LivingSurface: Biofeedback through Shape-changing Display

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ABSTRACT
In this paper we describe the concept, design and implementation of *LivingSurface*, an interactive wall-like surface as a shape-changing display of biofeedback. The surface changes its shape responding to an individual's physiological data, reflecting the internal bodily processes. The surface design basically consists of two layers: the pattern layer (front layer) and the actuating layer (back layer). The first is a complex paper-based structure with repetitive incisions created by laser cutting. The actuating layer serves as a medium transforming the force from servomotors, vibration motors or fans into an action on the pattern layer. The cutout patterns are stimulated to vibrate, swing, bulge, or rotate which is used to display physiological information in dynamic physical form. This work has been exhibited on Milan Design Week 2015; we collected and analyzed the feedback from the visitors during the exhibition and discuss the possibilities of the proposed surfaces as a shape-changing interface of biofeedback or an ambient display of information.

Author Keywords
Biofeedback; shape-changing; physical display; interactive object; information visualization

ACM Classification Keywords
H.5.1 [Information interfaces and presentation]: Multimedia Information; H.5.2 [Information Interfaces and Presentation]: User Interfaces

INTRODUCTION
Biofeedback is a technique of making unconscious bodily processes perceptible to the senses. In a biofeedback process, users' physiological signals are measured by bio-sensors and processed into information (feedback) about their body (bio), then fed back to the users by various forms in auditory, visual, haptic or multi-modal modalities. Biofeedback helps people improve self-awareness of subtle changes inside the body, and self-regulation to manipulate their physiology towards a more healthy condition [1].

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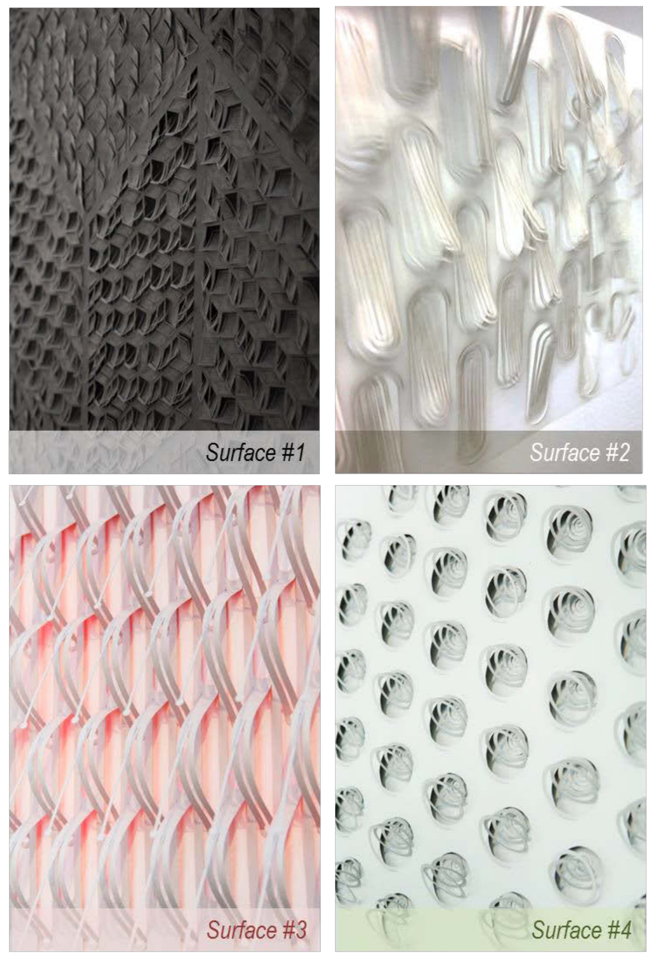

Figure 1: Close up of the *LivingSurface* at the Exhibition in Milan Design Week 2015

However, for a long time, biofeedback was only used for medical treatment. Not only the application of special sensing equipment, also visual display of biofeedback remains a high barrier to its casual use by non-specialists. We hope to bridge the gap between biofeedback techniques and their applications in daily life with *LivingSurface*. The design intention was to create a new shape-changing interface of biofeedback and to explore the interaction between human physiology and the physical objects during a biofeedback process. The *LivingSurface* has been designed with the following goals:

- Create a shape-changing display of biofeedback, providing people with the information about their internal physiological functions.
- Design cutout patterns of a flat surface that could evolve into a three-dimensional structure through applied tension and motion.
- Explore an appropriate actuating mechanism to achieve a controllable shape change.

In the following we introduce related works about biofeedback and shape-changing display and interfaces. Next, we describe the system framework and basic structure design of *LivingSurface*. Then the implementation process and the interaction design of each surface are described in more detail. Finally, we discuss feedback received from the visitors at a public exhibition, and indicate direction for future work.

