Drapely-o-lightment

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Drapely-o-lightment: an algorithmic approach to designing for drapability in an e-textile garment

Loe Feijs and Marina Toeters

The field of techno fashion is developing rapidly. The contributions come from fashion designers such as Hussein Chalayan [1], who use the technology to translate their views on fashion or even on society, but developments are also driven by needs in sports [2] and medical research [3-5], supported by progress in electronics, materials, and tools. There are also interesting developments in textile multi-modal interfaces [6, 7]. We refer to [8, 9] for overviews. In [7], the concept of embodied computing is studied in the context of “invisible computing”. Schiphorst [7] develops examples illustrating how our own body data can be used to create and share awareness in an intimate way in a social space – and we consider this worth exploring.

Most of the technological research on sensor networks and on-body networks seems motivated by medical objectives: monitoring for heart patients [3], unobtrusive monitoring for at-risk babies [4], seizure detection for epilepsy [5], and so on. Technically it becomes easier and easier to measure all kinds of body signals. Although the medical objectives are very worthwhile, we also want to bring the idea of self-expression to the attention of the technology developers. Traditional garments are not only used for functional reasons (warmth and protection), but they also allow a person to convey messages about his/her identity, state of mind, social status, etc. The covering and exhibiting of more or less intimate body areas is an important issue both in the fashion world and at a personal level for each user. Similarly, the possibility of showing or sharing new body signals such as breathing, Thecla Schiphorst’s exhale [7], muscle-tone in Philips’ fractal ([10] p.27), or heartbeat in Drapely-o-lightment) will become important possibilities worthy of exploration. In Drapely-o-lightment, interactivity is added to give the garment a kind of soul; it detects approaches, not only in exhibitions, but also when a person wears it. This almost gives the skirt its own will, which makes it more interesting and valuable.

Our work fits in with the vision put forward by Linda Worbin [11], that nowadays combinations of textiles and computational technology are usually tools for design and for speeding up production; but that in the near future the computational technology will be an active part even after production - it will be a part of the fabric during use. This is the case in our project, where the special Voronoi algorithm and the laser cutter were essential for design and production, and the Arduino and the OLEDs are also active computational technology during use. The result of our explorations is the skirt shown in Figure 1.

Drapely-o-lightment was shown at various opportunities in the Netherlands, and at Pretty Smart Textiles at Textiles Open Innovation Centre TIO3 in Ronse, Belgium [12]. In this article we describe the background, the design process, the result, and the lessons learned. The article targets readers in fashion innovation, and also designers and technologists developing new sensors and actuators to be used close to the human body.

Fig. 1. Drapely-o-lightment, the OLED skirt. Photo Brian Smeulders, model Stephanie Samson. (© Marina Toeters)

ABSTRACT

Drapely-o-lightment is a skirt created as an exploration of the integration of electronics and clothing. This prototype was made as a tool for research into design techniques that work well with components that conform to today’s standards for the manufacturing of electronics. The design takes account not only of the inclusion of squares in the visual design, but also of the tactile and visual properties of hard components in a traditionally soft medium. Because the electronics are standardized, the textile component is designed by adaptation. The skirt is the result of a collaboration between the companies by-wire.net (high-tech fashion), Philips (OLEDs), and TU/e (Industrial Design, theme Wearable Senses).
**Techno squares**

At present and in the near future we are faced with discrete components to be embedded locally in limited numbers in line-to-line conventional fabrics. Many of these traditional components are manufactured as squares or rectangles. Important examples are OLED (organic light emitting diodes), solar cells, QR codes, PCLs (printed circuit boards), and magnets; a few examples of which are shown in Figure 2. In theory these could be manufactured in other forms, but in practice they are most often just squares. We call them techno-squares.

The design challenge we wanted to explore was the integration and interplay of the textiles (with their inherently soft nature), and the techno-squares (with their typically hard nature). At present, the electronics industry is offering square OLEDs of increasing size, giving rise to the important question of how these can be embedded. In the future, perhaps in ten years, the industry may produce very soft, lightweight, and flexible components, which will give rise to new design questions. The challenges of embedding techno-squares are twofold. The first challenge is to visually integrate the techno-square into the fabric so that it appears to belong there, rather than being an island or alien body. The second challenge is the drapability, as in Figure 4 (d). Marina Toeters had done work with triangular patterns before, such as in the coat shown in Figure 5, which was designed for body-measurements.

