Interactive sonification and the IoT: the case of smart sonic shoes for clinical applications

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ABSTRACT

To date, little attention has been devoted by the research community to applications of the Internet of Things (IoT) paradigm to the field of interactive sonification. The IoT has the potential to facilitate the emergence of novel forms of interactive sonifications that are the result of shared control of the sonification system by both the user performing the gestures locally to the system itself, and one or more remote users. This can for instance impact therapies based on auditory feedback where the control of the sound generation may be shared by patients and doctors remotely connected. This paper describes a prototype of connected shoes for interactive sonification that can be remotely controlled and can collect data about the gait of a walker. The system targets primarily clinical applications where sound stimuli are utilized to help guide and improve walking actions of patients with motor impairments.

CCS CONCEPTS

• **Applied computing** → **Sound and music computing**; • **Information systems** → *Internet communications tools*; • **Human-centered computing** → Human computer interaction (HCI).

KEYWORDS

Interactive sonification, Internet of Things

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1 INTRODUCTION

The paradigm of the *Internet of Things (IoT)* refers to the augmentation and interconnection of everyday physical objects using information and communication technologies [2]. Recent years have seen the emergence of applications of the IoT to the area of Sound and Music Computing.

Concerning the musical domain, Turchet et al. proposed the *Internet of Musical Things* [17], where a number of devices for music production and consumption are connected within ecosystems that multiply possibilities for interactions between different stakeholders (including performers, audience members and studio producers). In the context of musical performance, Skach et al. proposed a garment allowing for the interactive manipulation of musical and non-musical sounds retrieved from the Freesound.org repository [11].

In the context of non musical sounds, the extension of the IoT to the audio domain include sensor networks for acoustic scene analysis [12]. A prominent example of this category is SONYC, a system that integrates sensors, machine listening, and data analytics to monitor and analyze urban noise pollution [3]. Along the same lines, acoustic sensor networks systems have been proposed by Ardouin et al. for monitoring urban soundscapes [1] and by Sethi et al. for the acoustic scene analysis of general ecosystems [10].

However, little attention has been devoted by the research community to applications of the IoT paradigm to the field of *interactive sonification* [6]. Interactive sonification is a subfield of the *sonification* research area [7], which deals with the involvement of dynamic human interaction in the generation or exploration of information transformed into sound. Such a transformation may be based on different techniques, including sonification models (see [6]). Interaction in sonification may be implemented as the transformation of the data into sound in real-time, i.e., at the moment in which the data is gathered. An example of system that transforms human gestures into sound as they are performed, is represented by shoes enhanced with sensors that track the foot-floor interaction and produce in response to this interaction a computerized sound (see e.g., [9, 13]).

To the best of author's knowledge, the challenge of interfacing interactive shoes for auditory feedback with the Internet has not been faced yet. The IoT has the potential to facilitate the emergence of novel forms of interactive sonifications that are the result of shared control of the sonification system by both the user performing the gestures locally to the system itself, and one or more remote users. This can for instance impact therapies based on auditory feedback where the control of the sound generation is shared by the patient and the doctor. The effect of such therapy can be remotely monitored and data from several patients performing such a sound-based therapy can be collected by means of big data analytics techniques [5].

In this paper, we present a prototype of connected shoes for interactive sonification that can be remotely controlled and can collect data about the gait of a walker. The system targets primarily clinical applications such as those related to the rehabilitation of Parkison's disease patients [4]. It is conceived to progress the the state-of-the-art of current devices dedicated to the use of sound stimuli to help guide and improve walking actions of patients with motor impairments (e.g., via the rhythmic auditory stimulation technique [14]).

Specifically, these shoes are equipped with sensors for tracking the gait of a patient and providing auditory feedback in response to the patient's footfalls, as well as wireless connectivity to smart devices and the Internet. They have been designed to analyze the gait of a patient and to monitor, locally and remotely, the progress of novel forms of therapy based on auditory stimuli generated interactively. This kind of feedback is hypothesized to be successfully involved in rehabilitation contexts due to its capability of modulating the gait of a person. Such an hypothesis is based on results of research on interactive sonification of foot-floor interactions, which has shown that ecological auditory feedback simulating footstep sounds on various surface materials is capable of modulating human locomotion (see e.g., [9, 18]).

