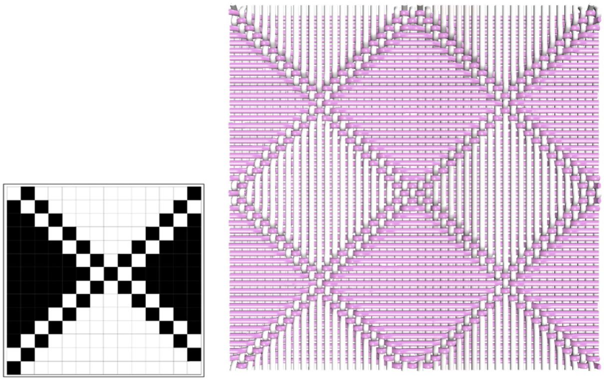

Figure 6 Waffle weave draft (left) and structural visualization (right)

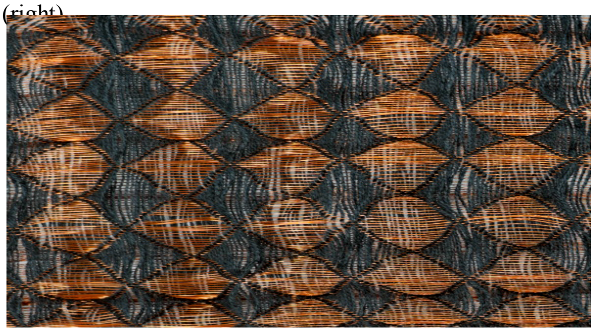

Figure 7 Waffle weave textile

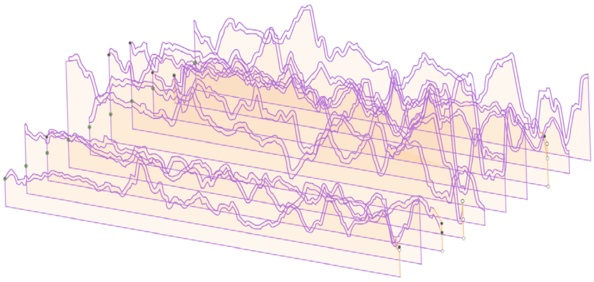

Figure 8 Visualization of electromagnetic texture of waffle weave structure

Waffle weave structure consists of a matrix of cells that form peaks and valleys on both sides of the textile (Figure 6). Warp and weft threads float on both surfaces, and the result is a textile of high volume and density where the peaks and valleys give dramatic visual effect dependent on scale and material selection (Sinclair, ibid., p.278). The combination of floating conductive and dielectric yarns in this structure can provide dramatic fluctuations in the electromagnetic field shape.

The textile is woven with a dielectric cotton warp and conductive copper yarn weft (10cm x 25cm) (Figure 7). Using the textile surface scanning method, 10 sequential sensor readings were made and a visualization of the electromagnetic field across the surface of the textile is presented in Figure 8. The textile was scanned horizontally over the course of 15 seconds. The visualization reveals strong variations in the electromagnetic field, where density changes in the conductive yarns are expressed as changing electromagnetic field strength across the surface of the textile. The electromagnetic field extends approximately 5-6 mm from the textile surface.

In this structure, field strength is increased in areas where there are long floats of copper yarns. Floats are yarns that are not tightly bound into the structure, and are left to move freely between two points. This allows parallel copper yarns to sit closer together than if they were bound in a structure, and which couples the electromagnetic fields across several yarns. This increases the electromagnetic field strength in those particular areas. Therefore, the use of parallel floats with conductive yarns is one technique to increase the electromagnetic field strength within a conductive uniform, voluminous texture, while the electromagnetic texture reveals irregular peaks and valleys due to the random coupling of floating conductive yarns. The electromagnetic texture is not a direct reflection of the tangible texture, rather it is a unique energetic expression of the textile structure.

