Wearable Networks, Creating Hybrid Spaces with Soft Circuits

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Abstract. With the emergence of augmented eyeglasses, smart watches, and health and performance monitoring wristbands, wearable computing has moved to the cusp of commonplace consumer technology. These technologies continue a trend already observed within mobile technologies, their exclusivity to the wearer. Users often project an aura of disengagement from their surroundings. To address this issue we developed the Lightning Bug, a light enhanced garment. The Lightning Bug signifies an extension of our existing channels of mobile communication into the directly perceivable realm, by deploying a visible mode of interaction and exchange of information. In a semantic analysis, we investigate the ability of the garment to represent information using different light-patterns, and develop a mode of intuitively interpretable signaling. Considering the established mental models concerning fashion, we further develop a system of controlling the device based on natural behavioral patterns by reading and utilizing the wearer's nonverbal communicative clues.

Keywords: Photonic displays, smart fashion, embedded electronics, wearable networks, hybrid space, applied semantics, interactive technology, Soft User Interface, physical computing, Lightning Bug.

1 Introduction

"We wear privacy like a pressure suit. Given half the chance we'll stuff the seat next to ours in a café with raincoats and umbrellas, stare unremittingly at posters about measles in a doctor's waiting room... Anything but invite encounter; anything but get involved..."

So commented Schluter and Lee in their book *The R Factor* on post-modern society in 1993, long before the advent of mobile technologies. They were not alone in their judgement, many other notable writers, such as Sennett, Baumann, Gehl and Fry, have described this process [1][2][3][4].

Accordingly, the prevalent individualistic retreat into some personal bubble cannot be solely attributed to mobile technology, but it is as much a sociological and cultural issue, deeply rooted in modernism's obsession with rationalization, separation and segregation.

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Nevertheless, current mobile devices do influence and aggravate this development. The experience of reality is constantly mediated through a device and any sociability, which has not been filtered by the set parameters of a social media service is rejected. Each individual spins a personal cocoon, a digital comfort zone, with virtual boundaries defined by online groups of contacts or friends, selected entertainment and news feed subscriptions, all whilst being “out and about”, moving through the public realm, physically present yet mentally absent. Social space and physical place drift further and further apart and in contrast to or maybe more correctly, as an extension of the modern era, where privatization implied a retreat in space, into the compact privacy of the nuclear family home, where as mobile privatization, signifies a retreat of space. Private space invades and displaces the public [5]. Nascent wearable technologies continue this trend of exclusivity to the wearer, they invert on themselves and allow their users to create huge amounts of data flow, that remain utterly imperceptible to those with whom they share space. Aided by their devices, users are paradoxically, increasingly interacting and exchanging ever growing volumes of information in their social space, whilst simultaneously, through this very exchange, increasingly hindered in direct personal engagement [6]. As a result, the user often projects an aura of aloof detachment and disengagement from the surrounding spatial environment.

In contrast De Souza e Silva speaks of Hybrid Space, where digital information does not constitute an "other" space, but instead creates an overlay onto existing, physical reality. De Souza argues that as technology is becoming more and more ubiquitous, partly embedded in objects and buildings and partly carried as a constant companion on or in close proximity to the body, differentiating between the digital and the physical ceases to make much sense. Instead the concept of spatiality itself must be redefined in order to encompass connected, social and mobile space [7]. Expanding on this notion by including the immediate physical proximity of the user we aimed to create everyday apparel with the ability to establish Wearable Networks and reunite digital social space and physical place through electronically enhanced fully embodied "human moments" [8].

2 Project Lightning Bug

Inspired by the sophisticated flash patterns deployed by some species of fireflies for communication purposes, we created the Lightning Bug (LB), a light enhanced garment, which can be characterized as an interactive and wearable user interface and display, with networking capabilities.

The Lightning Bug provides an extension of our existing channels of mobile communication into the directly perceivable realm, by deploying a visible mode of interaction and exchange of information, facilitated through embedded luminous materials.