RELATED WORK

Perceptualization of Biofeedback

Biofeedback is a process that enables an individual to learn how to change physiological activity for the purposes of improving health and performance. The biofeedback process can be divided to three stages: measurement, processing and presentation. The measured bio-signals are processed into targeted physiological information and then presented to users in various forms. Many efforts have been put into improving bio-sensing techniques and optimizing signal processing algorithms, whereas the perceptualization of biofeedback receives inadequate study. Although the biofeedback technique was developed for individuals to acquire self-regulation skills, but for a long time, it has only been used in guided therapy sessions under supervision of trained experts. As a result, it is often considered as a therapeutic tool limited to clinical application. This is why in most of biofeedback systems [2-5], the feedback is presented in graphic and numeric forms that are convenience for therapists to monitor the patient's physiological process, but not suitable for amateurs.

In recent years, biofeedback is gradually being used outside of hospital, accepted by ordinary families and goes into people's daily life. In order to facilitate the users' perceptualization of biofeedback, in some projects, the biofeedback is presented in forms of animation [6] or in games [7]. Specifically, the status and movements of animated on-screen characters are controlled by the player's bio-signals, and in this way, the player improves self-regulation skills by controlling the game. In addition to visual feedback, auditory display is also widely used, since it liberates users from visually focusing, allows them to close the eyes and generally improves their focus and pleasure during the training. An example could be seen in [8], a heart rate indication system has been developed to provide biofeedback by converting heart rate data into music with pitch and tempo changing in real-time. Similarly in [9], the authors designed four auditory displays of heart rate variability for biofeedback training. As the haptic sense lays the foundation for our sensory integration [10], haptic interfaces have also been explored to support biofeedback learning. In [11], a smart shirt has been designed for rehabilitation training by delivering feedback (muscle activities) in haptic modality. Recently, some multi-modal interfaces [12] or ambient lighting interface [13] have been designed for biofeedback with the purpose to enhance user experience during biofeedback.

Shape-changing Display

Shape change is increasingly used in tangible user interfaces for information delivery [14]. Shape-changing interfaces aim at using some qualities of physical change to enhance our interaction with digital information. For instance, orientation, volume, texture and spatiality of the interface can be dynamically coupled to the information measured from the user or environment. Here, we are curious about the possibility of developing a paper-based wall-like surface for display an individual's physiological information in dynamic physical form. We implement *LivingSurface* with four prototypes (Surface #1-#4), which can vibrate, swing, bulge, or rotate to evolve into a three-dimensional structure on its cutout patterns through applied tension and motion.

Interactive wall-like surfaces have been explored in many studies within the field of architecture. Usually, it responds to a person or environment by changing its shape, color, temperature, humidity, or other quality. *Aegis Hyposurface* [15] is a wall-sized structure made up of interconnected metallic plates. The surface of the wall can dynamically change its shape in response to external events such as human movement captured by a camera. *Shutters* [16] is a curtain composed of shape-memory-alloy actuated louvers that can be individually addressed for information display. *Murmur* [17] is an interactive kinetic sculpture made of one hundred computer CPU fans and surfaces. It responds to sound input from its environment via embedded microphones to produce patterns on a reactive surface. *BLANKET* [18] is a cylindrical envelope surface that is soft in its properties and performs responsive kinetic movements based on its responsive morphing system. Felecia et.al [19] designed a shape-changing wall panel named *TextileMirror* which changes its shape in response to people's emotions. In [20], the author explored the expressiveness of shape-changing surfaces made of computational composites. It shows potential in information delivery through the variations on its texture and topology patterns.

LIVINGSURFACE: A SHAPE-CHANGING DISPLAY OF BIOFEEDBACK

With *LivingSurface,* we aim to explore a new shape-changing interface to biofeedback for average users (non-specialists), which may be employed in a living space or home environment. The interface takes users' bio-signals as input and use shape change of the surface as output. The surface basically consists of two layers: a pattern layer (front layer) and an actuating layer (back layer). The pattern layer is made of a piece of ordinary paper being laser-cut with repetitive incisions. With different connection structures, the actuating layer transforms the force from actuators (vibration motors, CPU fans, and servo motors) into the action on pattern layer, changing the 2D layer into a 3D object. To explore more possibilities, we design four surfaces S1-S4 different shape-changing forms.