EXPERIMENT 3: HONEYCOMB

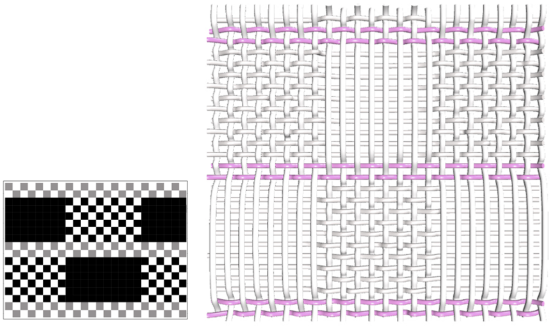

Figure 9 Honeycomb weave draft (left) and structural visualization (right)

Figure 10 Honeycomb textile

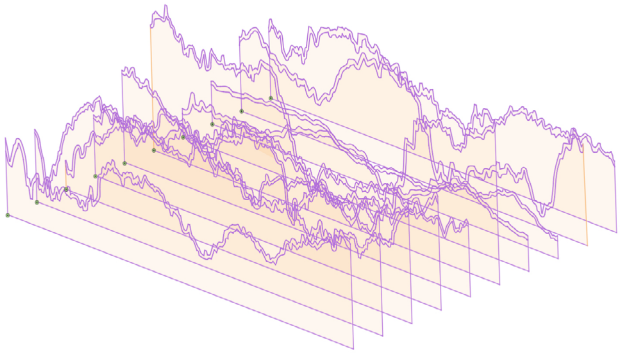

Figure 11 Visualization of electromagnetic texture of honeycomb structure

The honeycomb structure is characterized by an undulating weft that circles sections of plain weave in the ground layer (Sinclair, ibid., p.283). Honeycomb cells are designed as alternating blocks of larger and smaller size (Figure 9), and cell shapes are defined through contrasting yarn thicknesses between the ground and secondary wefts. The qualities of the yarns in combination with the tension of the bindings causes cells to condense and relax alternatingly throughout the structure, giving rise to the characteristic cellular matrix (Figure 10). By using a thick conductive weft that is made of multiple twist copper strands, an exaggeration of the cell shapes can be made in the electromagnetic field shape.

The textile is woven using a dielectric cotton primary ground weft, and 16 copper yarns twisted together as a conductive, secondary weft on a dielectric cotton warp (10cm x 25cm). Using the *textile surface scanning* method, 10 sequential sensor readings were made and a visualization of the electromagnetic field across the surface of the textile is presented in Figure 11. The textile was scanned horizontally over the course of 15 seconds. The electromagnetic field extends approximately 5-6 mm from the textile surface. In this structure, the thick copper weft yarn encircles the ground layer cells. The secondary weft generates a strong electromagnetic field that presents in the visualization as broad peaks. The broad peaks are strongest when four conductive weft yarns move close together at the top and bottom of each cell (Figure 10), and diffuses into wide valleys where the dielectric ground weft dominates. The honeycomb structure can be used to design field shapes with strong contrasts and broad peaks and valleys rather than steep inclines. Additionally, using multiple conductive wefts in a single pass assists in increasing contrasts in the field shape by increasing field strength along those passes.

ELECTROMAGNETIC TEXTURAL EXPRESSIONS IN SMART TEXTILES

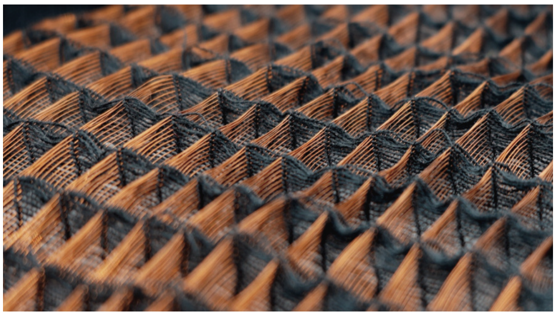

Figure 12 Copper and cotton yarn floats in a waffle weave

Figure 13 Diffusion of the electromagnetic field strength through patterning

Through a combination of method and materials, an extra-sensory textural quality can be found in the space surrounding a conductive smart textile. This hidden layer reveals an impression of the textile structure and material properties through its textural quality. It has been the work of conducting and analyzing the experiments that has guided the process of defining new design variables, and that enrich the methods of textile design.

