MASTER THESIS

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ABSTRACT

This thesis introduces the design and implementation of a musical device, with the aim of creating accessible avenues for music-making that promotes mutual engagement across diverse social groups, offering the possibility for active participatory music making and broadening electronic music aesthetics. Moreover, it seeks to bridge different communities through playful and engaging means, particularly including individuals who face barriers in traditional music-making practices.This Accessible Digital Musical Instrument (ADMI) is conceptualized based on insights derived from discussions and meetings with blind individuals and therapists. The primary objective is to explore the creative potential of the white cane as an interactive medium. The design process involves incorporating feedback and perspectives from these stakeholders to ensure the device's relevance and effectiveness in addressing the unique needs and experiences of users with visual impairments.To realize these objectives, a musical interactive installation has been presented, marking the initial iteration of a prototype for a multi-user experience. The project not only contributes to the inclusive design of musical instruments but also strives to create an environment where individuals from various backgrounds can come together, fostering collaboration, creativity, and engagement in the realm of music.

1. BACKGROUND

1.1 Motivation

This project is a continuation of the research of MultiSensory lab (ME-lab) of Aalborg University that the author was part of during his internship. The initial points of this project were the recent advantages of music technology in the field of ADMIs and the insights from the visit of the author with a small team of researchers who work in ME-lab in the Blindecenter Bredegaard located in Fredensborg municipality.

The visit in the center offered an introductory discussion and about the problems that visually impaired people with multiple disabilities are facing, strategies and goals for each different individual from the therapeutic prism. During the meeting, the group of researchers met the residents of this community in person, and shared some of their work and creations about inclusivity practices, research in multimodal therapies with them. The group encountered the daily lives of the residents and observed the ongoing creative activities within the center.

After the meeting, the author found this experience prosperous, offering some insights and thoughts about the therapeutic practices for triggering their senses, how the therapists tackle the different needs and the disabilities of each resident and how they are facing these problems. Creating an everyday routine to awaken senses through creative multimodal therapies for making the lives of people with multiple disabilities more sustainable in terms of the quality of life is a very complex topic that varies from individual to individual. One of the well-being inequalities that was observed during this visit is the social isolation that the community is facing, and this was observed and reported for different communities of disabled people with varied disabilities [1].

Summarizing the above, the initial design goals of the project were based on the points:

- Inclusion of visually impaired people to modern/electronic musical practices.
- Social inclusion through active music making.
- Bridge the communities of non-visually impaired people and visually impaired people.
- Make the non-visually impaired people more empathetic towards the visually impaired people.
- De-medicalization of creative therapeutic practices.

1.2 Design notes

There is a growing interest within the field of New Interfaces for Musical Expression (NIME) in creating accessible Digital Musical Instruments (DMIs) and promoting the inclusion of individuals with impairments in musical activities [2]. The idea of using music technology for inclusion can be traced back to the creation of the Fender Rhodes electric piano, and with the advancement of technology, it is now possible to customize DMIs to meet the specific needs and abilities of individual users or groups. In fact, some DMIs even have the capability to adjust the interaction for each user in real-time [2].

Designing such instruments could make the music making experience more accessible to impaired people by eliminating physical and intellectual barrier that people are experiencing with traditional musical instruments, although different social and technical barriers are being created.

Physical barriers are easier to identify and therefore easier to tackle, analyze, and create interactions and designs. The intellectual barriers have a tendency to withdraw themselves from the observer, and consequently the design process needs a more dialogical and iterative approach [3] [4].

In this project, we present a first iteration of a prototype of a collaborative ADMI between visually impaired people and sighted people, taking into consideration that each step of the iteration needs to include the disabled people's feedback without having the approach of 'fixing the problems of impaired people' by the prism of non-disabled researchers. Nevertheless, it is important to have an active dialog between users, therapists and designers to explore different affordances of different communities, and overcome the fear of using and testing new electronic musical devices [4] [5].

This paper has the following structure,**State of the Art** examining and reviewing previous works of ADMIs. **The Design** section, where the methods and the criteria of designing the interactions are explained. **The Implementation** section, where the technical aspects of the project are presented. **The Evaluation** section where the assessment process will present and its results. The Discussion section, where the overall conclusions, new ideas, problems about the project are drawn for each previous section separately. And lastly the **Conclusions**, where there is a small outro of this project with

2. RELATED WORK / STATE OF THE ART

Assistive Music Technology (AMT) can be considered as an established field with significant contribution from the music therapy field, although in the Computer Music literature is considered relatively unexplored [2] [6]. Recent literature and discussion about designing musical interactions for disabled people question the usage and the impact in their users. Also, it led to more broad questions in human centered design about the *design savior* complex [7].

In this paper, [4] is presented a middle ground in the dipole of participation-ism and tokenistic forms of participation. The author suggested using a dialogic design approach when it comes to create musical interactions, overcoming the problems of misinterpreting the true needs of the user's because of the designers' idea *of what is like to be*. And also, the dictating approach of designing without outer influences. Simplifying this idea, the designer should be part of the designing cycle and not in the top of the pyramid when a design decision must be taken.

Another crucial discussion and literature suggestion comes from [2], [8], where the author rises a distinction between which theoretical model (Social model or Medical model of Disability) is more inclusive when conducting a design for musical practices. In the medical model, suggests that the disabling barrier lies on the user and therefore put the user in a position that is something wrong within him/her, whether the social model suggests that the dictating affordances of musical interfaces and exclusive attitudes are the disabling factor and therefore invention of new musical devices that will serve the affordances of each specific community or user can be conducted. Within the same conceptual realm, Frid proposed that the terms *assistive* and *adaptive* fall into the Medical model, because they put the stakeholders in the position that they need/seek for help and that the designers adapt the already made technology for specific users/disabilities.