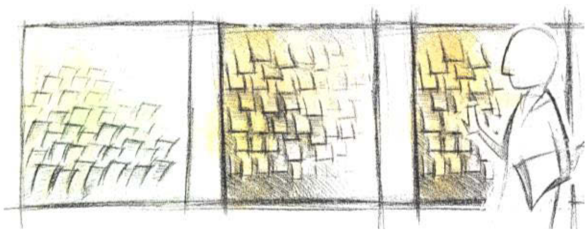

Figure 2: Design concept of *LivingSurface*

In this study, we focus on heart rate variability (HRV) biofeedback, in which the heartbeats activities are measured. When fitted with other biosensors, *LivingSurface* has potential in presenting various types of bio-information. As shown in figure 2, the design concept of *LivingSurface* is not just an interface for biofeedback; its innovations in sensitive and bio-responsive shape-changing surfaces could also be transformed into a novel bio-responsive wallpaper or spatial element as a peripheral display of user's physiological states in home or office environment. For instance, it could be used as a display of intervention on chronic stress during the work.

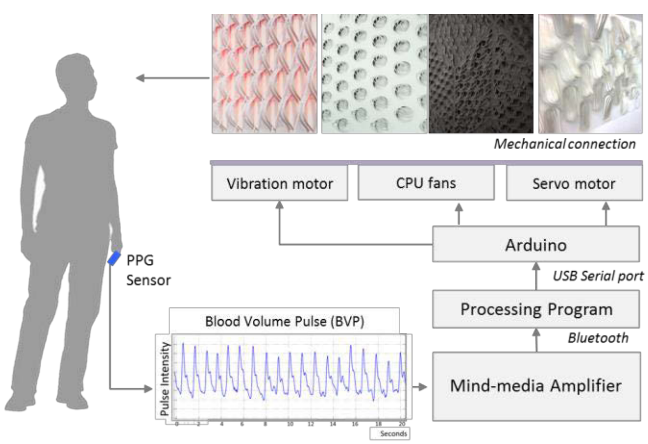

Figure 3: Framework of *LivingSurface*

General Framework

The basic framework of *LivingSurface* is shown in figure 3. The Blood Volume Pulse (BVP) signal is measured by a photoplethysmograph (PPG) sensor with *NeXus-10* amplifier *(Mindmedia, the Netherlands)* and transmitted to a Processing program on PC. In the program, the indices of heart rate variability (HRV) are calculated from BVP signal as feedback data. Then the feedback data is transmitted to Arduino through a USB serial port. The program on Arduino maps the data into the control of the actuators. The force from actuators acts on the surfaces producing dynamic changes on its cutout patterns.

Data Processing

In this study, we measure user's BVP signal for calculation of heart rate variability (HRV). The BVP signal is the phasic change in blood volume with each heartbeat. The detection of peaks in BVP signal locates the heartbeats in time domain. The Inter-Beat-Interval (IBI) is the time difference between two heartbeats. We compute the IBI from the BVP signal. The researches [21] show that human heart rate can vary in synchrony with respiration, by which the heartbeat interval is shortened during inspiration and prolonged during expiration, see Figure 4. With the feedback of IBI waveform, an individual can learn to regulate his breathing pattern and state of mind to modify IBI data into an approximate sinusoidal form and increase the variation of heart rate. After a few biofeedback sessions, he might be able to achieve a 0.1-Hz natural oscillation in heart rate [22], under which the efficiency of pulmonary gas exchange is maximized and the relaxing responses of autonomic nervous system are enhanced.

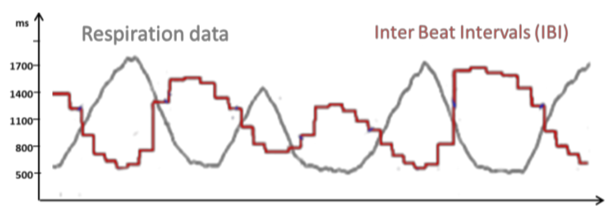

Figure 4: IBI data synchrony with respiration

In a HRV biofeedback system, IBI data can be presented to user directly as figure 4. It can also be analyzed by time and frequency domain methods for getting more physiological information [23]. In order to smooth the data but also provide a fast feedback, we average the IBI data based on a moving window of 16 heartbeats. The formula is: $IBI_{avg} = (15 \times IBI_{avg} + \text{IBI})/16$. The initial value of IBI_{avg} is 600 ms. SDNN (the standard deviation of IBI) is one of the most common indices of heart rate variability. We calculate the SDNN of the latest 16 heartbeats to indicate a user's HRV level. $SDNN_{16}$ is updated at each heartbeat by using a moving window. The formula is $SDNN_{16}$= ((15 × $SDNN_{16}$+ |IBI - IBI_{avg}|) / 16). Here, we use IBI_{avg} and $SDNN_{16}$, two main parameters of HRV, as the input of *LivingSurface*. The mapping between input and surface's shape changes will be explained below.

