ABBI: a wearable device for enhancing the spatial abilities of visually-impaired people

Gabriel Baud-Bovy
Istituto Italiano di Tecnologia, Genoa, Italy & Università San Raffaele, Milan, Italy
Gabriel.Baud-Bovy@iit.it

Lope Ben Porquis
Fabio Ancarani
Monica Gori
Istituto Italiano di Tecnologia, Genoa, Italy
Lope.Porquis@iit.it, Fabio.Ancarani@iit.it
Monica.Gori@iit.it

Abstract
This paper presents a wearable device that was developed to rehabilitate spatial, mobility and social skills of visually impaired persons. The ABBI system is composed of a small wearable custom-designed device with integrated audio system and wireless communication module to communicate with smartphone and computers. Several apps have been developed to interact with the ABBI devices. The hardware and firmware of the ABBI device are briefly described as well as some use cases that motivated its development.

Author Keywords
Rehabilitation devices and protocols; blindness; wearable; audio feedback; movement sonification.

ACM Classification Keywords
C.3 Special-Purpose And Application-Based Systems; K.4.2 Social Issues; H.5.2 User Interfaces

Introduction
Research suggests that the vision plays an important role in building cognitive processes necessary to process spatial information. In particular, vision of one's own movement provides crucial information for the processing of spatial information provided by the other sensory modalities (Gori 2015). Lack of vision affects the development of spatial abilities of visually-impaired and blind persons. It has also a detrimental impact on postural control, mobility and social interaction (Gori et al., 2014). The core idea of the *Audio-Bracelet for Blind Interaction* (ABBI) project is that spatial, mobility and social abilities of visually

impaired persons might be enhanced by rehabilitation protocols that use audio-motor associations to develop cognitive process and abilities which might have been hampered by the visual impairment. To that end, a goal of the project has been to develop a small, wearable device – the ABBI device - that can provide audio feedback as a function of the movement of the user (see Figure 1).

Objectives

A first goal of the ABBI device is to develop the sense of one's own movement in space by placing a sound source – the ABBI device - on the wrist. The idea is that the auditory system can substitute vision to provide information about the position of the hand to process proprioceptive information and build a proper spatial representation of these movements.

In a pilot rehabilitation study, several visually-impaired and blind persons, aged between 9 and 18 years, wore the ABBI device one hour per day during three months. During this training period, the ABBI device produced quick intermittent sounds when the user moved the wrist. The sound was triggered but not modulated by the movement. In addition, the participant performed a weekly training session with a therapist. These sessions included exercises where the visually-impaired person followed the movement in the room of therapist who was wearing the ABBI device for example. Preliminary results suggest that this protocol can develop the sense of space both in the peri-personal and extra-personal space (Finochietti et al., 2015).

Another goal of the ABBI project is to enhance the postural control and mobility capacity of visually impaired persons. To that end, the ABBI device needs

Figure 1. *Left*: ABBI2 prototype with smartphone LG D160 distributed to the visually-impaired and blind children and their families (Finochietti et al., 2015). *Right*: Inside view of the ABBI2 prototype.

to be placed on the trunk of the visually-impaired person and to provide information about the movement of the trunk while the person is performing exercises that challenge his or her equilibrium. In this case, the ABBI device must sonify the movement of the trunk, i.e. provide an audio feedback that is modulated as a function of the movement of the trunk.

A last goal of the ABBI project is to enable and develop social interaction between visually-impaired persons. In this context, several persons wear an ABBI and play sound-based games together (Rydeman et al., 2015). The audio-feedback in this context fulfills a set of complementary functions such as indicating the position and/or identity of each person, single out a subset of person, etc.

State of the art

Most of existing technology for visual impaired and blind people aims at maximizing use of residual visual capacities and/or using other sensory modalities such as haptics or audio as substitute for vision (a

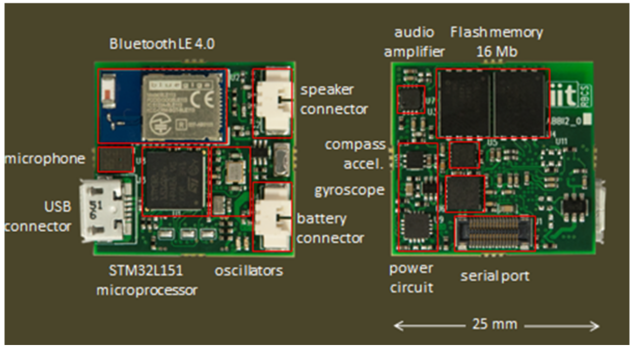

Figure 2: ABBI circuit prototype

comprehensive review can be found in Hersh & Johnson, 2008). This technology includes low-tech devices like the cane, embossed pictures to more advanced technology like electronic Braille displays, ultra-sound canes and GPS-based navigating systems.