Recent ADMIs focus on specific abilities of particular groups, using a wide range of different technologies and touchless or tangible interactions [3], like eye sensors [9], touch sensors [10], breath sensors, etc.

A very promising point is that there are commercial products released in the form of ADMIs. One of them is the *eye harp*, where an eye sensor detects the movement of the eyes and maps it to various audio parameters inside a computer software. Another product is the *skoog*, which consists of a cube where the user triggers audio events in the 5 surfaces through a touch sensitive sensor. The cube is connected to a phone app and the user has access to different abstractions for musical training and entertainment. Based on the design, it is possible to have one or multi users in one or multiple cubes.

An additional ADMI with a design focused for SEN schools is the *LoopBlocks* [3]. This apparatus is a DIY tangible wooden step sequencer with photoresistors as the sensors for the interaction. By blocking the light with a rounded token, the user unmute the assigned step of the sequence and trigger musical events. It consists of 4 different rows with each of them represents an audio cue, this features allows an interaction between multiple users.

In current studies, there is a shift towards multimodal designs like the installation *Sound Forest* that is presented in [11]. The installation consists of laser-emitting interactive strings and vibro-tactical platforms and speakers. The interaction was placed in a room of the Swedish Museum of Performing Arts in Stockholm, and it was tested from individuals with different abilities and ages. The musical interaction was coming from the excitation of the virtual strings by triggering audio events/samples in an already made composition, this technique called *adaptive music* and is being used widely in video games. The users were receiving multimodal feedback in the form of vibrations, sound and visuals. The haptic feedback was a whole body experience with the vibration being produce in the floor by 2 loudspeakers.

3. DESIGN

As it was reported above, the author based his design in the observations and the notes from the discussions from therapists and residents of the blind center. It was widely reported from the residents the use of the white cane in the everyday life. Also, inside the center they do lots of different creative activities (e.g. gardening, knitting, practicing musical instruments etc.) indoor and outdoor. Although the faculties seem closed to the public and the resident may experience social isolation in some degree. That might happen because some of the residents are very sensitive to be irritated by new stimuli, and their routine may be disrupted. However, other residents were very keen to socialize and interact with us (the visitors).

Based on these observations and some designing criteria for ADMIs the author decided to create a musical interaction with the white cane that would include music mutual engagement for visually impaired and sighted people and would introduce simple audio synthesis to make the user more familiar with electronic instruments and the electronic music making.

For creating an DMI, a significant consideration is the causal relationship between action and sonic outcome. In designing an ADMI this relationship needs to occur automatically, especially when the users don't have any experiences performing electronic instruments. To reduce the cognitive load of interacting with an ADMI and create an understood causal relationship experience, some designing conditions need to fulfil:

- Direct mapping between input and output.
- Multimodal feedback.
- Comprehensive and known affordances.

In these study, [12] [6] the authors present a set of principles and considerations for the development of musical instruments for people with disabilities. Extending these principles, Frid made a collection of properties for designing and evaluating an ADMI. These 9 properties are *Expressiveness*, *Playability*, *Longevity*, *Customizability*, *Pleasure*, *Sonic quality*, *Robustness*, *Multimodality* and *Causality* [8]. Other aspects of this design can be considered the following:

- Educational possibilities.
- Plug-and-play.
- Adopting the musical preferences of the users.
- Inspiring external design.
- Low cost.

3.1 Initial Idea

The initial idea behind our design approach was the exploration of music interactions with the white cane. This decision stemmed from the recognition that, while the white cane is an everyday and indispensable tool for individuals with visual impairments, it remains an unfamiliar object to the majority of the population.

It's crucial to note that various types of canes exist, each serving distinct purposes, with navigation and obstacle avoidance being their overarching goals. Despite its fundamental role, the white cane possesses unique affordances that are not widely understood by the public. This lack of awareness is compounded by the medicalization of the white cane, which has limited its perception as anything beyond a functional assistive device.

Furthermore, to enhance the interaction with the cane, the design incorporates designated spaces. The rationale behind this decision is to introduce a system of distinctive tiles or steps. The primary objective is to cultivate an interactive experience, allowing users with canes to navigate through the environment with the aid of auditory feedback.

This approach aims to establish a tactile and auditory landscape, where each tile or step offers a unique sensory cue. The deliberate use of varied surfaces is intended to create a specific sound when engaged with a cane. This auditory feedback serves as a guiding mechanism, empowering users to discern and follow a path seamlessly.

In essence, this design seeks to provide to individuals with visual impairments a mean of creative use of the white cane and familiarize sighted people with this medium. The integration of auditory cues through the cane's detection of unique tiles or steps aims to create an immersive, multiuser environment. This design enhances navigation for the visually impaired while fostering joyful engagement, targeting to bridge the gap between blind and sighted communities. we believe The shared experience promotes mutual understanding and empathy, empowering users and encouraging open conversations about diverse perspectives.

3.2 Current Iteration

The author opted for an iterative design process to assess the usability of the proposed design and address any usability issues or hardware-related challenges. The primary obstacle encountered in realizing the initial idea was the technological limitation associated with achieving a wide detection range for the tiles. While not insurmountable, this challenge required a thorough investigation, scheduled for after the usability evaluation of the interaction.

To address this technological barrier, the decision was made to scale down the prototype. This involved designing a smaller surface within an acceptable range for the tile to be effectively detected by the sensor. The current prototype, outlined in this report, features a custom cane equipped with haptic and auditory feedback, a tactile surface, and a musical application developed for iOS.

It's noteworthy that during the initial usability testing of the prototype, the focus was exclusively on individuals without visual impairments. This approach was chosen to evaluate the interaction's usability before expanding to users with visual impairments. This decision allows for a more controlled assessment of the basic functionality and user experience, providing valuable insights for further refinement before accommodating the specific needs of visually impaired users.