SHAPE-CHANGING SURFACE DESIGN

In the design process of shape-changing surface, we first selected the material of pattern layer. In our previous researches on material, we have explored various materials for novel wallpaper design. Here we selected ordinary paper due to its affordability, usability and ability of shaping. Then we play with repetitive incisions on pattern layer. During the design of repetitive incisions pattern, two aspects are mainly taken into account. One is the aesthetics of pattern, both in static state and dynamic motion; the other is its ability to deform and recover. Next, we determine what biofeedback information would be reflected by the surface. Specifically, for designing an appropriate mapping with consistent semantics, we consider the properties of the data, the physiology behind the data and the shape-changing features of the pattern layer. Then, a suitable actuator is selected to induce the shape change happen. Finally, we develop the actuating layer to transform the force from actuator to pattern layer, including the design of connection mode, mechanical structure and the control of actuators.

Surface #1 (S1)

In our first prototype, we started with the simplest mapping between bio-data and shape changes of the surface; specifically, the surface vibrates in response to user's heartbeats. After being fitted with PPG sensor on their index finger, users would see the surface 'dance' with their heartbeats, where a high heart rate is reflected by an 'active' surface with faster and stronger vibration.

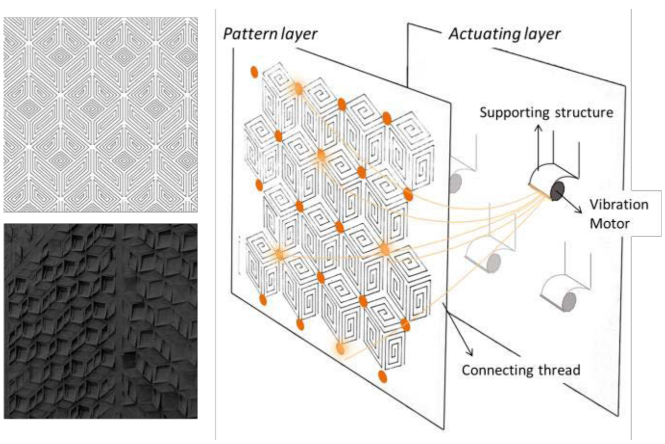

Figure 5: Pattern layer and connection design of Surface #1

The basic unit on the pattern layer evolves from classical key patterns. Each unit consists of multiple basic key patterns with different directions. We prototyped several different layouts of pattern, figure 5 shows one of them. In order to achieve a uniform shaking effect, vibration motors are not directly fixed on the pattern layer, instead, they are attached on the supporting structures of actuating layer. Actuating layer is a kind of press paper with four openings, carrying vibration motors. Each vibration motor is connected to several 'nodes' of pattern layer by soft thread (see figure 5). This flexible connection helps to distribute the power of vibration to a wider area and to absorb most of the vibration as a buffer. For an example in figure 5, there are twenty 'node' that are evenly connected to four vibration motors.

Regarding the mapping design, each heartbeat triggers once vibration of one second. The amount of actuated motors is changing according to the average HRV ($SDNN_{16}$). A higher HRV activates more motors (up to 4) providing a stronger vibration. The arrangement of the motors in each vibration is random. When the users breathe deeply and relax themselves, the heart rate goes down but its variability increases, accordingly the frequency of vibration decreases but the power of each vibration is strengthened. This design is an implicit expression of the relation between heartbeats and respiration. By deep breathing and relaxation, the heart rate variability can be improved, which suggests a balanced autonomic activity and a stronger capacity of stress coping.

Surface #2 (S2)

As shown in figure 4, when people relax with deep breathing, the IBI occurs a synchrony with breathing cycles. Therefore, the IBI waveform can also be used to indicate respiration cycle. Surface #2 was designed to present a user's breathing through its fluctuation. We use IBI data control the movement of DC-driven fans acting on the pattern layer as seen in Figure 6. The air pressure produced by the fans drives the cutout structures swing flexibly. Through the surface's fluctuation in different degrees and duration, users could 'see' their breathing acting on the surface and learn to influence the fluctuation with smooth breaths.