The ABBI approach differs in that it aims at developing abilities of visually-impaired people through the training and rehabilitation of related cognitive processes. ABBI technology is intended to be used only during a training or rehabilitation period, which the goal of bringing longer-lasting improvements at the cognitive and behavioral level.

A review of existing devices suggests that existing wearable technology does not fit the needs of ABBI. Smartphones and tablets are too big to be used on the wrist. Smart watches are often expensive and only a few smartwatches have an integrated speaker. More problematically, their Application Programming Interfaces (API) is very limited. There is also a large number of micro-controller platforms available on the market (e.g., Arduino Mini or Nano, Raspberry PI, Xadow). However, most of these platforms require extension modules for audio synthesis or communication. They are also not designed to minimize energy consumption.

The ABBI system

The ABBI system is composed of a small wearable custom-designed device with an integrated audio system and a wireless communication module to communicate with smartphone and computers. Several apps have been developed to interact with the ABBI devices.

Hardware

In its current version, the ABBI circuit measures 25 by 24 mm and holds all the electronics of ABBI (see Figure 2). The main components of the circuit are an ARM Cortex M3, a Bluetooth Low-Energy (BLE) module, an 9-axis Inertial Motion Unit (IMU) (gyroscope, accelerometer and magnetometer), a class-D audio amplifier and 16 Mb Flash Memory (two 8 MB modules). Most components of ABBI can be switched off individually to save power. In particular, the BLE module and the accelerometer have low-power modes, the audio amplifier and unused sub-systems of the mains processor can also be turned off to save energy.

The circuit also includes two connectors for the battery and speaker respectively, a JTAG connector for programming and debugging the device, and a micro-USB connector to charge the battery, load the firmware and high-throughput communication with the device.

Firmware

The current firmware version is based on FreeRTOS. Several threads (tasks) handle low-level communication between processor and the other components of the system such as the BLE module, the IMU and USB. Other threads control the functions of the diverse modules of the firmware.

Power Management

Power is managed by the System module with a Finite State Machine. To save power, the system module puts the device in a low-power (STOP) mode when the device is inactive. In this state, only the Real Time Clock (RTC) and accelerometer trigger are powered (power consumption < 1 mAh). A periodic Interrupt Service Routine (ISR) wakes up the device to monitor the battery level and eventually fully shutdown the device if the battery reaches a critical level. The ABBI device is normally awakened when the device is moved or connected to a powered USB port. In Normal (Awake) mode, power consumption is 16 mAh or 24 mAh depending on whether the BLE module is functioning. To save power, the BLE module is normally turned off on but it will start advertising if the device is shaken.

Audio system

The sounds are generated by the processor at 22050 khz, converted into an analogical signal and amplified by a class-D amplifier. The audio buffer holds 256 samples, which corresponds to a 11-ms latency. The maximum sound level at 1 meter is about 70 dB SPL (pure tone at 1000 Hz).

The sound synthesizer can combine up to five channels in its current configuration. Each channel has its own sound source, which can be a wav file stored in the Flash memory, or a wave generated in real time. Each channel has also parameters that define the attack, sustain and release of possibly periodic sounds and the volume of the channel. The output of the configured channels are mixed together. The maximum number of channels is limited by the computational power of the processor (about 4 or 5 sinewaves computed at 22050 kHz in fixed point arithmetic with a table look-up algorithm).

Sound onset and offset can be controlled remotely or started automatically when the device velocity exceeds an adjustable limit. The sound synthesizer is programmed with lock-free programming techniques that allow other threads to change the parameters of the sound sources and/or channels while the device is playing, which is important for movement sonification.