3.3 Tangible Interaction

The fundamental musical interaction within this project involves three key components: a custom cane, a tangible surface, and a musical application specifically designed for iOS. The core concept involves configuring basic sonic events based on the placement of the cane on desired steps or tiles. Additionally, the interactive experience extends to a second user, who can manipulate parameters and select the path to be navigated through the use of the iPad's touchscreen.

The custom cane is equipped with sensory technology that translates its placement on the tangible surface into unique sonic events. The tangible surface, designed with tactility, serves as a canvas for the cane's movement, creating a dynamic and responsive environment.

The iOS application complements this setup by allowing a second user (in this case sighted) to actively participate in the experience. Through the iPad's touchscreen interface, this user can manipulate various parameters, influencing the auditory landscape generated by the cane's movements. This collaborative and interactive aspect adds a layer of shared creativity and engagement to the overall experience.

3.4 Sound Synthesis

To facilitate sound synthesis in this project, we implemented a straightforward subtractive synthesizer. In this setup, users are assigned control over various parameters. The initial user selects a desired path, and the second user engages in the experience by activating MIDI notes corresponding to each step on the chosen route. Subsequently, the user controlling the iOS app gains the ability to modify the timbre and shape the sonic outcome.

The subtractive synthesizer serves as the foundational tool for creating the auditory elements of this interactive experience. Users can dynamically influence the generated sounds by adjusting parameters such as filters, oscillators, and envelopes. This approach not only adds a layer of musicality to the navigation process but also allows for a personalized and expressive sonic landscape and introduce the users to a basic sound synthesis.

In practice, the first user's selection of a path determines the sequence of MIDI notes triggered by the custom cane on the tangible surface. These notes are then interpreted by the synthesizer, creating a real-time auditory representation of the chosen path. The second user, through the iOS app, has the creative agency to alter the sonic characteristics, introducing a collaborative and evolving dimension to the auditory environment.

3.5 Feedback design

Multimodal feedback is important for the design of DMIs in general [13]. Acoustic instruments include a variety of multisensory instant feedback (haptic/visual/sonic). Potentially, multisensory feedback enhances the musical interaction and the sensation of controlling the sonic outcome. Recent studies suggest that vibrations play a significant role in music perception and improve the music experience [14].

The audio output consists of a single channel, which plays synthesized notes triggered by user actions. Haptic feedback is provided through a vibro-tactile buzz in the cane handle, activated when users make incorrect steps on the surface. The surface, designed for tactile feedback, responds to both cane contact and direct touch. This streamlined system offers a cohesive auditory and haptic experience, guiding users through navigation with a combination of synthesized sounds and responsive vibrations.

3.6 Mutual Engagement

Building upon the insights from [15], we incorporated design features to foster mutual engagement in music creation. Our approach was guided by the following design principles:

- Mutual awareness of action.
- Shared and consistent representations.
- Mutual modifiability.

The authors suspected that implementing all the design features that they proposed might have negative impact in the mutual engagement due to cognitive overload.

These three points were implemented by dividing the tasks and the interaction of the system. For the first point, we configured it by triggering new audio events and on these events the other user is capable of manipulate them having this loop of an initial action (trigger a note) and the contribution from the second user to manipulate some parameters of this note (length, timbre etc.) To follow the second point, we mapped specific parameters of the shared experience to each user without change them over time, and therefore the user could understand intuitively their individual contributions to the sonic outcome. And lastly the for the third point, we assigned to each user the parameters of the sound synthesis to be able to modify their mutual output.

Recognizing the potential cognitive overload associated with implementing all proposed design features, we strategically divided tasks and interactions within the system [15]. For the first principle, mutual awareness of action, we achieved this by configuring the system to trigger audio events. Subsequently, the other user gains the capability to sculpt these events, allowing for a dynamic and collaborative musical experience.

To address the second principle, shared and consistent representations, specific parameters of the shared experience were mapped to each user, remaining unchanged over time. This approach ensures that users can intuitively comprehend their individual contributions to the sonic outcome throughout the interaction.

Lastly, for the third principle, mutual modifiability, each user was assigned parameters of the sound synthesis to enable the modification of their shared sonic output. This division of responsibilities facilitates a collaborative and dynamic environment where both users actively contribute to shaping the musical experience.

In summary, our implementation carefully balances these design principles, optimizing mutual engagement while mitigating potential cognitive overload. The division of tasks and parameter assignments contributes to a user-friendly experience, try to create a dialog, and initialize trust, empathy and empowerment between the users.

3.7 Hardware and Software Design

The ADMI was initially conceptualized as a standalone wireless musical instrument utilizing Bluetooth capabilities. However, the Radio-Frequency Identification (RFID) reader that was used for tile/step detection can also function as a controller for external musical equipment. In an effort to establish an open framework for this design, various protocols can be utilized to control software applications (via OSC and MIDI), digital synthesizers and effects, as well as synthesizers (via CV). It's important to note that due to the wireless nature of the device, CV signals may not be the most optimized option.

The conversion of the unique RFID tags to musical information (in this case MIDI) gives the opportunity to explore various different mappings of this action (detection of the tag) and translate this movement to meaningful and creative metaphors, unlocking a spectrum of possibilities for expressing musical interactions.

For receiving and playback of both the audio and vibrotactile output, a decision was made to integrate a microprocessor development board with Bluetooth capabilities directly into the cane. This choice not only streamlines the communication between the cane and external devices but also enhances the overall flexibility and accessibility of the system. The embedded microprocessor serves as the central hub for processing and receiving audio, facilitating seamless connectivity for a more immersive and responsive user experience.

