Embodied Interactions with E-Textiles and the Internet of Sounds for Performing Arts

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TEI '18, March 18–21, 2018, Stockholm, Sweden
ACM 978-1-4503-5568-1/18/03.
https://doi.org/10.1145/3173225.3173272

Abstract
This paper presents initial steps towards the design of an embedded system for *body-centric sonic performance*. The proposed prototyping system allows performers to manipulate sounds through gestural interactions captured by textile wearable sensors. The e-textile sensor data control, in real-time, audio synthesis algorithms working with content from Audio Commons, a novel web-based ecosystem for re-purposing crowd-sourced audio. The system enables creative *embodied music interactions* by combining seamless physical e-textiles with web-based digital audio technologies.

Author Keywords
E-textile; Audio Commons; Internet of Musical Things; music information retrieval; technology probe; Bela

CCS Concepts
•Hardware → **Tactile and hand-based interfaces; •Applied computing** → *Sound and music computing;* **•Information systems** → Web interfaces;

Introduction
In our digital era, creating artifacts for tangible, embedded and embodied interactions becomes more and more concerned by the “humanization" of the digital. This can be addressed by looking at how analog and digital design spaces

Figure 1: Sketch of a performance, using integrated textile sensors on joints to create sound from body movement.

can be interlocked. Returning to traditional, natural materials as analog gateways to the digital world is central to the so-called *post-digital art* [1]. Applied to creative media, this is a two-way process in which access to and control of digital devices is enhanced by haptic interfaces and embodied interactions. In this work, we investigate how such a post-digital design approach can be applied to sonic and musical interactions.

Most *digital musical interfaces* [13] have been designed as objects separated from the body, often consisting of hard components such as plastic knobs. In this work we are concerned with *body-centric sonic interactions* fostering explicit action-effect loops without the barriers of screen-based media. Rather than tackling this using wearable controllers that are attached to the body, such as Myo gesture controlled armband (https://www.myo.com/), an approach traditionally used in *embodied music interaction* [24], we propose to design sonic controllers that work more closely to the body using garments incorporating electronic textile or *e-textile*, which are fabrics turned into soft sensors and actuators by using conductive material when manufacturing or manipulating a textile surface. In addition, we propose to leverage the vast amount of audio content available in the cloud and wireless network capabilities for communication of audio and sensor data. The *Internet of Things* (IoT) [2] brings cloud-based computing to everyday portable objects with the aim of improving our daily lives. In the digital audio domain, we find projects providing services for online audio content repositories and networked-based sonic interaction (which we coin as the *Internet of Sounds* (IoS)), such as Audio Commons [6] and the Internet of Musical Things [21]. Both explore the potential of cloud architecture and computing applied to audio applications for music makers, sound designers, and other types of consumers.

In this work-in-progress paper we explore the novel combination of two cutting-edge technologies, (1) e-textiles and (2) the Internet of Sounds. We present an embedded system for prototyping embodied sonic performances (see Figure 1) based on the Bela platform, designed for ultra-low latency audio and sensor processing [11]. Bringing together the e-textile and IoS domains can be of interest to several communities, from wearable and music technology designers to performing arts audiences. We aim to foster rich interdisciplinary exchanges between technology, fashion and sound art designers through the convergence of the digital and the physical domains.

Background

E-textiles

Textiles can be seen as an interface to the analog world through the sense of touch. Present on many surfaces, whether through chair covers, bed sheets, clothing, and so on, textiles are a promising and intuitive design material for HCI. In recent years, the idea of e-textiles has been explored through a growing DIY community (http://www.instructables.com/id/E-Textiles/) as well as through industrial and academic research (e.g., [15]). Especially noteworthy are applications for rehabilitation (e.g., monitoring movement in [23] and [12]), affect and event detection (e.g., [5]), as well as soft robotics (e.g., [3]). Advantages of using textile sensing systems and interfaces over other wearable devices lie in their unobtrusive character and in providing a natural interface for human interaction.

