SenseBox: A DIY Prototyping Platform to Create Audio Interfaces for Therapy

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ABSTRACT

Customizable systems that let children and adults with disabilities control audio playback can support different forms of therapy, including music therapy and speech-language therapy. We present *SenseBox*, a low-cost, open-source, customizable hardware/software prototyping platform to turn everyday objects into audio triggers for people with disabilities. Users can add tags to physical objects that when in proximity to SenseBox trigger the playback of associated audio files. We designed SenseBox with input from three therapists and an assistive technology expert. We detail our human-centered design process that took place over 16 months and describe a detailed example use case where SenseBox was used to create an accessible music player for a child with cognitive disabilities. This project illustrates how to design physical computing prototyping platforms for therapists to create customized interfaces for their clients without requiring prior programming or design experience.

Author Keywords

Accessibility; DIY Assistive Technology; Speech-Language Therapy; Music Therapy; Audio Interfaces

INTRODUCTION

The emergence of a variety of low-cost electronic and computational prototyping platforms, such as Arduino, Raspberry Pi and compatible sensors and actuators, has made it possible for people with non-technical backgrounds to experiment with designing and implementing novel interactive interfaces [[11], [32]]. The relatively low technical barriers to using these devices, along with their affordability and customizability, are often cited as factors that make them accessible to a range of hobbyists, makers and amateur artists and designers with creative ideas but limited programming or digital prototyping experience [[6], [38]]. For people with disabilities and their therapists, special education teachers, parents and caregivers, the possibility of utilizing these platforms to create Do-It-

Yourself (DIY) customizable interactive artifacts for expressive, educational and/or therapeutic activities is enticing [[15], [17]]. However, despite current efforts to create more accessible tools and processes to support participation in the creation of DIY interactive objects important technical barriers to participation still exist.
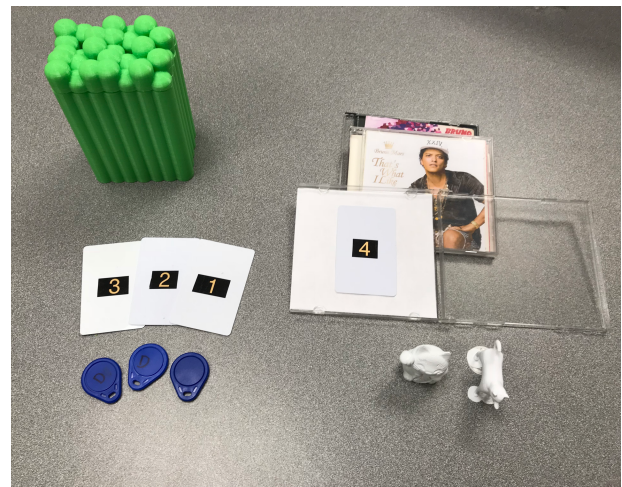

Figure 1. SenseBox consists of an audio playback module, housed in a 3D printed case (Left, top) and a series of RFID tags (Left, bottom) that can be embedded into physical objects (Right).

To better understand these barriers and to explore ways of overcoming them, we worked with two speech-language pathologists, a music therapist and an assistive technology specialist in a series of 10 sessions over 16 months to design a prototyping platform for users with little or no prior programming or physical computing experience to create customizable audio interfaces using physical objects. *SenseBox* (Figure 1) is a Raspberry Pi-based prototyping platform that consists of an audio playback module and a set of Radio-Frequency Identification (RFID) tags that can be embedded into existing or fabricated (i.e., 3D printed, or laser cut) physical objects to turn them into accessible audio triggers for use in therapeutic settings. Each tag is associated with a user-specified audio file that is played back when an object embedded with it is in close proximity to the playback module. Users can customize the system by (1) changing audio files, and (2) embedding tags in different objects. Neither of these mechanisms require any programming or electronics skills, making the system technically accessible to a wide group of users. We have incorporated these mechanisms to make it possible for

SenseBox to be used to create audio interfaces that are adapted for each user, a quality described in previous research as important in creating accessible electronic interfaces for use in speech-language therapy [[34]], music therapy [[25]], and the "Holy Grail" of designing music and audio interfaces for people with disabilities [[23]].