For the software design aspect of this ADMI's first phase, we employed an open framework for prototyping mobile applications through the visual programming language *Pure Data* [16]. Specifically, we utilized *MobMuPlat*, a mobile music platform that facilitates the creation of prototype user interfaces and audio engines. The following section will provide an in-depth overview of this framework, accompanied by a presentation of the current state of development for the software prototype intended for evaluation.

4. IMPLEMENTATION

In this section, the architecture and implementation of the customized ADMI is presented. In this iteration, a bespoke cane was crafted using a laser cutter, featuring embedded microprocessors to transmit spatial data from the ground—specifically, an acrylic surface—to the iPad. Simultaneously, it receives the audio and vibro-tactile feedback generated by the interaction of users with the iPad application and the cane. The elements of this interaction are visually represented in the accompanying Figure 1.

The first user engages with the iPad application by selecting a specific path (see number 1 in the Figure 1), while the second user tries to trace and activate the desired path in the acrylic surface (see number 2 in the Figure 1) by triggering MIDI notes using the cane (see number 3 and 4 in the Figure 1). Through the activation of these notes, the first user gains the ability to interact with the music application, modifying parameters of the sound synthesis. Also, the second user controls a parameter by adjusting the timing that triggers the next note.

This dynamic interaction creates a symbiotic relationship between the users, wherein the exploration of paths on the iPad becomes a collaborative music making experience. The bespoke cane, with its embedded technology, acts as a conduit, translating the users' movements into an auditory and haptic experience.

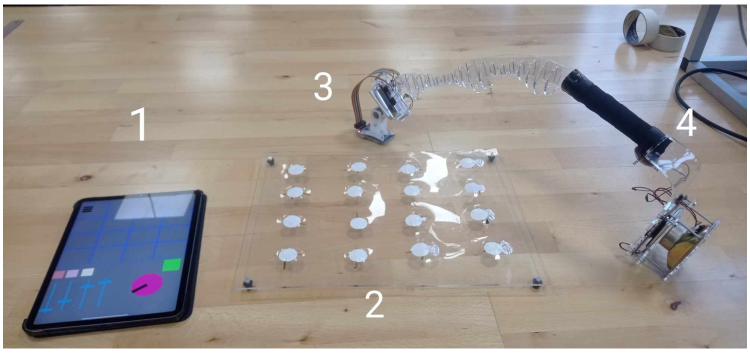

Figure 1. The finished first iteration of the prototype.

4.1 Hardware Implementation

4.1.1 Tip of the Cane

The central interactive element of the ADMI is the RFID reader module placed in the tip of the cane (as it is illustrated in Figure 1 number 3), and is capable of detecting the RFID ISO 14443 (Mirafe) tags where are located in the acrylic surface. The module is designed around the MFCR-522 chipset and operates at 13,56 MHz. In the module is integrated a PCB antenna which generates a high frequency electromagnetic field. The module utilizes the various different protocols for data transmission like SPI, I2C AND UART. In our case, we use the serial SPI configuration. Then the RFID module is connected with the ESP32 Thing Plus development microcontroller. This board was selected because of its wireless connectivity features. The board is designed around ESP32-WROOM, a generic Wi-Fi, Bluetooth and BLE (Bluetooth Low Energy) MCU module. The module carries a Xtensa® dual-core 32-bit LX6 microprocessor with a clock frequency up to 240 MHz, with 16 MB of flash storage and 520kB internal SRAM. The operating range is from 3.0 to 3.6V, and it provides 21 GPIOs. With As we mentioned above the RFID module transfer the data through serial SPI interface.

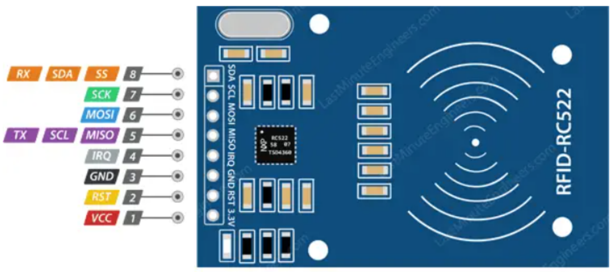

Figure 2. The RC522 module

4.1.2 SPI connectivity

The Serial Peripheral Interface (SPI) protocol is a synchronous serial communication standard commonly used

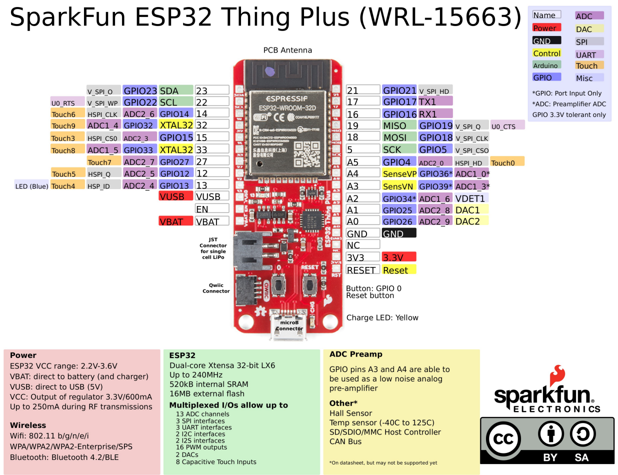

Figure 3. The graphical datasheet with the GPIOs of the ESP32 Thing Plus

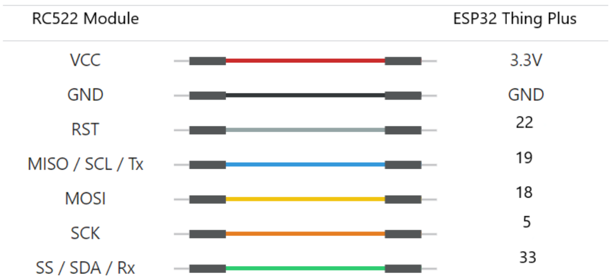

Figure 4. The hardware connection to achieve SPI connectivity between the RC522 module and the ESP32 Thing Plus microcontroller.