Internet of Sounds

A number of studies explore the use of Internet and networked devices for sound interaction, which we refer to as the Internet of Sounds (IoS). The Internet of Musical Things project [21] investigates interconnected *smart musical instruments* [22] and haptic wearables for performer and audience interactions [20]. The Audio Commons initiative brings Creative Commons (https://creativecommons.org/) audio content from online repositories, such as Jamendo (http://www.jamendo.com) and Freesound [7], to creatives from the music and audiovisual production industries [6]. The main goal of the Audio Commons initiative is to develop an ecosystem that promotes repurposing of crowd-sourced audio content through smooth creative workflows. This is made possible through a range of services accessible through an *Application Programming Interface* (API) [6], which addresses how to query and interact with sound files from online repositories for creative applications, and has already been tested during a workshop (http://designingsound-am2017.apps.devcloud.eecs.qmul.ac.uk/). To view the Audio Commons API, see: https://m.audiocommons.org/docs/api.html.

Embodied performative interaction with e-textiles
The performing arts have a rich history of incorporating technology to facilitate embodied interactions. As new technologies are developed, artists have used them to create new artworks and neither e-textiles nor IoT are exceptions. One such recent example is Flutter/Stutter which looked at the role of data and IoT technologies within an improvised dance performance [18]. In [14], a wearable helmet embedding sensors has been purposely designed for dancers, to unleash the potential of sonic generation from body movements.

In order to create new performances with embodied technology, tools that allow exploration and experimentation are needed. The e-textile platform presented here builds on a prototyping system designed by Anja Hertenberger and Mika Satomi for the eTextile Summer Camp in 2016 (http://etextile-summercamp.org/2016/etextile-and-performance/). Their system used a modular design to allow for easy experimentation with the placement of e-textile sensors and their mapping to audio parameters. Adding the IoS to our system brings an original contribution that can inform future e-textile sonic interaction projects.

Methodology

Technology probes
Our prototype design is inspired by *technology probes* [9]. Technology probes are a tool to understand social, engineering, and design aspects. We use the probes to elicit information on user experience to improve the next design iteration. We expect to collect such data from (1) a set of workshops (detailed in the next section); (2) showcasing our work-in-progress system to the TEI community; and (3) future performances making use of our system. We are interested in observing, from a user perspective: (1) how the tool is used to socially communicate in a performance setting; (2) what are the successes and failures of the technology; and (3) what are the creative and disruptive uses of the design.

Making workshops
The system detailed in the next section is tested during workshops welcoming both the music technology and performance art communities. A first case study at AlgoMech Festival (http://algomech.com/2017/) invites participants to explore ways of capturing body movement through textile sensors (see Figures 2, 3, 4) to create soundscapes. IoS is used to help participants to find online sound files to be used in their design artefacts. Such workshops are meant to evaluate the sensor design as well as the cycle of interaction as such. Findings are then used to develop further iterations of the system and to identify interaction and technological challenges. One of these challenges concern the type of gestures and postural cues that can be used to retrieve, modify and create sound for performative purposes.

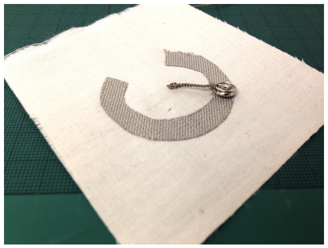

Figure 2: Tilt sensor from woven conductive fabric and twisted yarn.

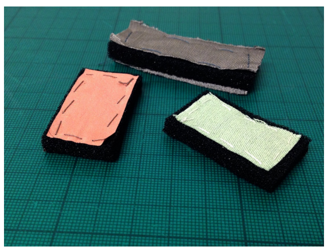

Figure 3: Pressure sensors made of different conductive fabrics (copper, silver thread and silver coating) and resistive foam.

Figure 4: Stretch sensor, knitted from stainless steel and polyester yarn.

User Interaction

Conceptual design

Our tool is designed to be a seamless e-textile augmented with IoS capabilities that can be useful to both novice and expert performance artists and potential technologist collaborators. The tool should be as intuitive as possible, keeping enough degrees of freedom to move and interact with sound. Each interaction should provide a unique, distinctive user experience.

Sonic control data are generated through movement of the e-textile (e.g., press, tilt, or stretch) and voice input (e.g., a melody, an onomatopoeia). The data is mapped to audio synthesis parameters (e.g., for pitch shifting, time-stretching, delay, granular synthesis, and so on) that affect sound files retrieved from online databases. Sound retrieval can be done prior to the performance using a browser-based desktop or mobile application, or during the performance using non screen-based mechanisms, such as through vocal input recorded by a portable microphone (e.g., lavalier). Notification signals are used to provide feedback to users through the visual, haptic, and auditory channels (e.g., LEDs, haptic feedback motors, speakers), deemed to be essential to provide information on the internal system processes.