The simple functionality of SenseBox, along with its flexibility make it useful in the context of speech-language therapy and music therapy, in which it is desirable for a client to exercise agency in generating alternative speech or audio sounds [[9], [34], [41]]. *Speech-Language Therapy* is a clinical practice used to support clients who experience difficulties in exercising communication skills [[9]]. Exercises used by speech-language pathologists (SLPs) can support non-verbal clients or clients with very limited speech to find alternative ways to express themselves and can include the use of Alternative Augmentative Communication (AAC) devices, such as communication boards [[24], [34]]. While a range of commercial AAC devices exist, they are often expensive, complex and their hardware is difficult to customize and adapt to specific users. *Music Therapy* is another established form of therapy in which music is used within a therapeutic relationship to address physical, emotional, cognitive, and social needs of individuals [[9], [41]]. After assessing the strengths and needs of each client, the qualified music therapist provides customized treatments which can include creating and/or listening to music. Music therapists use a variety of tools, including conventional musical instruments and digital music playback devices (i.e., iPods and CD players). The use of conventional devices can pose accessibility barriers to participation in music making for clients with motor or cognitive disabilities [[33]].

We next describe previous research in this area, followed by a description of SenseBox and the process that informed its design. We also describe a use scenario in which SenseBox was used to create an audio interface for a child on the Autism Disorder Spectrum (ASD). Finally, we describe and summarize SenseBox's design features and limitations.

RELATED WORK

The TEI and HCI communities have long been interested in developing systems that use physical objects to trigger and manipulate audio in different forms, including tabletop systems (e.g., [[20], [39]]), wearable instruments (e.g., [[35], [40]]), game controllers (e.g., [[22]]), and augmented physical objects (e.g., [[14], [18]]). These projects are complemented by the development of several physical computing platforms, such as Bela [[7]] or Satellite CCRMA [[12]] that have been specifically designed for high-quality music synthesis and playback.

While many of these systems are designed for use by artists, designers or researchers, several Do-It-Yourself (DIY) platforms and kits are specifically designed for use by non-technical users (e.g., [[14], [18], [28]]). An example is Makey Makey, a popular DIY "invention kit" designed to let users connect conductive objects, such as conductive

tape or pieces of fruit, to a computer to trigger specific mouse or keyboard button presses when the objects are touched [[28]]. Using this mechanism, users can interact with a variety of computer applications, including games and audio applications, using connected physical objects as input devices. While Makey Makey was designed for the general public, Rogers et al. used it as a mechanism to engage groups of older adults [[32]]. They found that their participants enjoyed using the kit for musical expression and came up with new application ideas. The researchers found it particularly important that using the kit does not require programming skills and presents a low barrier of entry for participants. Despite its strengths, some of Makey Makey's design features, including the need to connect objects to a separate computer using wires, and for users to hold a ground wire for the system to work, make it difficult to use with children with disabilities. SenseBox is inspired by Makey Makey and other similar designs, such as the Lilypad Arduino platform [[11]], that allow the use of everyday physical objects in creating interactive interfaces. It aims to incorporate other features, such as using wireless contact between objects and the audio playback module, and avoiding the use of a separate computer, to make it easier to use by therapists to prototype accessible interfaces.

While some of the systems and platforms described above can be used to develop accessible interfaces for people with disabilities, they are not specifically designed for them. Several other research projects have developed audio and musical interfaces specifically for people with disabilities, including people with visual impairments (e.g., [[42]]), people with motor disabilities (e.g., [[5]]), and people with cognitive disabilities such as Autism Disorder Spectrum (e.g., [[31]]) and dementia (e.g. [[33]]). Larsen et al. conducted a review of the current state of development in music-supported therapy, as well as recent trends in designing accessible musical interfaces for people with physical disabilities [[23]]. They identified the development of accessible musical interfaces that can be adapted for each user as the "Holy Grail" of designing in this space. Similarly, in a study of switches designed for children with limited mobility, Schaefer and Andzik stressed the importance of choosing devices that match a child's abilities and customizing activity outcomes to keep the child motivated to continue the effort required for sustained use [[34]]. SenseBox is designed with these goals in mind: it is built as a platform to make it possible to create a wide range of audio interfaces, each adapted to the specific physical and cognitive needs of a user.