to facilitate data exchange between a master device, typically a microcontroller, and one or more peripheral devices. SPI operates on a master-slave paradigm, where the master device initiates communication by generating clock pulses. Data is transmitted simultaneously in both directions, with separate lines for data (MOSI - Master Out Slave In, MISO - Master In Slave Out) and a shared clock line (CLK). Additionally, there are control lines such as Chip Select (CS) to enable communication with a specific slave device. In this case a 4-wire SPI interface is implemented with MOSI, MISO, CS and CLK. To actually achieve the connectivity, we needed to find the header file where the manufacturer configures the pins IO of the bespoken microcontroller.

4.1.3 Wireless Audio and Vibro-tactile feedback

To establish a solid and wireless playback sound produced by the iPad application, we have chosen the ESP32-Audio-kit development board. This powerful and inexpensive audio board allows receiving and transmitting high fidelity Bluetooth audio is based on the ESP32 A1S module. It consists of a Xtensa® 32-bit LX6 dual-core processor, 520KB internal SRAM and 8MB RAM, including support of different codec audio chips (ES8388, ES8311, AC101) which need to be configured usually via I2C. In the used board, the AC101 codec is used that can provides a sampling rate up to 48kHz. The codec is built with a stereo DAC and a stereo ADC and the development board includes a 3.5mm headphone jack, 3.5mm line-in jack, a pair of 2 pin headers for left/right speakers (up to 4ohm/3W output), and a couple of built-in microphones via a built-in audio mixer. To configure the right codec of the board to playback sound through it, we needed to edit the header file that set up the audio settings of the board and define the specific audio codec among 9 different selections. In the Left Speaker output of the board a 4ohm 3W speaker was connected to provide the audio output and in the Right Speaker output an audio transducer was connected to provide the haptic feedback.

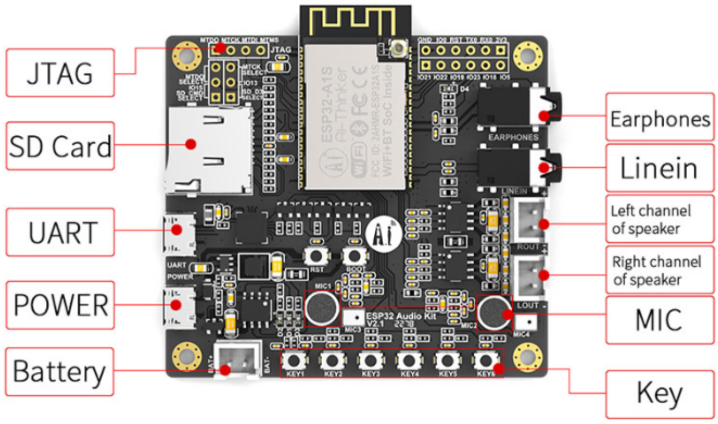

Figure 5. The ESP32-Audio-kit development board.

4.2 Software Implementation

4.2.1 UID to MIDI

To create a wireless communication and convert the UIDs to MIDI information, a custom code in the *Arduino IDE* was created, which was flashed in the ESP32 Thing Plus board. Three main libraries were used to create that code, the *MIDI* library, the *BLE* library and the *MFRC522* library.

The main architecture of the BLE is projected in the diagram 6, which clarifies that a peripheral device can be connected to only one central device (e.g., a mobile phone) at a time. However, the central device can concurrently connect to multiple peripherals. For data exchange between two peripherals, a custom mailbox system is necessary, routing all messages through the central device. The peripheral (ESP32 Thing Plus) is known as the GATT (Generic Attribute Profile) Server, which holds the ATT (Attribute Protocol) lookup data (store Services, Characteristics and related data in a simple lookup table using 16-bit IDs) and service and characteristic definitions, and the GATT Client (the phone/tablet), which sends requests to this server. GATT transactions in BLE are based on high-level, nested objects called Profiles, Services and Characteristics, which can be seen in the illustration 7. To make a MIDI-BLE device, we need to specify the MIDI service and the MIDI characteristic.

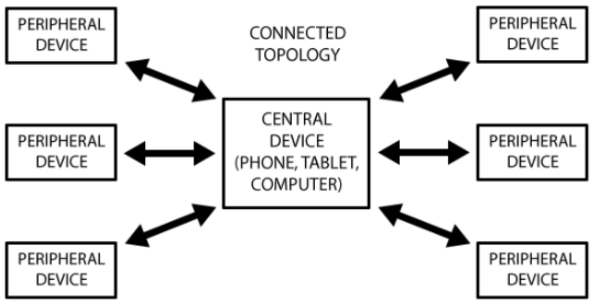

Figure 6. BLE device topology

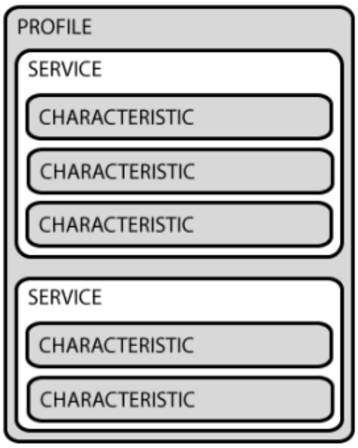

Figure 7. GATT transactions

After this, we enable the RFID reader to scan and detect the UID tags. Each UID has 4-byte size of information in the form of hexadecimal, which is converted into MIDI note on information. In more detail, if statements were created to translate each UID to a different MIDI note, inside these statements MIDI messages for note-on and note off are established with an assigned MIDI note. The structure of a MIDI message is the *Status byte* which specifies the type of the MIDI message (note-on, note off, pitch bend etc.) and the MIDI channel, the *First Data byte* which contains the data associated with the MIDI message and the *Second Data byte* which varies depending on the *First Data byte*, although in the case of note-on/note-off information represents the velocity of the notes.