Scenario

The interactive system has been designed to revolve around two use phases, rehearsal/preparation and performance. During the preparation or rehearsal stage, users map the on-body sensors to sounds. The sounds are obtained from online content repositories from the Audio Commons ecosystem either by keyword search or audio feature-based queries. Selected files are uploaded to Bela and allocated to the textile sensors.

During the performance phase, the artist can trigger sounds as well as modulate them through gestural movement and whole-body interactions (see Figure 1). Figure 5 shows a systematic overview of the interaction cycle.

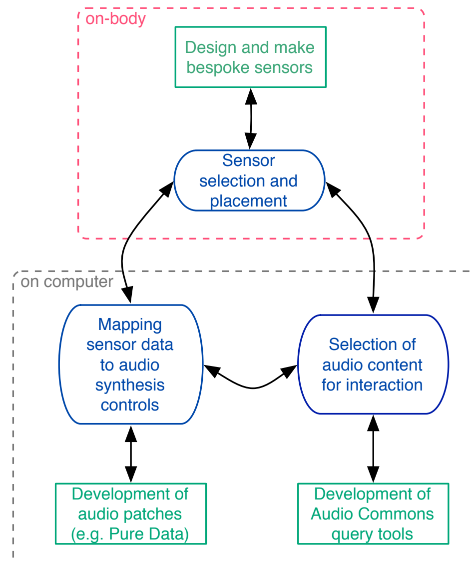

Figure 5: Rehearsal/Preparation Phase (circles: composer/performer processes, boxes: developer/maker processes).

Hardware and Software Architecture

The system architecture comprises four parts: (1) the wearable sensors and actuators; (2) the embedded computer; (3) the software running on the computer; and (4) the web services accessed by the computer. An overview of the system can be seen in Figure 6.

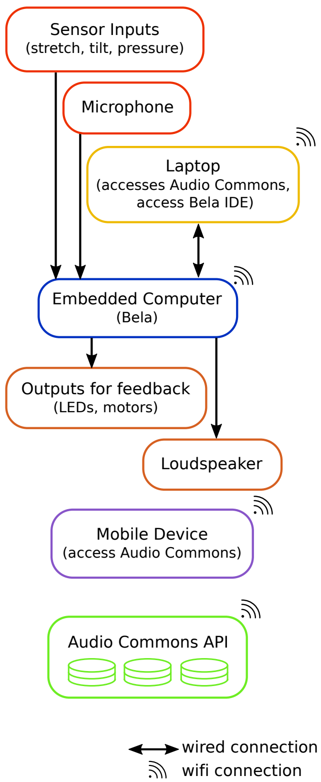

Figure 6: System architecture.

Sensors and actuators

E-textile sensors are used in order to capture body movement without inhibiting the movement or causing discomfort. While there are a variety of movements that can be captured with specific sensors, stretch, pressure and orientation/tilt are the most versatile. Knit stretch sensors are made of fabric knit from conductive yarns or from non-conductive knit fabric coated in a conductive polymer [19]. As they stretch, they change their resistance. Resistance-based pressure sensors rely on a material that changes its resistance under pressure; when two electrodes are placed on either side of the variable resistance material, the electrodes can measure the change in resistance when pressure is applied. E-textile tilt sensors use gravity and haberdashery items like metal beads to maintain an electrical connection that is correlated with a particular orientation.

For the making workshops, a kit of previously constructed handmade textile sensors (see Figures 2, 3, 4) are provided for participants to use in their prototypes. Participants are also taught how to make basic sensors so that they can construct bespoke shapes for their prototypes.

A small battery-operated loudspeaker is worn on the body to playback the generated audio. The complete prototyping system will also include actuation beyond the sound output, most likely in the form of LEDs and haptic vibration motors. These allow the wearer to know the internal state of the software, when it would not be appropriate to use sound. For example, if waiting for a search query to complete or to indicate a change in mapping between the sensors and sound.