The embedded technology is integral to the flexible substrate, so that the interface can be comfortably worn on the body. We define this type of smart garment as a Soft User Interface (SUI) [9]. As interfaces between wearers, networks and environments,

the garments do not invert on themselves, but are inclusive of the surrounding environment. The ability of the garment to represent information using different light-patterns, intensities and animations, is utilized both by the wearer as well as the surrounding environment to convey information. On the most basic level, the garments recognize and exchange information with other collocated devices. An unlimited number of such garments can influence each other to establish one or more networks. Within a network, the garments operate on several levels of inclusivity, unlike similar wearable devices, which tend to be exclusive to the wearers, such as bracelets that unobtrusively vibrate when encountering a like minded person wearing an identical device [10].

Neither is it a mere reactive display of perceived data, whether of its wearer or its environment, as seen in projects like HearWear [11]. For prototyping purposes we fashioned a total of nine knitted outfits with embedded light emitting fibre, however a much larger number is possible. The knitted base structure was chosen due to the ease of fitting the fibre, as well its everyday appearance and the easily attainable variety of expressions. The LB has three distinct modes, operating on different levels of intimacy, spatiality and chronicity.

2.1 Default Mode

The default modus is triggered by donning the LB. When in this mode the LB retrieves the heart beat of its wearer and translates it into a subtle harmonic light pattern, attuned to the visual style and existing coloring of the knitwear. This slight oscillating appearance of the garment does not interfere or overpower the initial statement of the dress, but adds an intriguing and aesthetically pleasing second dimension by displaying the inner state of the wearer in a subtle manner.

2.2 Active Mode

When coming into close proximity of other like garments a different light pattern emerges, indicating the garments to now be in "active mode". These pre-set light rhythmic animated patterns are individual to each garment and somewhat more dynamic, but stay within an harmonic relation to the knitwear and thus represent an extension of the expression of its design. To enter back into default mode the wearers will have to physically remove themselves out of the other person's personal space.

2.3 Interactive Mode

If the wearers of the LB's choose to dwell more than 30 seconds within close proximity of each other the garments enter into "interactive mode" by a slow exchange of patterns and hues with each other to so form a new rhythm based upon the individual expression in a kind of visual duet. This visual duet can be expanded upon with other wearers of the LB's joining into the experience, creating something which could be likened to a musical band/group or even a complete orchestra. The

experience lasts as long as near proximity is maintained, upon disengaging, it reverts back into active mode, followed by the default.

2.4 Processing of Spatial Data

Photoresistors enable the knitwear to adjust its brightness to its environment, as the glow would becometo overpowering in very low light situations, such as outdoors during the night. However all available brightness is needed when in a lit environment. Likewise it is envisioned that reaction times and functionality will be modified with the spatial data. Certain spatial conditions, such as riding a subway or an escalator, with little or no choice of proximity, would prevent LB's from reacting onto other collocated devices, other situations such as a crowded interior space, would delay reaction times. Empty or sparsely populated outdoor spaces on the other hand, would accelerate interaction.

2.5 Mode of Operation

The LB is controlled by non-verbal actions, which are an integral part of our established daily patterns and are very simple. Wearing it, switches it on and the active and interactive modes are activated by analyzing the proxemic and chronemic behavior of the user.

2.6 Technical Details

Each LB is battery powered and fitted with an arduino micro controller and a low range radio module. A pulse sensor registers the wearer's biometric data and the photoresistors register external parameters, such as light conditions of the immediate spatial environment.

2.7 Research Methods

Coming from a design background our research methodology stems from creative practice [12]. Meaning, we approached the project very much in a hands-on fashion. First developing a rough concept (hypothesis), next seeking feedback, reworking the concept based on the received feedback and lastly initiating the development of the project, adjusting features as we went along. In preparation for the project, a small preliminary qualitative study was conducted within the Trier University of Applied Sciences. The study included post graduate students, as well as design lecturers in the fields of Fashion Design, Human Computer Interface Design and Jewelry Design. This was followed by a second qualitative user study, also at the Trier University of Applied Sciences, with the first working prototypes. A large final study, within the prototype development will be conducted in a public performative setting, which has proved an effective research technique to gauge and observe underlying attitudes toward the design of wearables [13].