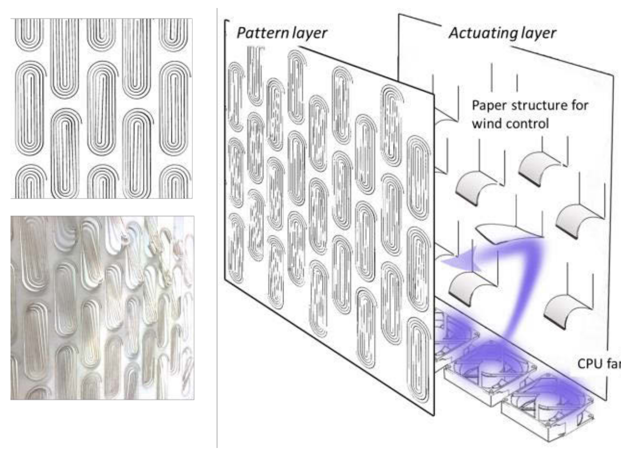

Figure 6: Pattern layer and connection design of Surface #2

The cutout pattern looks like a special spiral pattern evolved from 'paper-clip' shape, as shown in figure 6. Each unit seems like a 'window', thus we selected wind as the driving force behind the pattern layer. Three CPU fans fixed in the bottom blow the air up. The press paper of actuating layer is cut with several curled-down openings, directing the wind towards the 'windows'. The modulated air pressure opens the 'windows' flexibly, generating a fluctuating wave effects on the surface. About the mapping design, we map the increment between two consecutive IBI data to the states of the fan. When the user breathes out, the IBI data increase and the fans come into operation, the generated wind shakes the cutout spiral patterns. Conversely, when the user breathes in, the IBI data decreases and the fans stops, the layer becomes 'calm' again. We think this is an interesting and natural mapping because the start and stop of fans are a gradual process just like human breathing. After the fan is switched on, it starts turning and gradually picks up speed till the maximum, and vice versa.

Surface #3 (S3)

Regarding to the expression of the surfaces, the mapping design in S1 and S2 are explicit. In S1, one heartbeat triggers once vibration of the surface. In S2, one breathing circle is reflected by one fluctuation on the surface, like the wind acts on 'windows'. But one problem of S1 and S2 is that their shape changes are difficult to control. We hope that the actuation can be controllable so that the surface can return to its initial state and repeat the shape change. We try to solve the problem in design of S3 and S4 achieving a more "repeatable and controllable" shape change. This enables them to be an alternative to the graphic interface of a real HRV biofeedback system. S3 and S4 used a different connection design between layers. In S1-S2, the connection between two layers tend to be indirect and 'soft' (by soft thread and wind), which makes the motion of cutout patterns flexible and random. But in S3-S4, we used a direct connection by gluing the specific points of cutout structures to the actuating layer. The 3D structures on pattern layer are produced by the actuating layer's displacement, which can be controlled precisely with servomotors. This ensures that the information can be displayed more accurately.

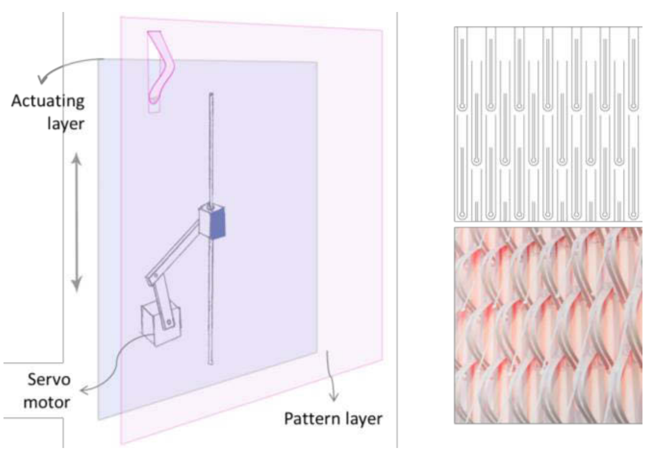

Figure 7: Pattern layer and connection design of Surface #3

S3 is designed to represent IBI waveform as shown in figure 4. A set of strip-shaped pattern are evenly spaced on the pattern layer. The opened side of each strip shape is stick to the actuating layer. Two layers are close to each other. The center of actuating layer is connected with the block of crank-slider structure that is fixed on the bottom and controlled by a servomotor. The IBI data is mapped to the rotation angle of servomotor, and then transformed into an up-and-down motion of the actuating layer. When the actuating layer moves up, the strip-shaped segments curves and bulges outward; when the layer moves down to the original position, the surfaces become flat again.

Before the interaction with S3, the user is fitted with a PPG sensor on the finger. During the early stage of interaction, user's IBI data varies weakly and irregularly. On the surface, this state is primarily expressed through an irregular surface undulation. Then, with the process of breathing regulation, deep and smooth breathing produces a sine-shaped IBI waveform (like the red wave in figure 4), and this is reflected on the surface by a longer and smoother undulation-cycle. When the user reaches an optimal training condition (i.e. the resonant breathing [21]), the users could see a cyclical undulation on the surface, consistent with user's breathing circle. We believe the user is able to learn his optimal breathing pattern in the interaction with the surface and that this interaction will make the learning process easier and more interesting.