4.2.2 Audio Bluetooth

For transmiting the audio via Bluetooth communication, the Arduino library Audio-tools [17] was used, created by Phil Schatzmann. It is a generic C++ framework for audio DSP for the *Audio-kit* development board. It utilizes all the possibilities of the board, having classes for every aspect of DSP (generators, filters, decoders/encoders, effects etc.). Making possible to make a custom embedded program easily by gluing audio processing components and libraries. Also provides very good documentation and examples for the different functionalities of the library. For this project, the already made example *basic-a2dp-audiokit.ino* was used. The code contains just some

```
if (content.substring(1) == "04 40 B4 22 3C 74 81"){
midiPacket[2] = 0x90; // note up, channel 0
  midiPacket[3] = 0x3C; // middle-C
  midiPacket[4] = 80;    // velocity
  pCharacteristic.setValue(midiPacket, 5); // packet, length in bytes)
  pCharacteristic.notify();

  delay(500);


 midiPacket[2] = 0x80; // note down, channel 0
  midiPacket[3] = 0x3C; // middle-C
  midiPacket[4] = 0;  // velocity
  pCharacteristic.setValue(midiPacket, 5); // packet, length in bytes
  pCharacteristic.notify();
```

Figure 8. A snippet of the code that converts the UID to MIDI. If a UID is detected then note-on for the note C3 with a velocity of 80, wait for half a second and then note-off in the same note with 0 velocity.

few lines where the audio Bluetooth transmission is being processed. After the inclusion of necessary header files and the global objects been declared, there is a callback function that read the incoming audio streams and writes them to the buffer. Then, in the `setup()` function It initializes the serial communication, sets up the `AudioLogger`, configures the board's object for output, and registers the audio read callback function with the Bluetooth object. And lastly, in the `loop ()` function, calls a method that contains all the dedicated functions or callbacks for processing the real-time audio. In that way, a smooth Bluetooth audio transmission is realized.

4.2.3 MobMuPlat

MobMuPlat [18] is a versatile platform, utilizing libpd, designed for running Pure Data (Pd) patches on mobile devices without the need for text coding. It not only executes Pd patches but also manages user interfaces, networking, interactions with mobile hardware and services (such as sensors and GPS), and communication with external devices like MIDI and HID devices. The graphical user interface (GUI) can be customized with additional features and widgets optimized for mobile use, such as swipable pages and multi-touch capabilities. MobMuPlat is a comprehensive software suite comprising an iOS app, an Android app, an OSX editor application, and a cross-platform (Java Swing) editor application, allowing for development and distribution on various operating systems. It supports multiple networking protocols, emphasizing robust group communication and aligning with its original focus on ensemble performance.

To facilitate and test the custom abstractions before deploying them on iOS or Android devices, the *MobMuPlatEditor* is a necessary tool. This computer software allows the design of the graphical user interface (GUI) for the abstraction, and it seamlessly links the GUI to the desired *Pure Data* patch. The process involves opening the *PdWrapper.pd* patch, which enables thorough testing of the GUI's behavior with the specified parameters controlling the audio engine within the Pure Data environment. This comprehensive tool ensures a streamlined and efficient development process, offering a preview of the abstraction's performance and interaction before integration into the mobile application.

For the creation of the GUI, a 4x4 grid with on-off switches was created in the upper side of the screen. The grid replicates the tiles/steps in the acrylic surface and by activate them the specific note is activated and will be reproduced when it will be triggered. In the bottom side, four faders 3 additional buttons and one knob were placed to control the parameters of the abstractive synthesizer.

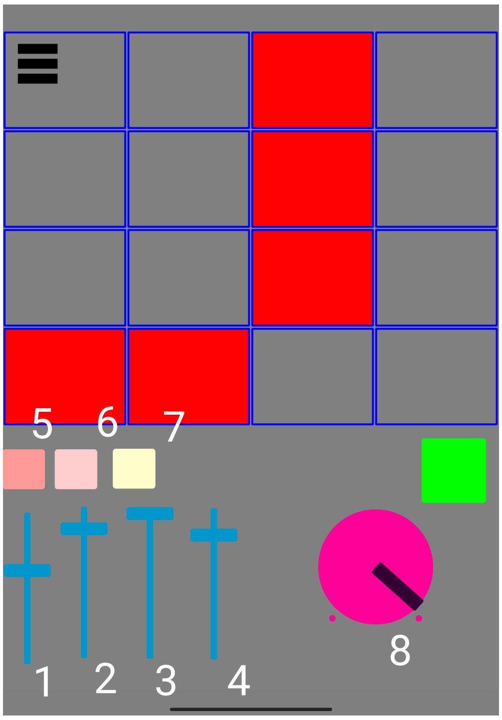

Figure 9. The GUI of the musical application. In the upper part the Grid is placed for choosing the path. And in the bottom part there are the parameters of the subtractive synthesis. 1-4 are the ADSR parameters, 5-7 are the wave form selection and 8 is the filter cut-off.