**Drapability**

Before we met and decided to do a project together, Marina Toeters was already exploring fabrics with patches, ways of cutting and attaching the patches, the visual effects of various patterns, and the impact on drapability. The main reason for doing so is the availability of laser cutters, and the desire to explore what can be done with them. Loe Feijs worked with Christoph Bartneck, Jun Hu, and design students, to develop Escher-style tilings, where the pieces were cut with the laser cutter, and where the most important learning goals were to teach geometry to the design students. Part of this work was published as [1] and presented at the art exhibition [2]. But those tessellations had not yet been used for garments.

When Marina Toeters and Loe Feijs met in early 2012 and decided to exchange ideas on textile tessellations, we tried to create tessellations in piriform Escher-style. It did not take us long to find out that these are incompatible with good drapability.

Loe Feijs suggested it would be easy to make smooth transitions from fantasy figures to squares (for embedding the techno-squares). But we soon found that the typical Escher-style shapes would interlock, leaving no folding lines at all. The samples of patches we used in the experiments are shown in Figure 4.

We made plots of the various experiments, measuring the folding radius for various directions, which can confirm what Marina Toeters was finding through more intuitive explorations: surprisingly, the pattern of regular equilateral triangles is the most effective for drapability, as in Figure 4 (d). Marina Toeters had done work with triangular patterns before, such as in the coat shown in Figure 5, which was designed for body-measurements.

**From triangles to squares**

If we were not to impose any conditions, there would be an infinite number of ways of making the transition from triangles to squares. This means that there is some freedom of choice for the designer, and we propose a specific way of implementing the transitions. Both natural animal skins and mathematics inspire it. These turn out to be connected in the theory of Voronoi diagrams, which describes certain cell structures in two dimensions. Our proposition is to have a structure of patches, some of which are squares, and most of which are triangular. The triangles provide for good drapability whereas the squares can be used to embed techno-squares. In the next two sections we discuss first animal prints, and then Voronoi diagrams and their connection to certain animal prints.

**Animal prints**

Prints inspired by animal skins are a favorite theme in contemporary fashion. For an overview of the history and the meanings of animal prints we refer to Tanya Wilson’s text on Animal Print [13]. The meanings include evoking the power of the animal, respecting the prey, associating their wearer with “the wild”, and having status (because real animal skin was precious). But Tanya Wilson also notices that, with the advent of new production processes, the meaning of animal prints tends to shift from wealth and status to a message that comes across as witty, playful, and bold. When exploring the design options for Drapely-olightweight, we felt that a loose and implicit reference to animal skin would make the pattern more interesting than a random pattern or a purely technical solution. And at the same time we felt that a link to nature would somehow counterbalance the technical and future-oriented meanings carried by the OLEDs, the metallic colors, the presence of a microcontroller, and the pure geometry of triangles and squares.

At a more abstract level we are happy to think our design fits in with the trend described by Li Edelkoort [14]:

> “our relationship with the natural world will need to become symbiotic if we intend to survive as a species, and by learning lessons from nature, we will be able to mimic its evolved forms, its mastered techniques and benefit from its proven knowledge. Our archaic roots will be transformed into contemporary ways of living, and in animistic fashion, we will connect with animals on entirely different levels. Mankind is after all a part of the animal kingdom.”

**Voronoi diagrams**

In mathematics, a Voronoi diagram is a way of dividing space into a number of regions. A set of points (seeds) is specified beforehand, and for each seed there will be a corresponding region consisting of all points closer to that seed than to any other. The regions are called Voronoi cells (Figure 6).

Voronoi diagrams are related to animal skin prints in a practical sense: many graphical designers and artists use Voronoi-based algorithms and tools to generate effects that resemble animal skin. A popular way of doing this is using the Filter > Texture > Stained Glass option of Adobe Photoshop. An example of this effect is shown in Figure 7.
In computer graphics this resemblance is exploited in special algorithms for generating animal skins for animation purposes. For example, Marcello Walter did this for the skins of various species of giraffes in his Ph.D. thesis in 1986 [15]. The computer graphics work is inspired by biological research into how skin develops in real animals. One theory is the Clonal Mosaic Model (Walters [15]).