Surface #4 (S4)

Surface #4 is also designed for HRV biofeedback, presenting the IBI waveform and average HRV ($SDNN_{16}$). The cutout design is a set of typical spiral shapes that are evenly spaced on pattern layer. The center of each spiral is stick on the actuating layer. The displacements of actuating layer drive the center point of spiral out of original position, producing a 3D helical sculpture on the surface. The further the spiral's center deviates from the original position, the more the helical structure is extended outwards. And while the actuating layer moving in different directions, the surface shows different pattern of helical structure, see figure 8.

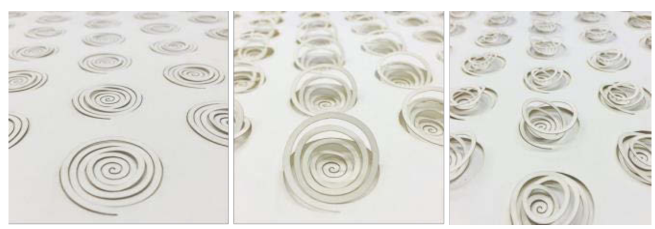

Figure 8: 3D helical structures on pattern layer caused by displacement of actuating layer

Compared to Surface #3, S4 has more flexibility of motion. Based on above dynamic features, we make the actuating layer move in a self-centered circle, which drives the center of spiral on pattern layer do a circular motion around itself.

The mechanical design is shown in figure 9. Basically, the mechanical structure consists of two parts: a round supporting platform rotating around its center and a crank-slider structure fixed on the platform to adjust the circle radius. Firstly, the center of supporting platform is fixed on the shaft of a continuous rotation servomotor, whose speed can be adjusted. Secondly, the crank-slider structure is connected with a typical servomotor. The changes of the motor shaft angle regulate the position of the block in slider.

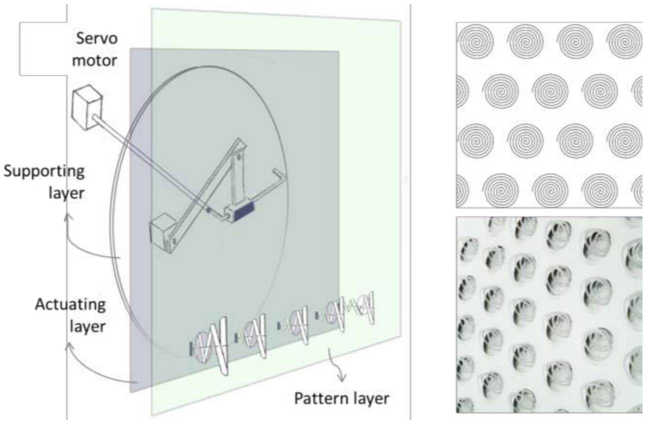

Figure 9: Pattern layer and connection design in Surface #4

In terms of mapping design, we map IBI_{avg} to the angle of the motor, which determines the radius of actuating layer's motion. When user breathing in, IBI_{avg} is shortened and thus the angle is small, the block stays near the center moving with a small radius. When user breathing out, an increased IBI contributes a larger motor shaft angle, moving the block out and expanding the radius of motion. A low HRV is proved closely related to chronic stress [21], and under a relaxing state, people show a large variability of heart rate. We map the low HRV ($SDNN_{16}$) to a fast speed of motion indicating a stressful state, and use a slow motion to indicate a more relaxing state. Under the common action of the dual movements, the actuating layer moves in a nearly circular path.

EXHIBITION AND AUDIENCE FEEDBACK

Figure 10. Photograph taken at Milan Design Week 2015

LivingSurface was installed at the Dutch Invertuals Exhibition at Milan Design Week, Italy, in April 2015. This allowed us to observe how audiences interact with the surfaces. For the exhibition, three surfaces (S1, S3, and S4) were developed with three 40 cm by 40 cm by 10 cm (length, height, width) wooden frame boxes, which were hung on the wall. The shape-changing surface was fixed in the outside of the box. One large-size double-sided surface (S1) was developed with a mental frame, which was hung in the showroom, as shown in figure 10. In this exhibition, only S1 and S4 were interactive due to constraints of the sensors and environment. And S3 was controlled by simulated breathing signal.