Inside the *Pure Data* patch, the information from the custom GUI is being received in the form of OSC messages. The states of each particular step in the grid are stored in a buffer and then are unpacked to match a specific MIDI note. Then by inserting the MIDI notes into the patch are being separated using an if statement. The logic of the if statement is that if a specified midi note and a specified point of the grid are activated, then this note is triggering the abstractive synthesizer. In the same spirit, the vibro-tactile feedback is produced, again if statements are used to filter the MIDI information and trigger the oscillator that is mapped to the haptic feedback. The statement was build around the idea that when a midi note is trigger from the RFID reader, but the assigned point on the grid is deactivated, then the fixed time envelope of the oscillator is triggered. The oscillator is a sine wave using the object `[osc ~]` with a fixed frequency of 220Hz, which is around the peak frequency of the tactile sensitivity [19]. The audio engine consists of a custom subtractive synthesizer. Then main elements are three oscillators with different waveforms based on the objects `[osc ~]` for the sine wave and square wave and `[phasor ~]` for the triangle. The `[phasor ~]` is indeed commonly used as a phase ramp generator, often to create a triangle-like waveform. It is used traditionally from *Pure Data* community as the initial ingredient for wave shaping techniques, alongside with the expression statement `[expr ~]`. We create a triangle wave by checking to see if the output of the `[phasor ~]` object is greater than 0.5, then if it is the expression statement `[expr ~]` outputs an inverting waveform otherwise it stays as it is. For the square wave, we used the `[osc ~]` object combined with the `[expr ~]` object, the output of it was checking when the value was greater than a fixed value (in this case 0.6), then if it is the statement outputs 1, otherwise -1. By making the number inside the statement variable, we could create PWM (Pulse Width Modulation). The pitch of the oscillators is controlled by the MIDI notes that have been passed from the if statement and are converted to frequencies. Then these oscillators are interconnected with a filter, and then an amplification stage is being added. In this stage, an ADSR envelope is connected and also an LFO (Low Frequency Oscillator) has been added in the final stage of the amplification to create amplitude modulation in the synthesis.

The output of the audio synthesis is assigned to the left inlet (channel) of the object `[dac ~]` and the output of the oscillator for the haptics is assigned to the right inlet.

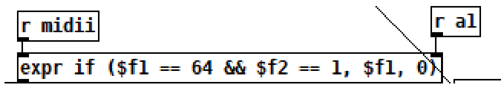

Figure 10. Using the object `[expr if]` we created an if statement. In the left inlet we received the MIDI note and in the right inlet the state of a specified point of the grid. If the note is detected and the state is 1 then the MIDI note is passing through it.

4.3 Mappings

Among the reasons for the creation of new instruments are the real-time control of new sound-worlds, and the control of existing timbres through alternative interfaces to enable individuals in the spontaneous creation of music [20]. The term *mapping* is used widely to indicate the mathematical process of relating the elements of one data set onto another. In computer music, mapping is often used in relation to algorithmic composition, where a parameter with a particular set of values is scaled or transformed so that it can be used to control another parameter. The main question to be solved was related to the actual choice of which mapping strategy to implement. The ultimate goal in designing new Digital Musical Instruments (DMI) is to be able to obtain similar levels of control subtlety as those available in acoustic instruments, but at the same time extrapolating the capabilities of existing instruments [21]. Considering mapping as part of an instrument, two main directions could be deduced from the analysis of the existing literature:

- The use of generative mechanisms, such as neural networks.

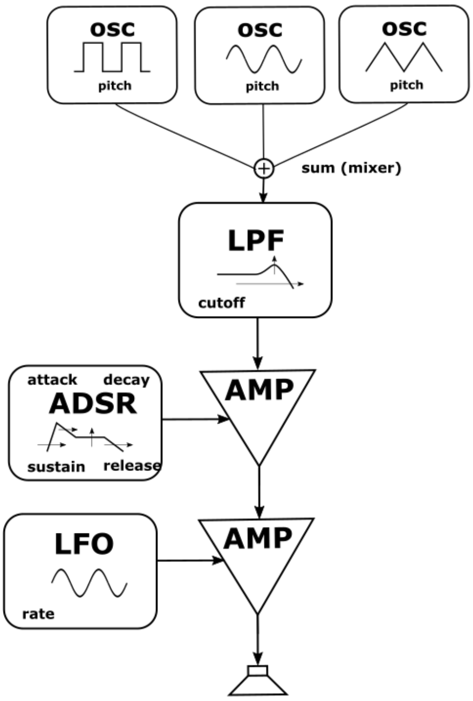

Figure 11. A block diagram of the audio engine that implemented in *Pure Data*

- The use of explicitly defined mapping strategies.

Our decision was to use explicit mapping strategies, presenting the advantage of keeping the designer in control of the implementation of each of the instrument's component parts, and therefore providing an understanding of the effectiveness of mapping choices in each context. Also, defined mappings are one of the most important aspects when it comes to design an ADMI [3] [12] to reduce the cognitive load of the user. A last key component for choosing explicit mapping strategies is the design principles for mutual engagement in music making that were presented is the in the Section **DESIGN**, followed by the literature [15]. We believe that for achieving shared and consistent representations and mutual awareness of action, the explicit mappings were the best choice.

4.3.1 Explicit mapping strategies

The available literature generally considers mapping of performer actions to sound synthesis parameters as a *few-to-many relationship*. Considering two general sets of parameters, three intuitive strategies relating the parameters of one set to the other can be devised as [22]:

- *one-to-one*, where one synthesis parameter is driven by one performance parameter,
- *one-to-many*, where one performance parameter may influence several synthesis parameters at the same time, and
- *many-to-one*, where one synthesis parameter is driven by two or more performance parameters.