Designing the pattern
The main layout of the skirt was made in Adobe Illustrator by the straightforward tailoring of a standard skirt pattern for the basic skirt substrate. The size was 36 (European measures). For the patches, a copy of this pattern was subdivided into the patches by laser cutting. The patches were separated by borders of about 3 mm. The pattern was shifted in the four colors and cut out with four different Illustrator files.

The pattern of patches was created with a special algorithm programmed in Processing (an open source Java-based platform also used for teaching in TU/e Industrial Design). After some puzzling trials consisting of triangles, except for 17 areas around a square. In total there are about 2500 patches, mostly triangles, and 17 squares. Around each square there are about 30 irregular polygons. Six of these squares actually contain an OLED, whereas ten are there for pattern consistency and prevent the upper skin area becoming boring. Figure 9 shows the pattern. The original pattern has all its triangles of the same size, and, by means of a subsequent straightforward geometric transformation, was texture-mapped to the layout of the basic skirt.

REALIZATION
The total of about 2500 patches were transferred manually from the four laser-cut fabrics to the skirt. The fabric was fixed by cotton interlining carrying a glue layer, and then it had to be activated by hot ironing. This was a very labor intensive process. The exact positioning was done with the help of a template: the network of 3 mm borders left over from one of the cuts.

We also discussed and played with various design options regarding the behavior of the light. We implemented two behaviors. The first behavior is a scanning behavior: the six OLEDs go on and off, with smooth transitions, in a low frequency rhythm of 0.3 Hz. The lights are not fully synchronous, but follow each other with a 0.5 second delay between adjacent OLEDs, similar to the effects of breathing. The second behavior is a heartbeat pattern. This pattern is a double-blink, similar to the pulse pattern picked up by a PPG sensor or felt when feeling a person’s heartbeat. For the heartbeat behavior, all OLEDs work synchronously (so the effect is more pronounced, and draws attention). It is technically possible to show the real heartbeat of the woman wearing the skirt, for example using a PPG or ECG sensor, but for demonstration purposes we implemented only a simulated heartbeat of about 70 beats per second. The main reason is that we were aware that the skirt would be shown at various exhibitions on a puppet, not a real model. We felt it was sufficient to refer to the possibility of showing body signals in a more abstract and poetic way. The simulated heartbeat is programmed in C using Arduino.

The possibility of interactivity also had to be part of the demonstration: there is a sensor to detect movement in the environment, so there is interaction even with a static dummy: visitors to the exhibit trigger the heartbeat pattern. Technically it works with two LDRs (light dependent resistors) and an Arduino LilyPad (a microcontroller intended for textile applications). The Arduino calculates a moving average light intensity level, and uses that to detect fast changes in intensity. The LDRs are put in a Voltage divider circuit with distinct resistor values so that the detector mechanism works under both dim and bright conditions. In practice it is quite robust and will trigger the heartbeat when a visitor gets nearer than 0.5 meter. After about eight seconds of heartbeat operation the skirt returns to scanning mode.

The skirt is designed to be comfortable to wear. The wearer can sit, walk, and dance without practical problems. The OLEDs are clearly visible during normal in-house conditions, also when daylight enters through the windows. However, in bright sunlight, the intensity of the OLEDs is simply not enough. Note that it is an essential point in this design that the effect of the lights is subtle (and not screaming “this is an LED skirt”). The dynamic effects of the breathing rhythm and the heartbeat certainly have aesthetic qualities (but these are hard to show in this paper - we shall provide a movie or a simulation as supplementary material for the readers of the electronic Leonardo).
Woods in the 1930s [22]. Similar pat-
tens were explored by Escher [23], who is apparently more famous (particularly in the Netherlands, where N. de


torijn organized the first exhibition of Escher for the World International Congress of Mathematicians in 1954). Woods worked in textile research where he fo-
cused on the color pattern rather than on the folding and the drape of the fabric. Regarding the semantics of our pattern, we would also like to put it in the con-
text of the epistemological theory of K. Kraft [24], who argues that beyond the possibility that patterns are deployed as carriers of ornamental cultural values, there is the important perspective that all kinds of symmetries arise during the production process (knitting, plaiting, weaving etc.). We envisage new tex-
tiles that do have very interesting sym-
metries, but where the story told by the symmetries is a more complex mixture of computer-aided design, laser-

er-aided production, functional require-
ments, and ornamental requirement. 

