Fibres, Fabrics and F-Formations.

About Sensing Social Interaction through Smart Textiles.

Sophie Skach, Rebecca Stewart and Patrick Healey
Queen Mary University of London, UK

ABSTRACT

Body movements contain a great deal of information about patterns of participation in conversation. For example, speakers and addressees move their hands in systematically different ways. Existing approaches to identifying patterns in social interaction typically employ relatively complex sensing devices such as fixed cameras or mobile phones.
With this work, a new, non-intrusive method for sensing patterns of social interaction using only fabrics is introduced. Using a textile surface as a sensing material for capturing body movement shall be discussed further in the scope of this project.

KEYWORDS

Social Interaction, Posture Classification, Electronic Textiles, Smart Fabrics, Textile Sensors, Conversation Analysis, Non-Verbal Communication

ACM Reference format:
Author details removed to preserve anonymity. 2016. Fibres, Fabrics and F-Formations.. In *Proceedings of ACM Conference, Washington, DC, USA, July 2017 (Conference'17),* 4 pages.
DOI: 10.475/123_4

1 INTRODUCTION

This research is considered as an intersection of textile technology, wearable computing and human-human interaction. These disciplines are, in their own operating world, all well established and have been explored over the decades and in part over the past centuries.
With a currently growing interest in exploring applications for electronic textiles from the fashion industry, amongst others, projects like Google Jacquard [11] have gained great attention and have helped lazing a path for a new generation of smart textiles.
Most of these recent developments engaging in introducing smart textiles to everyday-life scenarios have focused on designing textiles as an interface, replacing other wearable, more gadget-like devices; more or less acting like a remote control or measuring tool. However, an entire area of potential applications has not been taken into consideration much so far. There have in fact been few attempts to explore wearable computing systems integrated in textile surfaces to benefit the understanding of human behaviour and to contribute the analysis of social interaction.

DOI: 10.475/123_4

Many wearable devices are seen as gadg
tiles at all. Wristbands, belts, necklaces l
commercial products in various fields - most popular in the sports sector and in healthcare, as well as increasingly in designs for the fashion and lifestyle sector.

Body movements contain a great deal of information about patterns of participation in conversation. For example, speakers and addressees move their hands in systematically different ways. Existing approaches to identifying patterns in social interaction typically employ relatively complex sensing devices such as fixed cameras or mobile phones.
With this work, a new, non-intrusive method for sensing patterns of social interaction using only fabrics is introduced. Using a textile surface as a sensing material for capturing body movement shall be discussed further in the scope of this project.

2 RELATED WORK

To be able to understand human behaviour through a textile sensing system, it needs to be determined of what measurable cues social behaviour consists of. How do we recognise engagement and relevant behavioural patterns? What does a sensor measurement, for example data from pressure measures or heart beat really tell us about people's dynamics in interaction with each other? A lot of it has been discussed in relation to movement. Muscular movement in the human body may provide such cues, as well as temporal changes in temperature, pulse or heart beat.
But also more visible cues have been identified before. In a situation of group interactions, such as conversations between two or more people, certain spatial formations are created and maintained. These arrangements, described as F-Formations by Kendon [9] also provide information about the participant social role within an interactional scenario - e.g the self positioning of people to avoid overlaps in transactional segments with existing predetermined spaces (for this, Kendon defines circular spaces as O-, R- and P-spaces, created by individ- uals and ranging from inner to outer circles).
Joining or leaving such formations as well as adjusting them can also reveal hints on other activities of the subjects, as well as about the content of conversations. It was, for example, suggested that sidewards movement on a seat can be associated with measures of higher nervousness [1]. In other works, the gestural movement between speakers and listeners has been assessed [8]. Attention was also drawn to gaze and the postural relationship between upper and lower body as cues for participation in a conversation [12].

With cues to social behaviour ranging from spatial orientation to invisible changes of pressure applications on the human body, the techniques for measurements vary as well. Answers to questions that have been raised by Pentland [5], such as "Who are the people we talk to? How often do we talk to them and how long do the conversations last? How actively do we participate in those conversations?", have been approached by wearable sensing systems before (e.g. with a device named Sociometer, [4]), but have so far always been integrated in an intrusive way. Therefore, in several works (e.g. [13]), privacy is raised as a concern in regards to sensing systems capturing social interaction. This derives from the fact that most sensors are video or audio recording devices. This furthermore derives from the fact that 90 percent of body gestures (that we treat as behavioural cues) are associated with speech ([13]), which is why such recordings provide the easiest solution to capture such scenarios. In current research, it is still a challenge to develop sensing systems that protect privacy and still capture all relevant data (e.g. mentioned in [7]).