Wearable computer

The computing system is controlled by Bela [11], a low-latency audio signal processing platform based on the Beaglebone Black. We choose this platform because it integrates both audio and sensor processing, which is suitable for performing arts projects.

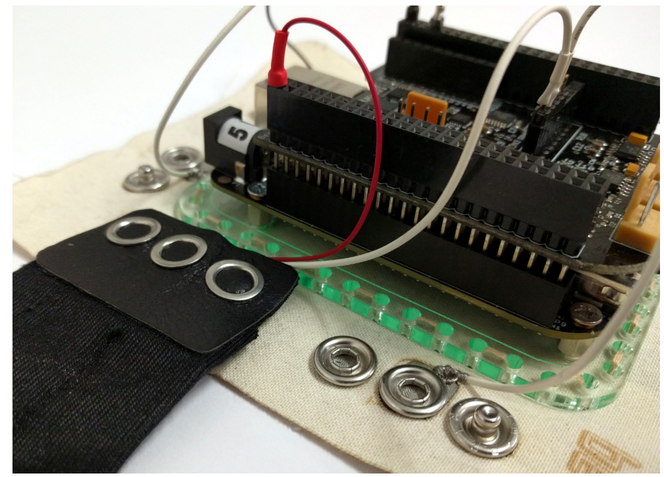

Figure 7: Bela on the fabric breakout board with a textile connection cable.

Care needs to be taken when designing the connections between the flexible textile circuitry and Bela's traditional PCB construction. A fabric circuit board, seen in Figure 7, was created to provide a soft circuit breakout board for five analog inputs and two digital inputs. Snaps provide an interface between the conductive fabric pads and the fabric connection cables which attach to the sensors. Wires soldered to header pins on one end, and stitched to the conductive fabric pads on the other, provide the connections between the Bela board and the fabric breakout board.

Internet connectivity is added to the Bela board with a Wi-Fi USB dongle interfacing with a router delivering Internet to a local network. The complete system is powered by a rechargeable USB battery.

Software

Bela supports multiple audio programming languages, such as Pure Data [16] and SuperCollider [10]. Pure Data (PD) was chosen for this project as it is accessible to those new to programming and is commonly used by artistic communities. For example, in our workshop participants can easily start learning by using example PD patches that demonstrate how to map sensor data to audio playback or trigger a search query.

Web services

A client script running on Bela provides an interface to the Audio Commons API. The script allows selected files to be downloaded from the Internet to the board so that they can be played back and processed by Pure Data patches.

The Audio Commons environment provides tools that allow to search sounds using language or audio-based filters relating to technical and aesthetic characteristics. For instance, sounds can be filtered based on key, BPM, and duration, among others. The current design provides a browser-based audio content search engine for querying the sounds and sending them to Bela using Internet protocols. The software and web services modules are being developed and will be integrated next.

Final Remarks

We have proposed a new embedded system using e-textile for embodied music interaction that targets novice and expert performers as well as their technologist collaborators. Compared to other existing interactive systems that enhance sound design through wearable devices, our design innovates in the use of lightweight textile sensors directly integrated into worn garments.

As next steps, we plan to evaluate: (1) how bespoke e-textile sensors can be used in a performing arts context; (2) what mappings from the sensor to the audio synthesis domains can be implemented using sensor fusion algorithms in light of user expectations; and (3) what audio query and retrieval filters to access sound files from the Internet motivate users in a performative context.

Of particular interest for future investigations are creative queries of sound files using gesture or voice inputs. In the music information retrieval (MIR) field, textual-based search has been expanded to query-by-humming, e.g., the tune of a song [8]; or query by gesture-to-sound [4]. With the advent of the Web Audio API (https://www.w3.org/TR/webaudio/), new browser-based applications point to potential directions, such as querying Freesound with a microphone [17].

Within the overall theme of embodiment in HCI [25], this work presents several other interesting domains of applications worth investigating, including music listening of pre-recorded media, post-production, design for well-being, sports, fashion design, and affective computing.

Acknowledgements

The project Audio Commons is funded by the European Commission through the Horizon 2020 programme, research and innovation grant 688382. This work was supported by the EPSRC and AHRC Centre for Doctoral Training in Media and Arts Technology (EP/L01632X/1). Thank you to Giulio Moro for his assistance with the Bela platform and to An Liang for her help with preparing the workshops.

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