By far, sound production is the main consumer of battery power (up to 320 mAh for a continuous sound at maximum volume). For this reason, it is important to optimize the design of the sound to save power (e.g. by using intermittent rather than continuous sounds).

Motion sensing

A period motion task continuously reads the IMU sensors (accelerometer, gyroscope and magnetometer) and dispatches this information where needed. In particular, this information is used for

- Triggering and/or modulating the sound depending on the sound control modality.
- Sending notifications with this information via the BLE module to the smartphone
- Monitoring the activity of the subject. In this case, a summary of the motion data is stored in the Flash memory for off-line analysis.

Data Logging and File System

The Flash memory stores the sound (.wav) and log files. The log files monitor the state and movement of the device. This information can be downloaded and analyzed by the experimenter to know, for example, whether the rehabilitation protocol has been followed by the user at home or not. Given the characteristics of Flash Memory (128x64Kb clusters), a simple file system was implemented to manage these files more efficiently than a FAT system. However, the file system requires that the files be stored continuously and does not provide hierarchical folders.

Communication and Control

The ABBI device can communicate with other devices (smartphone or PCs) through the USB port and the BLE module. Bluetooth LE is a new standard for the “Internet of Things” that is optimized for low power applications. Bluetooth LE is designed for sending small chunks of data and does not have a streaming mode. The achievable throughput is around 1 kB/s. Bluetooth LE devices must implement the Generic Access Profile (GAP) and Generic Attribute (GATT) services to communicate with other devices. As a peripheral device and GATT server, the ABBI device can advertise and respond to connection requests from a central device (smartphone or computer). A limit of BLE technology is that a peripheral device can connect to a single central device only. In contrast, a central device can connect to several peripheral devices. A consequence is that two or more ABBI devices can communicate only via a central device.

Most communication with the central device in ABBI takes place through custom GATT services. Existing services allow the user configure the audio synthesizer,

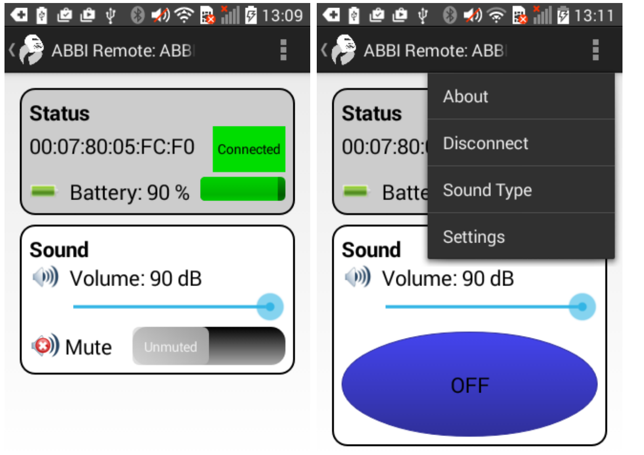

Figure 3: Screenshots of the Android app developed by Lund University as part of the ABBI project. *Left*: End-user mode. *Right*: Expert mode.

start and stop the sounds and movement sonification. The ABBI device can send IMU data to the central device as notifications. Finally, it is also possible to download the log files through the BLE module although this operation is relatively slow due to the limit of the BLE technology. A faster way to download the log files is to use the USB port, which can also be used to manage wav files.

Smartphone Apps

Several smartphone apps have been developed to fit the needs of the different users (see Figure 3). A first app is aimed at the end-user, family members of visual-impaired children who are using the ABBI device at home. This application provides information about the battery level of the device, and allow the user to control the sound volume or mute the device (e.g. during transport). A second app is aimed at the experimenters and/or therapists and provide additional control of ABBI functionalities. This app allows the advanced user to change sound parameters, remote control the onset and offset of the sound, etc.

Future developments

The current version of the firmware provides a solid basis for the development of new functionalities. This development is guided by experimental studies about design of the sound feedback, workshops and other methods as well as feedback from users. At the hardware level, users have expressed the wish to have some basic control of the ABBI device through a button, which will be integrated in the next version of the device. At the software and application level, much development remains to be done. Research about which audio feedback provides spatial information in the most effective manner is needed (Wilson et al., 2015). We also need to develop ways of allowing several ABBI devices to interact together, which is important when the ABBI device is used in group. Finally, the smartphone apps need also to be tested with visually-impaired and blind people.

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