When focusing on fabrics as sensing materials, with special consideration to garments, there of course also limits that occur in this spectrum. Textiles may be able to sense things that are invisible to the human eye, but may not be able to capture what is recognisable, for example, to the human ear. Therefore, another aspect of this research project is the exploration of what textiles - or garments in particular - can and can not sense. Garments could detect acceleration, tilt, pressure, temperature and probably many other measurable elements that a human body provides when in social interaction with others. But could jumpers ever capture gaze or voice as well, or detect laughter? Where are the limits of sensing garments? And towards which areas of sensing human behaviour could garments enrich our world?

3 METHODOLOGY

There are three main studies that have been layed out to explore the social performance of textiles.
As the first interface to the world beyond our skin, fabrics have been part of the human appearance for approximately 40 000 years. Techniques like weaving, felting or knitting have existed for equally long and have not only helped to cover the naked human body, but also to comfort it - in domestic environments amongst others.
So it has come that we have not only developed fabrics to dress with, but also, for example, to sit on or to walk on.
Therefore, dedicating to turning fabrics into sensing surfaces to explore social behaviour does also encounter investigation of chairs, carpets, table cloths or curtains. Chairs in particular are an object on which much postural movement is performed and chair covers are made out of stretch fabric that makes the textile surface itself a potentially promising sensing material.

3.1 Sensing Chairs

Informal observations of the postural behaviour of listeners and speakers suggest that people frequently change the position of the torso, lower body, and feet during seated conversation. These movements cause pressure changes on the surface of the chair and are therefore relatively easy to detect.
Research on non-verbal communication has tended to take advantage of video and, more recently, motion capture equipment to capture and analyse these movements (e.g. [8]; [13]). The rapid development of new sensor technologies and their application to

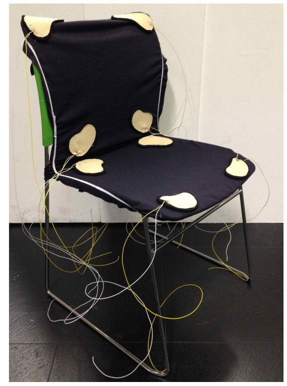

Figure 1: Backside of the chair cover, all sensors attached, before connecting them to other hardware.

social signal processing has opened an intriguing new space of possibilities for detecting patterns of interaction [13]. Here we explore the potential of this approach for the most commonly used parts of the physical environment for social interaction; chairs. Moreover, chair covers are often made out of stretch fabric that makes the textile surface itself a potentially promising sensing material. Using metallic yarn gives a fabric conductive properties so that it can be turned into a pressure sensitive surface.

Drawing on informal observations of peoplefis leg and torso movements in meetings we decided on a configuration of eight sensors that were integrated in the chair cover and distributed in a symmetric arrangement; four in the seat of the chair and four on the back. Using these custom built fabric sensors we tested whether we can detect people's involvement in a conversation using only pressure changes on the seats they are sitting in. An experiment was conducted with 9 three-way conversations (27 participants in total), each of them lasting about 30 minutes. They were placed around a round table and given a task to discuss. The interactions were captures with video and audio recording devices as well and were later annotated and synchronised to the collected sensor data. The data from all eight sensors were analysed in a General Linear Model Multivariate Regression using SPSS v.24. Talking, Laughing and Backchanneling were included as binary predictors coded as 1 or 0 for presence / absence of each behaviour.

The results show that it is possible, in principle, to detect significant aspects of social interaction from quite limited, indirect and noisy data. The small movements detected by pressure sensors embedded in chair seats are small-scale and almost completely invisible correlates of the gross body movements that typically distinguish speakers from hearers and laughter from silence.
Further work to optimise the size and position of the sensors would doubtless improve the quality of the sensing. It is also likely that other approaches, such as training person-specific classifiers, would improve the accuracy and robustness of the approach although this would also undermine the advantages of anonymity. The demonstration that even relatively crude sensors can detect minimal changes in posture, suggests that future work should explore the possibility of capturing more complex social behaviour, especially relational

questions such as whether interactions are, for example: autocratic or egalitarian.

What could this form of sensing be used to do? The principle opportunities for application are in any situations where there is value in the ability to unintrusively gather information about general patterns of social interaction including levels of interest and engagement. One example is architecture where the ability to sense a building's energy performance and patterns of air flow is highly valued but currently has no social counterpart. We speculate that the ability to make simple, systematic assessments of a building's social performance by instrumenting the chairs in a building could also have a significant positive impact on domestic and workplace design. A second example is in the evaluation of audience responses. The deployment of such a sensor network in an auditorium, meeting room or a classroom could help to assess levels of engagement of students and other audiences. In addition, there are possibly applications to augmented human interaction where, for example, live feedback about how much people are dominating (or not) a conversation can have significant effects on the conduct of the interaction [6]).