3 Discussion / Preliminary Results

3.1 Fashion First / Overcoming Established Mental Models

In the initial user study, the participants were shown small samples of the proposed knitwear and during this process the initial idea of using electroluminescent materials was rejected. The majority of the questioned subjects clearly indicated that they would not consider wearing such a garment in a day to day setting, due to its staginess, and flashy or geeky appearance as well as the high - frequency sound caused by the inverters. Subsequently a second material was developed, using optical fibre, that could be more subtly integrated into the knitwear with a more pleasant and customizable color range. In addition this material provided a greater control over the appearance of the garments and we were able to integrate the fibre as a natural part of the individual knitwear designs as opposed to a high-tech add on.

The inconvenience experienced in this design was the need for an additional source of light to illuminate the fibre, adding to the bulkiness and electronic components being carried. However developments in the area of photonic textiles are extremely promising and there are commercial products available that could more elegantly be deployed in further iterations of the LB than our prototype construction. [14][15].

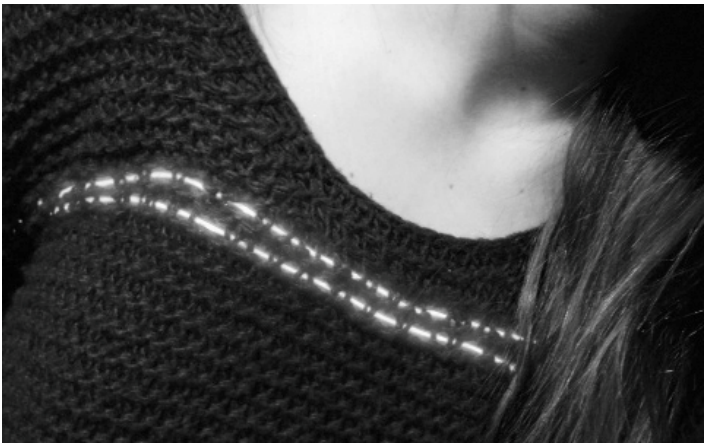

Fig. 1. The EL-Wire in the first prototype is too dominant in the garment

Due to the familiarity of knitwear, integrating the fibre as a natural part, proved to be challenging. Knitwear has a documented history dating back to 3BC, and as such carries with it established mental models about what it is and what it can do. Namely to provide warmth and, as a fashion item, to convey a certain style. Although this is true about any type of clothing, knitwear especially is associated as being self-made, low-tech, and regarded as a rather conservative and old-fashioned, or even non-fashionable garment.

In order to overcome this perceptional hurdle, we strove to integrate the technology into the garments as subtly as possible, with the initial functionality leaning aesthetically, into the design of the garments, by using color harmonies and patterns derived directly from the yarn used in the knitwear. Further the integration of the light emitting fibre was

worked to seamlessly blend with the structure of the knit. Hence, we were able to create a garment which does not scream 'tech', but conveys a subtle impression of apparel that has been beautified and enhanced. The integrated technology allows for a faint personal approach in that the heart rate of the wearer is used as the rhythmical signal controlling the emitted light signals. This extends on the concept within fashion, of clothing acting as "second skin", or interface of the self to the world. The biometric data is only shown when the wearer is not within the personal space of others. This development away from the first concept arose out of reactions of the interviewees in the preliminary study, who indicated feelings of discomfort to openly show their physiological reaction to others. As a strategy we chose to develop a visual cue more integrated into the visual expression of the garment to signal interest, determined by established proxemic and chronemic conventions, without disclosing the exact impact.