The use of this portable device could enable patients to perform sound-based rehabilitation exercises while being comfortably at their homes. Patients and their families could be provided with cost-effective tools to autonomously monitor the progress of a therapy. By enhancing these shoes with internet connectivity, doctors could be enabled to remotely monitor each patient and control the sonic feedback at each exercise. This has the potential to prevent patients to visit frequently the hospital by decreasing the cost for both patients and hospital institutions.

2 CONNECTED SONIC SHOES FOR CLINICAL PURPOSES

To date, the state-of-the-art system for interactive sonification of foot-floor interactions is *SoleSound* [19], a shoe-based system capable of producing sounds and tactile vibrations interactively with the footfalls of a walker. Sensors embedded into each shoe detect the interaction of the foot with the floor and transform it, in real-time, into sounds and vibrations by means of the audio-tactile footstep synthesizer described in [15]. The sounds are provided to the user via small loudspeakers attached to the shoes and the vibrations are generated by means of actuators embedded in the thickness of the sole.

These shoes are capable of creating the compelling illusion of walking on a material different from the one the user is actually walking upon. For instance, a person walking upon an asphalted road could experience the tactile sensations and the sounds corresponding to footsteps on gravel, or snow, or a puddle of water. This kind of ecological audio-tactile feedback might be successfully involved in rehabilitation contexts due to its capability of modulating the gait of a person [9, 18]. The results reported in [18] and [9] suggest that novel forms of motor therapy leveraging such type of auditory and plantar vibro-tactile feedback may be designed and applied. Nevertheless, SoleSound is not equipped with wireless internet connectivity.

This paper proposes a prototype based on the Bela-Mini board [8], a very small computing unit for ultra-low-latency audio and sensor processing which runs Linux. The board can be extended with USB dongles to provide wireless connectivity to local and remote networks, as previously shown in various Internet of Musical Things applications (see e.g., [16]). Differently from SoleSound, this prototype only provides auditory feedback, not an additional vibrotactile one. A schematic representation of the local and remote interactions enabled by the developed prototype is illustrated in Figure 1. The next section details the components of the developed system.

3 APPARATUS

The developed system consists of the following components:

- A pair of smart sonic shoes;
- A network infrastructure comprising a wireless local area network and the Internet via a Wi-Fi router;
- A server;
- An app for smartphone;
- A program running on a PC remotely connected to the shoes via the server.

Smart sonic shoes

Figure 2 shows the developed sonic shoes. These consist of a pair sandals each equipped with two force sensing resistors placed under the sole in correspondence to the heel and the toe, which detect feet pressure during contact with the ground. The sensors analog signals are digitized by means of the Bela-Mini board and used to drive the footstep sound

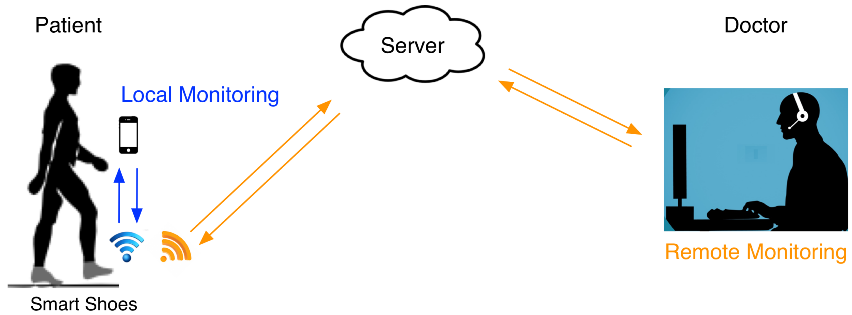

Figure 1: A schematic representation of the local and remote interactions enabled by the developed system as well as its main components and users.

synthesis engine described in [15] which is implemented in Pure Data. The engine allows to render a variety of surface materials, including aggregates, solids, liquids, and hybrids.