The introduction of an *electromagnetic texture* offers a new notion for the design of textural qualities that expands the textile convention of visual and tactile sense. Moreover, it allows one to design expressions within the space of yarns and electrons, which present as two disparate material scales. Much like the conventional quality of texture in textiles, *electromagnetic texture* is dependent on the structural and material selections of the textile, yet it is both designed and expressed in different ways.

Electromagnetic texture is designed through variations in the placement and density of conductive yarns through variables of *field strength, diffusion*, and *field shape*.

Field strength is the rising intensity of the electromagnetic field which is represented by peaks in the graphical plot of the sensor data. It can be designed through the strategic placement of conductive yarns in the structure, where field strength increases when conductive yarns sit closer to the surface, are more densely set in the structure, or are free to float, allowing them to move closer together than when they are bound in a structure.

Diffusion is the decreasing intensity of the electromagnetic field as it becomes obscured by dielectric materials, or where conductive yarns are spaced apart in the textile structure. It is marked by valleys in the graphical plot. Diffusion occurs when dielectric yarns pass over or between conductive yarns, diminishing the field strength before it reaches the outer surface of the textile (where it is sensed by the magnetometer), or spacing conductive yarns apart in the structure so that the electromagnetic fields cannot couple, resulting in lesser field strength.

Field shape is the contouring of field strength and diffusion qualities in the textile structure. A field shape is designed as a result of the balance between these two variables, and leads to the overall expression of electromagnetic texture.

Notably, *electromagnetic texture* may contradict the conventional textural quality of a textile. A textile with a visually smooth surface and little tactile texture may express a highly textural and nuanced electromagnetic field as the result of the placement of conductive and dielectric yarns in the structure. This is evident in Experiment 1: Twill Stripes, where a conventionally flat and smooth textile reveals a high peak and long slope as the field strength decreases over the dense dielectric area. Similarly, in Experiment 2 the uniformity of waffle weave peaks in the tangible textile are expressed electromagnetically as being highly irregular. This discrepancy between expressional domains is what makes *electromagnetic texture* an intriguing textile design notion – it follows its own expressional way of being, and that may be inverse to our perception of the tangible textural expression of the textile.

The scale of textile design refers to the layering of perspectives in the designer's process: the zooming in and out of textile properties, from fibre to yarn, yarn to structure, to the gestalt of the textile as its broadest expression. The scale of electron flow allows designers to work deeper with this non-visual, non-tangible, domain hidden within the fibres of conductive yarns. As textile designers move fluidly between scales of smart textile design, they can use the methods, notions and variables presented here to design with electromagnetic expressions in mind.

DISCUSSION

The result of this paper is the presentation of an experimental method for observing, visualizing and describing electromagnetic fields in conductive smart textile designs. It responds to the call for new methods, techniques, and terminologies for working with smart textiles and materials (Hallnäs, 2008; Worbin, 2010; Kettley, 2016; Ishii et. al, 2012). As smart textile design is an interdisciplinary practice, this method may also benefit those in intersecting fields such as interaction design and textile engineering, when forming a collaborative design.

Notably, the experimental method of *textile surface scanning* has led a textile design notion of *electromagnetic texture*, and the design variables that define it within the textile structure. In addition to a novel understanding of the scales of textile design, a deeper scale of smart textile design has been identified: design at the scale of electron flow. The reach of the smart textile designer can now extend from the minutiae of electron flow outwards towards the scale of textile interactions in the environment. The expansion of this design space is simultaneously a narrowing of the gap identified by Dunne (2005, p.7) and Ishii whereby expanding upon the scales of textile design allow designers to move in closer range to the phenomena of electromagnetism, perhaps towards designing at the scale of *radical electrons* (Ishii et. al., ibid.).

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