3.2 Socially Aware Garments

After looking at body movement during a seated conversation, the viewpoint on this scenario can also be taken from the body itself, or from garments. Drawing on previous results and observations, postural cues can also be investigated through fabrics that are worn on the body directly. Imagine trousers that can detect whenever a leg is crossed, whenever we touch our knee with our hand, or whenever we lean from one side to the other. Furthermore, imagine jumpers that are aware of social roles within a group conversation by sensing touch (e.g. crossing arms), or that are able to sense the spatial orientation of its wearer.

This yet speculative concept of a socially aware garment has shown potential success by conducting a user study with pressure sensors on chair seat covers. When simple "DIY" pressure sensors can contribute in such detail to the understanding of social behaviour, what more could we find out when using textiles that sit even closer to our body - the body providing cues to social behaviour?

While a chair is not capable of sensing heartbeat or sweat, a garment is! Compared to a fabric cover of furniture, garments are in general closer to the body and able to capture more subtle changes in movement (whether this is concerned with gross body movement or small changes in muscular movement).

Dividing our everyday clothes into two categories - lower and upper body garments - there are different measurements that can be taken from the human body that become more or less relevant for detecting social interaction. Working with accelerometers or capacitive touch sensors, for example, becomes relevant when looking at arm or leg movement; whereas ECG sensors (electrocardiogram) for heart beat activity would make more sense to be integrated in a jumper than in trousers. For future studies, it is therefore to be examined which measures can be taken from which area of the body that reveal information about our behaviour when interacting with other people. Furthermore, this raises questions about determining behavioural patterns and extract such patterns from simple sensor data.

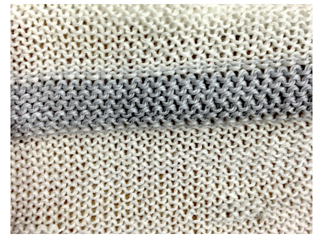

Figure 2: conductive stripe knitted on one needle bed on a Dubied flatbed machine

Figure 3: conductive yarn knitted on a second needle bed and linked with non conductive yarn

3.3 Knitted Sensors

In addition to the consideration in which garment or as which surfacesuch fabric sensors are integrated, also the size, shape and position of sensors needs to be well designed in order to collect relevant data.

The use of micro controllers becomes a challenge in designing wearable sensing systems as well. While in trousers, micro controllers could be integrated in an unobtrusive way, for example in pockets or the bottom seam (hem stitched), it is a bigger challenge to do so in jumpers. In general, a solution and design for soft and wearable circuits needs to be found to be able to manufacture such garments. In knitting experiments, there are different stages in which techniques could be explored. Considering the lack of literature on reviews and surveys of different knitted sensors and their characteristics, there are numerous aspects to look at and to be taken into account. When assessing sensing properties of knitted textiles, the following elements have to be considered:

(1) thread counts (change of resistance depending on number of threads)
(2) distance between two points (length of conductive thread also results in change in resistance)
(3) knitting structure (different structures require different amounts of thread per stitch (e.g. compare single jersey stitch and half cardigan stitch, floats with tucks with stitches))
(4) stitch length (different tensions mean more or fewer touching points of neighbour stitches)
(5) size of sensor or conductive surface (even within the same knitting structure and same amount of needles (courses and wales), different stitch lengths result in different overall sizes)

In an initial and preliminary study, different swatches were knitted, showing variations of knit structures and stitch lengths (the tension the thread is pulled through the needle on the knitting machine). These swatches were tested as stretch sensors, assessing their behaviour through a repeated and mechanically created stretching and releasing. These self made sensors were compared to commercially available conductive jersey knit fabrics, as well as to hand knit sensors made of conductive yarn. Initial testing showed that However, more experiments of such kind are planned to be undertaken to evaluate knitted sensors against all criteria listed above.
This evaluation plays an important role in relation to the previously mentioned studies on social behaviour. Encountering dynamic objects like garments and working with self made fabric sensors, the data we receive from such studies must be easy to translate into social cues, or, for a start, clear indications of which body movement was performed. So the lab studies on knitted sensors that are to be made into garments (the most discussed garment in this context, considering the materials and techniques we use, was a jumper), help to design studies of cognitive behaviour. This is where the disciplines that are mentioned in the beginning, textile technology and social interaction, find common ground.