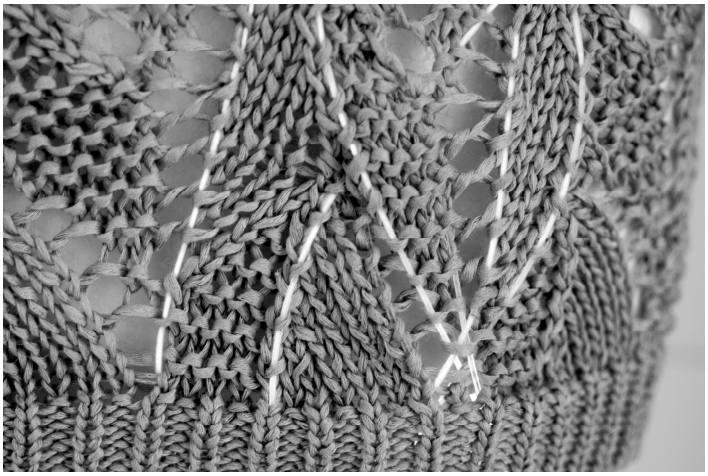

Fig. 2. Fitted optical fibre detail on

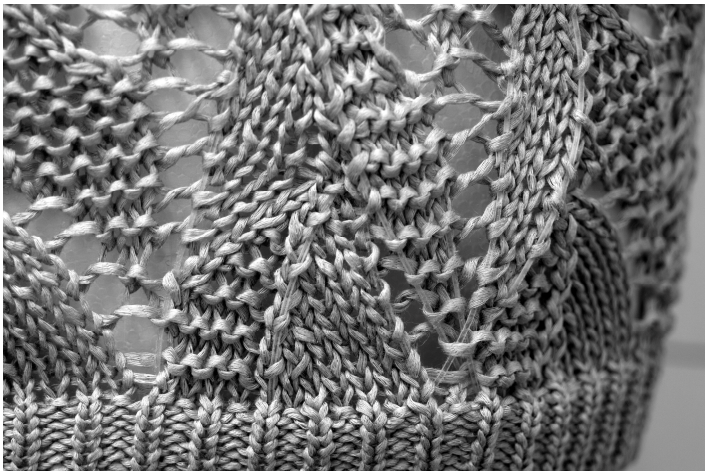

Fig. 3. Fitted optical fibre detail off

3.2 Complexity and Simplicity in Wearable Interface Design

Following the second user study, we eliminated our initial idea of mobile phone connectivity and app-based configuration because having to configure the item was perceived more as a hurdle, than a desired feature. The phone connectivity did not truly add any value for the user, who expressed interest in revealing a different kind of content integral to the LB, not in wearing an additional "screen". One user expressed: "just another potential advertising platform", and "the choice between wearing a black sweater and the LB was all the configuration needed."

We subsequently decided on a more direct approach, resulting in a much less complex design. In addition to the mobile phone connectivity and personal profile, we further removed any on/off settings. The LB is now completely controlled by the actions of its wearer. Wearing the garment is an act of acceptance and it switches on automatically. Likewise the different reactive and active modes are controlled purely by the spatial proximity to others. If the user does not wish for interaction he or she must remove him/herself from the situation. The reduction in functionality and expression created a much clearer message in the design. Perceived as being stylish and dynamic the LB was seen as a novel and interesting type of fashion with added dynamic properties, rather than being yet another electronic gadget made to fit into or onto a garment. This approach in many ways heightened the interest in and acceptance of the garment.

3.3 Social Interaction

At this stage of the project our main concern lies with the social interaction between the different dress wearers. How it is extended by this new channel of information and whether light, luminous forms and animated light can be a feasible mean of communication within wearable computing.

Previous experiments by the authors show that the wearer tends to disappear behind the glowing signage. This due to both the novelty value and also to the way the information is presented. One important design aspect we could isolate here was that when using luminous materials intended for everyday wear it is important to keep it peripheral and place it away from the face as this otherwise tends to retreat into the shadows. In addition, it was perceived to be difficult to maintain a conversation with the wearer due to the distraction caused by the light and the difficulty with reading facial expressions.

The trials within the university proved to create a heightened and more easy social interaction between the participants. However, as the participating group was very small, as well as physically concentrated, it will be important to conduct a bigger study with a larger number and more dispersed LB's.

One feature which was received very positively amongst the participants was the very natural and intuitive interaction, not requiring the learning of any additional skills. The LB is turned on when worn, reacts when within close proximity to others and engages when that closeness is maintained. In this way the interaction is modeled to mimic natural human behavioral patterns. The experience of the interaction between the dress lasts as long as the near proximity is held. Upon disengaging it briefly reverts back into the personal pattern, then only the default is displayed. In this

way the LB imitates already established customs. For example, it is typical human behavior to stay for a prolonged period of time within the proximity of another human with whom it wishes to establish contact. Negative feedback was received about the initial proposal of displaying intimate personal data through the light patterns when entering personal space of others.