Several projects have explored the possibility of using tangible and embedded physical interfaces to create accessible customized therapeutic devices for occupational therapy (e.g., [[30]]), music therapy (e.g., [[21]]), speech-language therapy (e.g., [[13]]), and educational systems for children with autism (e.g., [[2]]), as well as, deaf children (e.g., [[16]]). These devices are often designed in collaboration with therapists and offer a degree of customizability to let them adapt interfaces for their clients. Moraiti et al. presented a DIY-toolkit for occupational

therapists and caregivers to create customized computer user interfaces for their clients out of soft objects [[30]]. The Skweezee system allowed therapists to embed electronics into existing or newly fabricated soft objects, such as pillows or mats, that could then be used to detect a range of tactile interactions, including squeezing, pushing, grasping and pinching. The interactions could be mapped to computer input actions, such as mouse clicks or keyboard input, which would then turn the soft objects into input devices for interacting with a range of existing computer applications, including games. The system was evaluated with seven occupational therapists and one assistive technology expert who used it to create potential solutions for clients. The therapists found the development of the system and other similar DIY platforms valuable and emphasized the importance of not requiring the users of such platforms to have advanced programming or electronics prototyping experiences.

In a different study with three stroke patients, Kirk et al. found that using a digital drum set connected wirelessly to an iPad application to trigger percussion sounds in musical exercises led to significant levels of self-managements and an increase in functional measures [[21]]. The participants also reported high levels of motivation and enjoyment. The drum setup was fabricated in consultation with therapists who also helped choose a set of favorite songs to accompany for each of the participants. The researchers concluded that using digital musical instruments can offer health and therapeutic benefits to users and that it is important to have health professionals on board when deploying such systems to ensure their successful uptake.

Finally, several studies have explored design opportunities for new interactive interfaces in the context of speech-language therapy [[13], [19]]. In a study of five children with disabilities who use AACs in a special education school, Ibrahim et al. identified a series of design opportunities for future AAC solutions, including incorporating an embodied view of communication and designing to emphasize children's competence and agency [[19]]. The study found that the complexity of existing AACs creates a high entry barrier to their use by children. This often means the children have to undergo long trainings before being able to exercise agency in using the systems. The authors recommended the development of flexible communication technologies that place child users' agency in communication at the forefront of the interaction and develop and grow in complexity with their users over time.

In another study, Hamidi et al. presented TalkBox, a DIY low-cost open-source communication board for non-verbal users, that was designed as an affordable and customizable alternative to commercial AAC devices [[13]]. TalkBox was designed as a kit that could be assembled by therapists and adapted to meet the needs of each client. The researchers employed a participatory design process to develop the system in collaboration with special education teachers and therapists. While the physical form of the system could be adapted for each user, the users still needed to touch a conductive part of the system in order to activate audio sounds. While we take a similar approach to DIY interface design, our aim is to develop a more flexible approach to allow a range of physical objects as wireless audio triggers during interaction.

In summary, previous research has shown that there are design opportunities for developing DIY prototyping platforms for therapists to create customized audio and music interfaces for their clients. Further, these interfaces should be designed so that non-technical users can utilize them to create therapeutic experiences for their clients that support client agency and self-expression. As we will describe in the next section, we have designed SenseBox with these goals in mind.

SENSEBOX: A PROTOTYPING PLATFORM FOR TURNING PHYSICAL OBJECTS INTO ACCESSIBLE AUDIO TRIGGERS

SenseBox (Figure 1) is a Do-It-Yourself (DIY) prototyping platform that allows users to create audio triggers out of existing or fabricated objects. It is primarily designed for use by therapists and special education teachers to create interactive audio experiences for children and adults with disabilities. In this section, we first describe SenseBox's design process which was informed by perspectives from its user community. This is followed by a description of SenseBox's design and functionality.

Design Process
SenseBox was designed using a human-centered design approach in which representative users were included in the iterative design process early on. Participants provided several rounds of feedback on design ideas to ensure that the system reflects their desires and needs [[29]].

Methods and Participants
SenseBox's design process took place over a period of 16 months where we worked closely with two speech-language pathologists (SLPs), a licensed music therapist, and an assistive technology expert. The SLPs and assistive technology expert work with children and youth with cognitive and motor disabilities and the music therapist works with both children and adults, including older adults who experience cognitive disorders and difficulties due to aging. The participants were all female and had worked in their fields between 3-10 years.