A Wi-Fi USB dongle (A6100-100PES by NETGEAR) was plugged to the Bela-Mini board to enhance it with wireless connectivity. A light box containing both the board and the USB dongle was attached to a belt; the wires coming out from the shoes and directed to the board are attached to the user’s trousers by means of a velcro and secured to the external side of the lower limbs. The synthesized auditory feedback is then conveyed to the user by means of the headphones. Power supply was provided by means of a lightweight power bank (5V/2A) selected for size, weight, shape, and endurance, which was attached to the box.

Figure 2: The developed smart sonic shoes.

Networking

A small router was utilized to create a wireless local area network and interface with the Internet. The used model (TL-WR902AC by TP-Link) features the IEEE 802.11.ac Wi-Fi standard as well as a USB port for 4G dongles enabling direct Internet connectivity. Internet connectivity can also be routed from a standard ethernet cable plugged into the router. The delivery of data coming from the shoes to the smartphone app was achieved by leveraging the Open Sound Control (OSC) protocol over the User Datagram Protocol (UDP). Conversely, data transmission from the shoes to the remote PC and back was achieved by means of sockets connection over TCP/IP thanks to a dedicated Python application running on both ends. However, sending the patient’s sensitive data over the cloud poses privacy issues. For this purpose, standard cryptographic techniques were utilized involving the PyCrypto library[1].

Smartphone app

An app for smartphone was created by using the TouchOSC[2] environment, which enables the creation of modular control surfaces for mobile applications leveraging OSC messages. The app displays the following temporal data received from the shoes: heel-to-heel, heel-to-toe (for both left and right foot). Moreover, the app displays and allows one to select the type of surface material rendered with the synthesized auditory feedback. The app also enables the user to input personal data such as name, family name, age, gender, as well as biometric data such as height, weight, shoe size. Such personal data are stored in the program running on the Bela-Mini board and delivered to the remote user.

Remote application for PC

The data coming from the shoes are delivered to the cloud and received on a computer that allows a potential doctor to visualize the gait of a given patient during his/her exercises conducted at home. The program running on the doctor’s computer is coded in Python programming language using the PyQT libraries[3]. This program not only enables the doctor

[1]https://github.com/dlitz/pycrypto
[2]www.hexler.net/software/touchosc
[3]https://wiki.python.org/moin/PyQt

to monitor remotely the progress of a motor therapy based on the auditory feedback provided by the shoes, but also allows him/her to change remotely the feedback produced by the shoes.

4 DISCUSSION AND CONCLUSIONS

This preliminary work, along with all the examples of applications of the IoT to the audio domain reported in Section 1, points to the emergence of an area that can be termed as "Internet of Sounds" or "Internet of Audio Things", an extension of the IoT paradigm to the audio domain (considering in particular non-musical sounds). The shoes-based system proposed in this paper provides a use case for such an emerging paradigm, where a remote user can monitor and interact with the interactive sonification process accomplished by another user. The system spurs novel forms of therapy for patients with motor impairments (such as those resulting from Parkinson's disease), which are based on interactive sonic stimuli and on the remote control of the interactive auditory feedback.

Patients, by wearing the developed portable device, could be subjected to sound-based therapies while being comfortably at their homes. Patients and their families could be provided with cost-effective tools to autonomously monitor the progress of a therapy. In addition, by enhancing the shoes with internet connectivity doctors would be enabled to remotely monitor each patient and change the auditory feedback generated in response to each footfall. This has the potential to prevent patients to visit frequently the hospital, which may decrease the costs for both patients and hospital institutions. These aspects have the potential to improve the patients' lifestyle and through personalized programs they could manage more efficiently their motor-perceptual deficits.

In future work we plan to evaluate the developed prototype involving both doctors and Parkinson's disease patients. We also plan to extend the current prototype, which only retrieves temporal data from the act of walking, with an inertial measurement unit sensor in order to enable the retrieval of spatial data such as step length. Furthermore, we plan to create a system for collection and analysis of data coming from several displaced patients.

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