The first question that arises is whether there is a demand for this kind of device to enhance the already established modes of human interaction. Our research clearly shows there is, especially as the new dominance of mobile devices changes the way we communicate with each other. It could even be claimed that nonverbal communication has become more important than it was before. For example, this can be seen through the prominence of text based communication such as sms and email, which has sparked a whole new methodology for people to convey emotions, with the use of smileys. Similarly, as the where and when of communication becomes increasingly liberated from the physical environment, chronemics and proxemics gain increasing importance as it signifies choices made by the user as opposed to unavoidable circumstances [16].

Fig. 4. The optical fibre fitted to follow the ropestructure of the knitwear

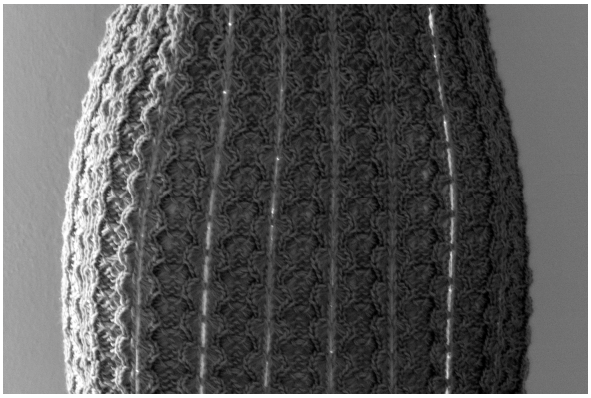

Fig. 5. The optical fibre fitted to the sub structure of the knitwear

3.4 Applied Semantics of Light Patterns and Colors in the Lightning Bug

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3.5 Acceptance of the Proposed Technology

The embedded digital functionality enhances communication between strangers when they meet, in that it adds an element of surprise and excitement, without hindering the natural gestural communication. Wearing and controlling the garment is extremely intuitive as it builds on existing and established patterns of behavior. As such the wearer does not have to specifically "do" anything when wearing the LB. The expression of the technology within the dress is subtle enough to be pleasant in day to day situations, whilst maintaining a novel and fashionable statement. Detriments to the garments practicality are more of a technical nature, i.e. the bulkiness of the required hardware and the battery life. With the rapid development in alternative energy harvesting methods in recent years, such as photovoltaic, kinetic and induction charging methods, etc as well as the advent of new photonic fabrics, we do anticipate these issues will be successfully resolved.

4 Discussion and Conclusion / Further Work

Lightning Bug (LB) investigates the possibility of SUI's as a design approach to developing a wearable luminous display with the aim of counteracting the historical, cultural, social and technological development towards the observed increasing detachment of the users of mobile technologies from their physical environment. The LB addresses this issue, in that it challenges the established social structures and enhances interpersonal communication. In contrast to the usual wearable and mobile

technologies the LB does not invert on itself, but is inclusive of its surroundings. It becomes an interface between its wearer, networks and the occupied environment. It changes the conventional handling of information and provides a means to modulate social interactions by adding an element of curiosity and playfulness to everyday interactions.

There is a general willingness to accept new fashions, yet these are expected to be reasonably uncomplicated to wear and not demand any significant relearning. Accordingly, augmented and interactive clothing aimed at everyday wear and general user acceptance needs to agree with established mental models. The proposed technology and interface must be approachable and intuitively interpretable. This can be achieved by reducing the interaction to be an integral part of already existing behavioral patterns, that does not demand additional attentional effort, as well reducing symbolic representations and focusing on indexical and iconic signs. The light emitting materials must be discreetly integrated to form a convincing unit, where the emissions emphasize the expression of the garment and do not obscure the wearer behind glowing signage.

This is a work in progress and the main focus has been on establishing the fundamental requirements to develop an agreeable and fashionable item, whilst seamlessly integrating the interactive technology. The research is taking place within the university and study groups have been correspondingly small and inclusive. The next step we will be to conduct a large study at a public event with over 30.000 visitors, over six days. The large amount of potential subjects pose particular challenges to the set-up of the study. The number of personal interviews would be around an estimated 200 - 250 from a broad spectrum of nationalities and individual backgrounds. Upon evaluation of the results we will enter the next phase of development. We will concentrate on expanding the possibilities of the natural interaction of the SUI by adding additional sensors, which will be able to assist in reading nonverbal communicative clues, so that the LB can react accordingly to the interactants' interests within the LB network.

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