In total, we conducted 10 interview sessions, each taking between 40 to 60 minutes, where we discussed different aspects of the system and how it could support therapy. Most of the sessions (7 out of 10) were conducted with two participants and the remainder with one participant. Employing an iterative design process, we fabricated and used a series of mockups and functional prototypes as objects for participants to reflect on and give us feedback about. These included a series of existing objects (e.g., empty CD cases) and newly fabricated ones (e.g., 3D printed rings and small animal shapes) to demonstrate the range of audio triggers that can be used with the system. Additionally, if they desired, participants could choose to

keep the prototypes between meetings to think about them and provide us with their reflections afterwards. We incorporated participants' feedback into subsequent design iterations.

We encouraged the participants to ground their input on specific outcomes they desired in their practice and they often, anonymously, described how clients that they had worked with could benefit from aspects of the system. The design process resulted in a total of four working prototypes and six 3D printed mockups (Figure 2) and culminated in a functional prototype that we will describe in the next section.
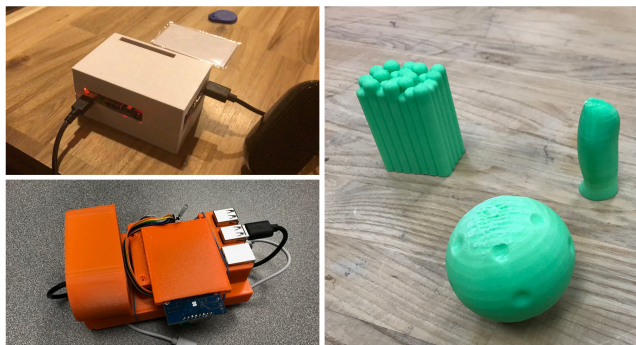

Figure 2. Two functional SenseBox prototypes (Left), and three 3D printed mockups (Right) used during the design process.

During the sessions, we took detailed notes that we annotated with our reflections after the meetings. We analyzed these notes using an inductive thematic analysis [[9]] where we coded the data and categorized them to identify emergent themes. The themes were then discussed with members of the research team and incorporated into the next design iteration of prototypes.

Design Considerations
We identified three themes in our participants' input that we will use to structure our design considerations below:

The Importance of Physical Objects in Therapy. Both the SLPs and the music therapist described how they use physical objects with some of their clients during therapy sessions. The SLPs described how working with abstract symbols, such as images or words, can be challenging for some of their clients. One SLP described how some clients with cognitive disabilities have a hard time associating a 2D image (e.g., a picture of a ball) with a 3D object (e.g., a ball) or an activity (e.g., playing). For these clients, using physical objects, such as rubber balls, pieces of textile or wooden or plastic objects can be more effective. The SLPs described how using objects is often a stepping stone to learning more vocabularies and expanding the client's expressive abilities. One SLP uses a set of everyday objects, including a fork, a hand mirror, a pen and a cup, among other objects (Figure 3) to introduce her clients to new vocabulary and ask them about their preferences. She described how for some clients, she uses physical objects to refer to activities. These can include a small rubber ball to

signify going to the gym and a small baby shoe to indicate going for a walk. The SLPs described how these objects are often chosen to be appealing or meaningful to their clients. Additionally, the SLPs described how they use a range of objects with different textures and materials (e.g., metal, fabric, …) for some of their clients who have low vision.

Figure 3. A collection of physical objects used in speech-language therapy to introduce clients to new vocabulary: During therapy the therapist would ask a client to touch and hold an object (e.g., a fork or hand-held mirror) and would repeat its name with them.

The music therapist utilizes physical objects differently in her practice: She described how she often encourages her clients to use existing musical instruments (e.g., drums or shakers) to express themselves musically or participate in group musical activities. She described these activities often involve her playing music on a piano or guitar with her clients listening, dancing, singing or playing along on an instrument. She stated that many of her clients find the use of existing instruments physically challenging and require guidance, practice and some level of customization of the instrument. For example, one of her clients, a lady in her late 80's, enjoyed accompanying music by playing a small hand drum. However, her motor control and strength had been declining and she had difficulty making audible sounds by hitting the drum with her hands. To accommodate for these changes, the music therapist had been experimenting with drums that the client could play with her feet or with a mallet attached the sleeve of her shirt rather than one that she needed to grasp in her hands. The music therapist described how she is often looking for instruments, such as percussion instruments or portable musical keyboards that do not require a high level of skill or hand dexterity to play for her clients. Additionally, she mentioned that multisensory experiences are important and when choosing instruments or objects for her clients she tries to select a variety of textures (e.g., objects with fluffy or smooth surfaces and handles) when possible.