Audience Interaction

Based on our observations of audience interaction with *Livingsurface*, we found that the first expectation was an immediate feedback. After wearing the PPG sensor, visitors would directly look to the surface in anticipation of an immediate response. For S4, the IBI_{avg} and $SDNN_{16}$ data are respectively mapped to the radius and the speed of circular motion. Visitors did not know that the heartbeats data was averaged over time (time window of 16 heartbeats), and this lack of immediate response to their input caused some confusion as to what *LivingSurface* was responding to. Moreover, the interaction with the surfaces is a self-regulation process with feedback. For example, it would take about 5 breathing circle (30 seconds) to regulate IBI_{avg} waveform into the desired state (sinusoidal pattern), which means visitors new to *LivingSurface* would need to spend some time interacting with it (through deep breathing and relaxation) to achieve its smooth and elegant shape-changing pattern. But sometimes, a few visitors seem to lack patience to this gradual physiological process. Lack of interactive time limited visitors' ability to well control the surface and also their experience of the interaction. In addition, sometimes, the sensor instability, such as data loss or noise data, caused by hand or finger movements also disrupted the dynamic pattern on shape changes. It also might undermine visitors' understanding of the mapping between their data and the surface's shape. As a result, we often needed to explain the mapping to visitors after their interaction. We believe this dilemma can be solved by upgrade of pulse sensor, an optimization of data processing algorithm as well as users' more exposure to the surface for biofeedback.

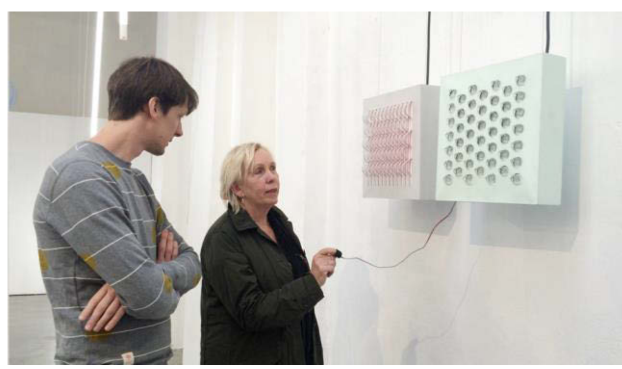

Figure 11. An audience interacting with the surface

Post-Exhibition Reflection

During the Exhibition at Milan Design Week 2015, we have interviewed over 100 visitors to investigate a general assessment of *LivingSurface*. The following several comments were made in regard to the mapping between bio-data to the surfaces' shape change:

Firstly, most of visitors thought that the expression of S1 was easiest to understand due to its explicit mapping. They could perceive the vibration of S1 associated with their heartbeat quickly. But most of visitors did not notice the variations of vibration intensity, which is controlled by amount of motors and mapped to user's averaged HRV ($SDNN_{16}$). We think there are two possible reasons for this. One is the repetitive incisions on the pattern layer make it too prone to be deformation. It makes the difference between a vibration of one motor and vibration from many motors imperceptible visually. The other is human factor. Breathing can influence human heart rate, but the process takes time. In a short interaction, the increase of HRV is minor, which is difficult to notice. We think possible solutions could be mapping the HRV to the duration of vibration or using a tougher material instead of ordinary paper.

Secondly, S3 and S4 suffered a similar problem caused by interruptions of servomotor. It is difficult to transform a series of discrete IBI data into a continuous movement of servomotor. Although we have used a moving window (window length of 16 heartbeats data) to average data as a low-pass filtering, in the beginning of interaction, the discontinuity and irregularity of visitor's IBI data lead to a 'stressed' or 'broken' movement of motor, diminishing the elegance of surface design. We think one possible solution is to try new mapping strategy other than direct-mapping. We could develop a 'model' of surface motion and define some 'rules' for motion control. Therefore, the bio-data is not mapped to the parameters of the motor, but to the parameters of the 'model' of motion. When there is no data coming in, the surface could also follow its 'rules' to change the shape with a flowing movement.

Thirdly, in some ways, we also think *LivingSurface* is a multi-sensory display that appeals to two senses (visual-audio): the shape changes of paper and the sound of the paper pieces or motors. And the wind produced by the fans in Surface #2 could also stimulate tactile sense. We think this is the biggest difference between *LivingSurface* and screen-based graphic biofeedback. To our surprise, the visitors did not think the sound of the papers rustled in the motion or the noise of servomotor interrupted their interaction with *LivingSurface*, instead they thought the sounds made the surface more organic and life-like.