4 DISCUSSION

Within the scope of this research projects, there are several aspects that are yet open for discussion. Amongst others, some key areas to consider are the following:

4.1 Processing Data

After having encountered the challenge of which data should be collected, the next step is the processing of this data.
In such studies, researchers aim to find a method to automatically detect behavioural patterns and reliably estimate and predict social behaviour, to give machines the ability to interpret human behaviour. This is not just a central topic in social sciences but also in machine learning and computer vision research (such as mentioned in e.g. [10]). Machine learning approaches have been applied to extract and detect patterns for behavioural discrimination ([2], as well as to model such behaviour in real time.
A method that has already been explored involves hand coding in a software called Elan [3], for annotating data from video recordings as well as from sensors. For this, sensor data was synchronised with video recordings from an experiment to compare and analyse body movement and extract patterns in the sensor data that would allow to identify speakers by just looking at the sensor data alone. For future experiments, it was also discussed to use a software that was developed at [remover to preserve anonymity], called Sonic Visualiser, to enable easier classification of audio data. Simple machine learning approaches were also discussed and will probably be experimented with throughout this research.

4.2 Fashion and Aesthetics

When investigating social behaviour through garments, the component of fashion should be studied as well. This is meant in regards to fashion as a social and cultural phenomenon that has the power to influence our social perception, as clothing is what makes us as humans culturally visible. In these regards, a critical review of the aesthetic aspect of the garments that are to be designed, could help to find the point of intersection between digital media and human interaction.
Moreover, with the rise of With the rise of electronic textiles, smart fabrics and soft computing systems, it might now be time for the young discipline of Computer Science to turn towards such craftsmanship that have accompanied humanity since its early years, enhancing its properties and learning how to benefit from them, rather than the other way around. Understanding the history of textiles may help to determine where wearable technologies could take us, exploring their potentials and limits (within the current century anyway) and providing answers to questions such: How is technology to be worn?

ACKNOWLEDGMENTS

The authors would like to thank the anonymous referees for their valuable comments and helpful suggestions. The work is supported by EPSRC.

REFERENCES

[1] Bert Arnrich, Cornelia Setz, Roberto La Marca, Gerhard Tröster, and Ulrike Ehlert. 2010. What does your chair know about your stress level? *IEEE Transactions on Information Technology in Biomedicine* 14, 2 (2010), 207–214. DOI: http://dx.doi.org/10.1109/TITB.2009.2035498
[2] Louis Atallah and Guang Zhong Yang. 2009. The use of pervasive sensing for behaviour profiling - a survey. *Pervasive and Mobile Computing* 5, 5 (2009), 447–464. DOI: http://dx.doi.org/10.1016/j.pmcj.2009.06.009
[3] Hennie Brugman, Albert Russel, and Xd Nijmegen. 2004. Annotating Multi-media/Multi-modal Resources with ELAN.. In *LREC*.
[4] Tanzeem Choudhury and Alex Pentland. 2003. Sensing and Modeling Human Networks Using the Sociometer. In *Proceedings of the 7th IEEE International Symposium on Wearable Computers (ISWC '03)*. IEEE Computer Society, Washington, DC, USA, 216–. http://dl.acm.org/citation.cfm?id=946249.946901
[5] Tanzeem Choudhury and Alex (Sandy) Pentland. 2002. The sociometer: A wearable device for understanding human networks. *CSCW'02 Workshop: Ad hoc Communications and Collaboration in Ubiquitous Computing Environments, New Orleans, Louisiana, USA* (2002). DOI: http://dx.doi.org/10.1.1.57.9810
[6] Judith Donath. 2002. A semantic approach to visualizing online conversations. *Commun. ACM* 45, 4 (2002), 45–49.
[7] Gabriele Frediani, Hugh Boys, Stefan Poslad, and Federico Carpi. 2016. Enabling wearable soft tactile displays with electroactive smart elastomers. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* 9775 (2016), 326–334. DOI: http://dx.doi.org/10.1007/978-3-319-42324-1_32
[8] Patrick GT Healey and Stuart A Battersby. 2009. The interactional geometry of a three-way conversation. In *Proceedings of the 31st annual conference of the cognitive science society*. 785–790.
[9] Adam Kendon. 1990. Spatial organization in social encounters: The F-formation system. *Conducting interaction: Patterns of behavior in focused encounters* (1990), 209–238.
[10] Alex Pentland. 2000. Looking at People : Sensing for Ubiquitous and Wearable Computing. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 22, 1 (2000), 107–119.
[11] Google Jacquard Project. https://www.google.com/atap/project-jacquard/. (????).
[12] Emanuel A Schegloff. 1998. Body torque. *Social Research* (1998), 535–596.
[13] Alessandro Vinciarelli, Maja Pantic, and Hervé Bourlard. 2009. Social signal processing: Survey of an emerging domain. *Image and vision computing* 27, 12 (2009), 1743–1759.