Supporting Client Agency and Self-Expression. The therapists described how it is important in their practice to support clients in exercising agency, in the sense of making decisions that somehow impact them [[8]]. For the SLPs, making choices and acting on them are important therapy goals that can lead to increased independence and self-

expression for their clients. The SLPs described how they deliberately choose words and phrases that are personally meaningful to their clients. They then respond consistently when clients express these words and phrases. For example, one of the SLPs described how she was teaching one of her clients to say "more" and "finished". When the client expressed these phrases clearly, the SLP would respond to them by pausing current activities or giving them more of something that they desired (e.g., a food item). She described that once the client mastered these phrases and the idea of them associating to consequences, she would move on to new ones. She described how the choices of words and phrases to practice also depends on a client's background and culture. For example, she described how for one of her clients whose parents speak Spanish at home, she sometimes used both English and Spanish phrases.

The music therapist described how supporting clients' self-expression and agency were important in her practice as well. She encouraged clients to express themselves musically and participate in group activities in order to find fulfilment and well-being. She described two elements that are important to her clients' successful self-expression and exercise of agency. The first element involves initiating and completing an action that has a desired outcome, for example hitting a drum with stick or pressing a button on an audio player. The second element involves perceiving that the completed action had a desired effect, for example by hearing the sound of a drum or music coming out of an audio player. She stated that this perception is important because otherwise clients might lose interest in the activity and become demotivated. She described how she considers both of these elements when choosing which instruments or objects to use with her clients. For example, she described how for one of her clients who had limited strength in her hands, she chose a drum that made a relatively loud sound when hit with a light stick. The drum's characteristics allowed the client to experience hitting the drum and perceiving the resulting sound in a manner that matched their abilities. In contrast to the drum, using a violin with an untrained client would pose a barrier as making a pleasant musical sound on this instrument requires a high level of skill and hand dexterity.

The music therapist also described another aspect of client agency that was important in her practice: agency over one's sound environment. She described how some of her clients are very sensitive to music that is nostalgic or holds strong emotional memories for them. Playing back such music without checking in with the clients can cause negative emotions in them, leading to sadness and hurt. She described how one of the hospitals she works at has guidelines on how staff should avoid playing music or tuning into radio stations without continuously checking in with clients. Further, the therapist stated that since emotions can shift over time and constant supervision is not practical in some cases, it is desirable to have accessible interfaces that older adults can use to stop or play music themselves.

Customizing Client Experiences. All of our participants underlined the importance of customizing therapy for each client based on their abilities, needs and interests. The SLPs described how they assessed a child's communication and cognitive abilities in initial consultations and used this information and any other available from previous assessments to customize therapeutic activities accordingly. The assistive technology expert also described that part of the initial assessment, often conducted in collaboration with an SLP, is a consideration of the types of assistive technologies that the client had successfully or unsuccessfully used before and deciding what existing solutions might be appropriate for them. She described a range of software and hardware solutions for speech-language therapy, including software apps, such as GoTalkNow [[4]], as well as, hardware solutions, such as Logan® ProxTalker® Modular [[26]].

For software systems, customization often took the form of changing parameters, such as the set of vocabulary or images used, for each client. A challenge for some clients was that using the visual interfaces of digital tablets, as well as, desktop and laptop computers, could be overwhelming or distracting. For these clients, the therapists opted for applications with simple interfaces with few onscreen elements. Other times, they would limit the use of digital systems altogether. For hardware systems, the form factor and physical features often needed to be customized and adapted for each client. One of the SLPs described how it is often difficult to change the physical form of existing commercial solutions beyond small changes since they are designed to be sturdy and not tampered with by users. Additionally, they are often expensive, making it risky to void their warranty by tampering with their form. For example, she described that in addition to communication disorders, some clients have visual impairments which makes it desirable to change the color, size and even texture of buttons or other areas of devices for them. However, the therapists often had difficulty implementing these changes and settled on more minor changes instead. Example modifications included adding a sturdy waterproof case to an iPad or a keyguard to a computer keyboard to make it easier to use by clients with limited motor abilities.

The music therapist also described how she customized musical activities based on specific clients' needs. Since she worked primarily with older adults her therapeutic goals were different from the ones described by the SLPs working with children and included motivating clients to make decisions, participate in group activities, exercise and make movements, and find ways to express themselves.