Looking Back

In retrospect we are glad that the Es-

cher-style tilings were not so drapable because the present reference to nature is much more subtle. The point is that
stiffened textiles with non-straight edges tend to interlock rather than fold nicely at the edges. Before doing the experi-
ments we had an impression intuition that perhaps any tessellation would improve drapability, but then we found that the chosen triangular pattern outperformed all others (and certainly the Escher-like patterns).

At a higher level, we draw several conclusions about the process. We found that computer-driven laser cutting is a very valuable innovation, and that its creative possibilities are far from ex-
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temporary design challenge. We found that the difference in background between Mari-

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technology) was the main reason that our cooperation led to something new; for example, Loef Fejs could have continued doing tessellations as usual [26], but it would have been more of the same. We found that a rich and open studio environment (such as the setting of the TU/e Industrial De-
sign department and its theme space of Wearable Senses) is an excellent meet-
ground for initiating and executing multi-disciplinary cooperative projects. We believe that the possibility of show-
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beats, and heartbeat variability are worth exploring - not only for medical reasons, but also as a new semiotic language and a way of sharing something intimate. We believe that new technologies such as laser-cutting and welding instead of cutting and stitching will gradually find their way from the experimental studios into the factories. This is already hap-
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Finally, we would like to put it in the con-
text of the World International Congress of Mathematicians in 1954 (see also, for example, De Bruijn's pentagrids [29], but here the situation is much simpler since we need only a "duoagrid"). A duoagrid is a set of verti-
cal strips of width $\lambda = 1/2$ and height $\sigma = 1/2$. A grid would thus be defined as a set of horizontal strips $\lambda = 0$ and vertical strips $\lambda = 1$ and $\sigma = 0$. A duogram can be used to produce the $(x,y)$ coordinates of a hexagonal point grid, and it can also be used to produce the $(x,y)$ coordinates of a square grid, as shown in figure 12.

The trick is to turn to algebra, as De Bruijn did, and, in our case to construct a formula-pair which gives the $(x,y)$ co-
ordinates for the hexagonal grid:

$$x = 1.5i + odd(j-i)? \frac{1}{2} : 0$$

$$y = 1.5j$$

and for the square point grid:

$$x = 1.5i + odd(j-i)? \frac{1}{2} : 0$$

$$y = \frac{\sqrt{3}}{2}j$$

where the notation $c? \frac{1}{2} : 0$ means if $c$ then $\frac{1}{2}$ else 0. And of course we have

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Loe Feijs (1954) has an MSc in electri- cal engineering and a PhD in computer science. In the 1980s he worked on video compression and telephony systems. He joined Philips Research to develop for- mal methods for software development. In 1994 he became part-time professor of Mathematics and Computer Science, in 1998 scientific director of the Eindo- hoven Embedded Systems Institute, and in 2000 vice-dean of the new depart- ment of Industrial Design at TU/e. Eindo- hoven. At present he is professor for the Industrial Design of Embedded Systems chair. Loe Feijs is the author of three books on formal methods and of over 100 scientific papers.

Marina Toeters (1982) – educated as a graphic and fashion designer - fin- ished her Master of Arts cum laude at MAHKU Utrecht by exploring the gap between designers and technicians in the world of fashion. She initiates and motivates collaboration for fashion innovation, and is the initiator of by- wire.net (design & research in fashion technology), working for, among oth- ers, Philips Research, Philips Design, Kwintet workwear, and the European Space Agency (ESA). Marina Toeters is a member of the research group Smart Functional Materials at Saxion Uni- versity for applied science, and teaches New Production Techniques for textile & garments. She is coach in Wearable Senses at the TU/e and lecturer / project coach Fashion ecology & technology at the Utrecht School of the Arts and De- sign. More info: www.by-wire.net.