CONCLUSION AND FUTURE WORK

The motivation of this study is to create an object that connects people with their own physiology by bringing awareness to how their conscious control could effects their internal physiological process. Since *LivingSurface* takes heartbeats data as an input, we managed to design a novel interface for a HRV biofeedback system, which could teach people to improve their heart rate variability by regulating their breathing pattern and mental relaxation. We took inspirations from origami, paper sculpture and plane composition to create a shape-changing surface, which can be used as a tangible display. The user interacts intentionally with the surface by regulating their physiology, and an elegant change in shape indicates a good effect of regulation on health. Although sometimes we had to instruct the interactors, most of them managed to establish a correlation between the bio-signal and the surfaces' shape changes. This might reveal in part that an appropriate shape-changing surface can be used as a medium for biofeedback information delivery. In addition to *LivingSurface* current application as a tangible display of biofeedback, we also conceived of it as a prototype for a bio-responsive element in a public space as well as an art object.

In the future, we plan to explore the coupling of *LivingSurface* with different bio-sensors that can measure various physiological processes to provide rich feedback about their health, such as chronic stress. We also plan to explore more materials, sculptured patterns and mechanical design for shape-changing surfaces that can be integrated in the living environments and work spaces. We envision an entire wall decorated with *LivingSurface* reacting to human physiological activities.

ACKNOWLEDGMENTS

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TEI16

TENTH ANNIVERSARY CONFERENCE ON TANGIBLE EMBEDDED AND EMBODIED INTERACTION

Proceedings of the Tenth Anniversary Conference on Tangible Embedded and Embodied Interaction

14-17 February 2016, Eindhoven, the Netherlands

Conference Chairs: Saskia Bakker, Caroline Hummels, Brygg Ullmer
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TEI’16 Chairs’ Welcome

Welcome to ACM TEI'16, the 10th-anniversary edition of the International Conference on Tangible, Embedded and Embodied Interaction, hosted at Eindhoven University of Technology, the Netherlands from February 14th to February 17th, 2016.

This year’s conference marks TEI’s tenth anniversary. We see this as a perfect opportunity for recalling some of our founding values and complementing these with contemporary values, for reemphasizing the relationship between interactive products and systems and the body, and for learning from each other’s approaches and rationales. To do this, we have established the theme ‘**Our Body Is Our Manual**’: As the interactions we propose in our products and systems are aimed to inform our embodied selves, we should also allow ourselves to be informed by our bodies when designing and researching these interactions. Through a wide palette of work ranging from highly technical to highly artistic, and from highly applied to highly conceptual or theoretical, we wish to trigger discussion and reflection, with the aim of emphasizing what binds us.

TEI’16 hosts a four-day program, starting out with the **Graduate Student Consortium** and a series of **Studio-Workshops** that embody the essence of our community by offering intellectual and practical experiences to conference attendees with diverse skills and backgrounds. The main program is kicked off by **Takeo Igarashi**, who in his opening keynote discusses computer tools that allow end users control over the design of artifacts in their lives. After the opening keynote, the Papers track commences, in a slightly different set up than before. This year we do not include Q&As in the presentations but instead wrap up each session with a reflective discussion between the presenters. The day concludes with the **Demos, Posters** and **Work-In-Progress** exhibition. From day two until day four the **Art Exhibition** questions and frames the impact of new technologies on our lives and proposes new modes of embodiment. Following day three’s Papers sessions we host a full afternoon of **Studio-Workshops**, engaging all TEI attendees in active, hands-on discussions. Day four includes three Papers sessions, a lunch lecture and panel discussion, and the closing keynote by **Tom Djajadiningrat**, who reconsiders tangible interaction by discussing new technologies, illustrated through examples by Philips Design.

This year we received 178 submissions to the Papers track, which were all equally subjected to a double-blind peer review process of at least three reviewers and a meta-reviewer. A total of 45 accepted papers makes for an acceptance rate of 25%. For the Work-in-Progress track we received 100 submissions, which were subjected to a double-blind peer review process of two reviewers each. This resulted in 40 accepted submissions, making for an acceptance rate of 40%.

Of course, organizing this conference could not have been possible without the energy and commitment of many, many people. We would like to thank everyone who contributed to TEI’16: the authors for submitting their quality work to the conference, all the organizing committee chairs for managing their part of the conference, the program committee and external reviewers for safeguarding the quality of the conference, the local organizing committee, the sponsors, supporters and partners, and the TEI steering committee.

We wish you a great conference!

Conference Chairs

Saskia Bakker
Eindhoven University of Technology (NL)
Caroline Hummels
Eindhoven University of Technology (NL)
Brygg Ullmer
Louisiana State University (USA)

Program Chairs

Luc Geurts
KU Leuven (Belgium)
Bart Hengeveld
Eindhoven University of Technology (NL)
Daniel Saakes
KAIST (Korea)

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Art Exhibition

Graduate Student Consortium

Student Design Challenge

Studio-Workshops