She identified how she often used her phone and speakers to find music that her clients liked and reacted positively to. She stated that, "*YouTube is a music therapist's best friend*", explaining how such streaming platforms provide access to large databases of music for engaging different clients. The music therapist also searched for ways to involve clients in music making or other activities participatory (e.g., dancing). To this end, she looked for

instruments that were easy to use for clients in individual or group sessions. As described previously, these instruments had to be chosen to be both easy to use and also make sounds perceptible by clients to keep them motivated. She asserted that for many aging clients it is difficult to use conventional instruments because of weakening motor abilities, especially in the hands. Also, for clients who experience dementia and other condition due to old age, it is often difficult to use digital interfaces. She stated that often "*one of the first things to lose is computer access*". Additionally, she described that for many older clients who do not have experience using digital technology, newer digital systems (e.g., iPads) can be overwhelming. Thus, having simple mechanisms to activate sounds would be useful in including these clients in musical activities.

Summary. Based on our participants' input, a prototyping platform that would let therapists easily create customized audio experiences for clients to express themselves and exercise their sense of agency would be useful in therapeutic contexts. Additionally, using augmented physical objects with different sizes, shapes and textures as part of the system can let therapists engage clients with a range of cognitive and physical abilities.

SenseBox System Description

SenseBox consists of an audio playback module and a series of Radio-Frequency Identification (RFID) tags that can be embedded in existing or fabricated objects to turn them into audio triggers (Figure 1). A series of audio files, each corresponding to a tag are stored on the module (and can be customized by users, as described below). When a tagged object is detected in close proximity of the audio playback module, the corresponding audio sound is played back.

Figure 4 shows a schematic of the SenseBox audio module that consists of a Raspberry Pi microcomputer connected to a RC522 RFID Reader, a battery and a USB speaker. The electronics are housed in a 3D printed enclosure (approximately 2.3" X 4.2" X 3").

The 3D printed enclosure is designed to incorporate participants' recommendations to make the system engaging and durable. By incorporating geometric patterns and a fastening mechanism, it provides an appealing appearance and protects the electronics from direct touch. We also intended it to be small enough for young users to carry. After experimenting with several forms (Figure 2), we decided on a rectangular shape with rounded edges and a top surface that consists of a series of randomly generated geometric cone shapes. The 3D model was designed using the Rhino 3D modeling software with the Grasshopper algorithmic modeling plug-in. We are currently developing a library of 3D models for a range of enclosures that can house the electronics and that users can choose from in the future depending on the needs and desires of their clients.
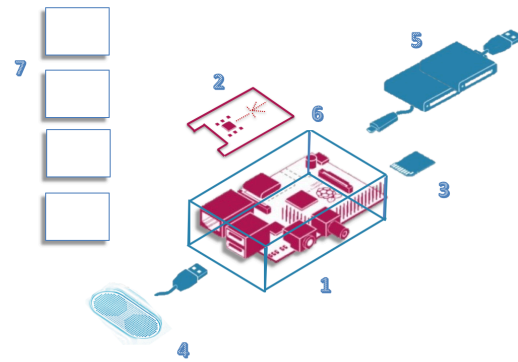

Figure 4. SenseBox Schematic: The electronic components of the audio playback module consist of a Raspberry Pi (1) connected to an RFID reader (2), with software on a SD card (3), and connected to a speaker (4) and a battery (5). All of these components are housed in a 3D printed enclosure (6) whose shape, color and texture can be customized depending on user needs and desires. The audio module plays back sounds when in proximity to RFID tags (7).

We have currently utilized three different sizes of RFID tags to embed in objects: credit card-sized tags (5" x 2.2"), keychain tags (1.1" X 0.8"), and small circular tags (0.8" X 0.8"). The RC522 RFID Reader operates at 13.56 MHz and can detect different commercially available tags. In our experience, the choice for which ones to use in an application depends on the size of the objects to be tagged: smaller tags are more suitable for smaller objects because they will not add to their size.

The software running the system is based on the open-source Linux operating system and is written in Python as firmware for the device that loads automatically upon power up. By default, the system stores a set of RFID tag ID keys in its memory, each associated with an audio file also stored as part of the software, as a Waveform Audio File Format (WAV) files. For tags to be detected, their ID key needs to be registered in a database stored as part of SenseBox's software. The system can work with a large number of tags.

Non-technical users can utilize SenseBox as a DIY prototyping platform to create customized audio interfaces using two mechanisms: 1) loading their own audio files onto the audio playback module, and/or 2) adding tags to existing or fabricated objects. For mechanism 1, users need to format their audio files as WAV files, naming each to correspond to the RFID tag that should trigger it (e.g., naming an audio file that should be triggered by RFID tag 1 as S1.WAV) and copying the files onto a USB stick. Inserting the USB stick into any of the audio module's USB ports would then automatically copy the sounds onto the module. The new sounds would subsequently play back when corresponding RFID tags are in proximity to the sensor. This mechanism is implemented such that users can switch SenseBox vocabularies without having to interact with any code or display.

Mechanism 2, adding tags to objects, can be accomplished using different methods, including using glue or Velcro strips to attach tags to existing objects (e.g., a table or a plate), or newly fabricated objects (e.g., a 3D printed, or laser cut object).

SenseBox Usage Scenarios

SenseBox can be used in several ways. In one scenario, the audio playback module can be placed on a table or similar surface (e.g., a wheelchair tray). If more stability is needed, it can be fastened to the surface using Velcro or glue strips. When tagged objects are brought to the proximity of the sensor, a corresponding audio file is played back. Since in this scenario the audio playback module remains stationary and tagged objects are brought to its proximity, it is best suited to using small tagged objects and for users who would have difficulty with grasping and holding the audio module. The objects can then be used in different speech language therapy exercises, for example when therapists want to teach the name of objects to clients or encourage them to communicate using objects that symbolize activities or greetings. For music therapy exercises, musical sounds can be activated when a client brings an object close to the module.

In a second usage scenario, tags can be attached to potentially larger objects (e.g., tables, chairs, …) and a user can hold the audio playback module with their hands and move it close to the objects to trigger the playback of corresponding audio sounds. An example of this usage in the context of therapy is when a client with visual impairments is encouraged to explore a space or environment and scan tags in a room using SenseBox. Needless to say, the two scenarios described above can be combined in a single therapy session and a therapist may choose to keep the module stationary for only part of the time and for specific exercises.

Despite its strengths, the current design of the system presents limitations, including limited use beyond therapy contexts due to a practical limit of how many objects can be tagged and kept together with the playback module, and the need for audio files to be created elsewhere before being loaded onto the device. The system is unsuitable for socially contextualized communication (e.g., in a classroom setting) due to the limited number of tagged objects that are practical to use by a single individual. However, it can serve as an accessible bridging device to scaffold learning experiences needed before moving on to using more sophisticated AAC systems [[34]].

Example Use Case

To illustrate how SenseBox can be used as a prototyping platform, we describe a real-world use case in which we used it to create a customized audio interface in the form of an accessible music player for a young client who is receiving therapy from two of the SLPs who participated in the project.

The music player is designed for a 16-years-old boy who is on the Autism Spectrum Disorder (ASD). He is non-verbal and has low-vision. He uses corrective lenses, which he occasionally refuses to wear and is generally more responsive to audio prompts than visual prompts. His SLPs have been using 3D objects, such as a rubber ball or a baby shoe to communicate activities, such as recreation or walking, on his schedule. He is interested in music and is especially fond of the popular artist Bruno Mars. Sometimes he finds Bruno Mars' YouTube videos on an iPad by looking for his pictures displayed as part of the website's interface. However, using YouTube poses difficulties because the many on-screen elements on the platform's interface can be confusing and also navigating through it can lead to undesired or inappropriate videos and needs to be done under adult supervision. The SLPs described that currently, one of their therapy goals for this individual is to teach him about cause and effect through the use of images and objects that correspond to specific outcomes and activities, a common activity in speech language therapy [[34]]. Acquiring these skills would improve his overall communication, leading to gains in independence and quality of life. To this end, the SLPs recommended using SenseBox to create a customized Bruno Mars music player for him that he could activate himself.

The customized music player was created by first identifying three Bruno Mars songs that the client liked and also finding images that correspond to them on YouTube (including album covers and pictures of the artist). The three songs were then copied to the SenseBox playback module using the process described above and each associated with an RFID tag. The RFID tags and images were each attached to one of three empty CD cases, that would serve as an audio trigger for the music player (Figure 1, Left). CD cases were chosen because they are large enough for the client to use and light enough for him to move close to the audio playback module to play a song. In the future, we plan to evaluate the music player and other similar designs, including both therapist and client perspectives.

SENSEBOX'S DESIGN FEATURES

SenseBox's design incorporates several important features based on our participants' input. These features confirm and build on previous recommendations for designing accessible physical interfaces for people with disabilities. SenseBox's design illustrates how these features can be concretely incorporated in the design of DIY prototyping platforms for therapists, special education teachers and others who work with people with disabilities.

Simplicity. SenseBox does not require the use of a visual interface and only relies on audio and physical interactions. This feature is based on the participants' input that described how visual interfaces can be distracting or complicated for many users with disabilities, an observation made by previous research on systems designed for children with disabilities [[13], [19]]. Additionally, we have intentionally kept the functionality of the audio playback system simple and currently limited to the playing back of

audio files, rather than other functionalities such as looping, adding effects to or recording new audio files. While these functionalities could be added to the system if users want them, we have prioritized simplicity and avoided adding extra features to the core functionality of the system.

Customizability. The importance of customizability was underlined both by input from our participants and by previous research (e.g., [[13], [19], [23], [25], [30]]). As described before, we incorporated two mechanisms for non-technical users to customize SenseBox's hardware (i.e., physical audio triggers) and software (i.e., embedded sounds). RFID tags can be attached to objects of different sizes and textures and users can load musical sounds, speech samples, or relaxing sounds among others onto the audio playback module. This DIY approach allows therapists to change the system's physical form to meet the needs and desires of specific users as well as, their preferences as to the appearance and attractiveness of the physical device. These are key differences of this approach from existing switches and other alternative input devices that have fixed form factors [[34]].

Affordability. We chose to use open-source, affordable and widely available computational components (i.e., the Raspberry Pi and RC522 RFID Reader) to implement SenseBox, to make it easier for users to fabricate and modify it themselves in the future. Currently, the cost of building a SenseBox from scratch is under $120. While more sophisticated physical computing platforms, such as Bela [[7]] or Satellite CCRMA [[12]], that are designed for high-quality music playback could possibly provide a better audio performance than the current implementation, we chose to build the system with materials that are more widely available. This approach is in accord with DIY and maker priorities that prioritize platforms that more people can assemble and fabricate themselves over highly specialized and technically complex ones [[15], [17]]. In the future, we plan to make SenseBox's design, including the software, 3D models and instruction on how to assemble the system, available online to let users assemble and fabricate variants of the system themselves.

Accessibility. The features described above all contribute to the overall accessibility of the system, in the sense of lowering barriers to use for its users. The simplicity and customizability of the system make it possible to use it to create audio interfaces adapted to a wide range of adults and children with different motor and cognitive abilities. The non-technical mechanisms to customize it lower technical barriers to its use for therapists and other professionals who might not have prior programming or design experience. Finally, its affordability lowers financial barriers of access and makes it possible for users situated in a range of socio-economic settings to use it. In these ways, we hope that SenseBox exemplifies a new generation of DIY prototyping platforms that make physical computing available for a wide range of applications and accessible to user populations beyond professional technologists and designers.

LIMITATIONS AND FUTURE WORK

In this paper, we focused on the design process of SenseBox without a formal user evaluation of the system. In the future, we plan to evaluate the system with representative users including therapists, special education teachers and children with disabilities. We also currently focused on therapists' perspectives since they are the primary users of the system. However, we recognize the importance of including input from participants with disabilities, as pointed out in previous research [[37]], and plan to do that in the future. Additionally, we plan to refine SenseBox's design further using a participatory design approach in which we ask participants to identify new audio applications that we will then co-design with them.

In terms of technical features, we have so far focused on using a single audio playback module. We plan to explore implementing a network of multiple SenseBox units that can communicate and interact with each other using a Musical Instrument Digital Interface (MIDI) interface [[27]] or taking advantage of Raspberry Pi's Sonic Pi built-in open-source audio programming environment [[36]]. This approach might allow several users to interact with each other using a network of SenseBoxes.

CONCLUSION

DIY prototyping platforms can enable users to create customized audio interfaces in support of music and speech-language therapy. We presented SenseBox, a DIY prototyping platform to enable therapists to design audio interfaces that fit the needs and desires of their clients. SenseBox is implemented using a Raspberry Pi microcomputer, sensors and corresponding electronic components. This project demonstrates that with appropriate design features open-source DIY components can be utilized by users without prior programming or design experience to create accessible interfaces for use in therapeutic contexts. We hope that SenseBox inspires future platforms that combine the computational power of low-cost embedded hardware with usability features that allow non-technical users to create their own therapeutic and expressive applications.

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