Concerning explicit mappings between two sets of parameters, many ways of abstraction of the performance parameters have been proposed, from perceptual parameters to focusing on continuous parameter changes represented by gestures produced by the user [21]

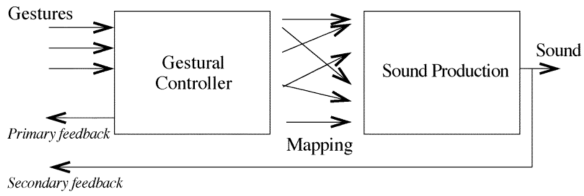

Figure 12. Conceptualization of a DMI from [21]

4.3.2 Two and Three-layer mapping

In designing an explicit mapping strategy for our system, we decided to adopt a two and three-layer mapping model. In this model, the first layer is interface-specific, since it converts the incoming GUI's information into a set of chosen (intermediate or abstract) parameters of the sound synthesis that could be perceptually relevant or derived from other forms of interaction, like a gesture. Some of them (two) are mapped into a second layer onto the specific controls needed for a particular synthesis engine. The advantages of this model are that the first mapping layer is a function of the given input device and the chosen abstract parameters, while the synthesis engine could be changed by addressing the second layer. We choose mostly to have two-layer mappings to making a link between gesture and sonic output and make the user more familiar with the subtractive synthesis. Although, the grid for choosing the path and the difference in time that the RFID detects and activates the MIDI notes are considered three-layer mappings.

Attack	Blue fader 1 in the GUI
Decay	Blue fader 2 in the GUI
Sustain	Blue fader 3 in the GUI
Release	Blue fader 4 in the GUI
Sine wave	Button 5 in the GUI
Triangle wave	Button 6 in the GUI
Square wave	Button 7 in the GUI
Filter cut-off	Knob 8 in the GUI
MIDI note state (mute/unmute)	GUI Grid

Table 1. The two-layers mappings. All the parameters of the subtractive synthesizer mapped to the GUI elements (one-to-one mapping) (see Figure9for the number references).

The selection of the mappings between the users was made upon the idea of with what are interacting, number of the parameters of the synthesis and the mutual engagement. The user with the cane was controlling the :

- Trigger the event

MIDI activation (Pitch)	acrylic surface
Vibrato Rate (LFO time)	Time difference of activation between current and previous note

Table 2. The three-layers mappings. All the parameters of the subtractive synthesizer that mapped to the Grid and the cane.

- Pitch
- Vibrato Rate

And the user with the iPad was controlling the :

- Midi Note state
- ADSR
- Different wave forms
- Filter cut-off

The third layer mappings hold the essence of our interaction — influencing the path formation, the cane interaction, and the tracing of the path. We've deliberately kept these features modular, adding an element of intrigue and mystery to captivate our users. The GUI grid and acrylic surface serve as the key elements, designed to effortlessly carry MIDI information. This format flexibility allows integration with various sound engines without requiring adjustments. The mapping of time difference to vibrato rate transforms the cane's identity from a navigation tool into a source of musical expression. This innovative approach not only enhances user experience but actively challenges and reshapes perceptions, disappearing the stigma associated with traditional uses of a cane.

4.4 Fabrication

Because of the decision to test only pairs with sighted people, the usage of a normal white cane was unpurposed, and a custom cane was designed. Also, enclosures for the sensor, the microcontrollers and the speaker were fabricated. For designing all of these components, the software Illustrator was used. For most of the components, were taken measurements of the exact dimensions of the hardware and the screw holes that were embedded in the PCBs. The material that was used for building the prototype was transparent acrylic in 50x50 cm sheets of 3mm width. This material was because is sturdy and esthetical pleasant, also the decision about transparent was taken for the possible creation of semantics about blindness to the sighted people. After the designing all the parts in *Illustrator*, we cut the acrylic sheets with an infrared laser cutter. Also, the acrylic was bent by applying heat very carefully with a heat gun. For the acrylic tactile surface, each spot of the passive tag stickers (16 in total) was bent by using heat to create this tactility. For the handle, a wooden piece was used and adjusted to have connection with the two acrylic parts-the speaker and the cane- and was wrapped with handle bar tape for bikes.

5. EVALUATION

For the experiment, 22 people in 11 pairs (with the minimum age to be 23 the maximum 52 and the mean age 28, 10 males, 9 females and 3 other), were recruited on a voluntary basis. The participants were presented with the goal of the experiment and a written consent was obtained prior to each participation. The experiment was conducted at Aalborg University (campus of Copenhagen), in the Augmented Performance Lab.

5.1 Experiment

The experiment was carried out in pairs of two and constituted of three phases. All the participant were sighted without significant visual impairment (we had two participants with major degree of myopia). The first phase consisted of a short introduction to the system and what is required from the user. They were given an overall explanation of the aim of the ADMI, the parts that are included in the interaction, the rules and the tasks that were asked to complete. After that, any remaining questions from the participants were answered, and they were encouraged to explore the system to feel more familiar before the beginning of the main phase.

For the second phase, they were picking the initial roles by themselves and the user with the cane was asked to wear a mask to make the experience more realistic. Then, the second user started to make a simple path with 4 or 5 blocks selected. During the main phase of this part, the user with the iPad was allowed to give instruction for navigation of his/her partner and change parameters of the synthesis. After the completion of the task, they asked to change roles and try to interact with the medium that they hadn't had.

In the end, they were asked to fill a questionnaire and assess the interaction, their engagement with their partners and the possible social impact. The questionnaire included 22 questions, and it was divided into two parts. The first part was based on the System Usability Scale (SUS) [23] and was consisted of 12 questions and a Likert 7-point scale system offering 7 different answer options (with a neutral midpoint) related to an agreement or disagreement that would be distinct enough for the respondents, without throwing them into confusion. The second part, was consisted of 10 questions with a Likert 5-point scale system offering 5 different answer options similar to the previous questionnaire. 5 of the questions were evaluating the mutual engagement based on the insight of this research [24] and the rest 5 were assessing the social impact - empathy that may be created. After the questionnaire, the participants gave an oral feedback about their experience, thoughts and ideas about the further development.

The whole experiment lasted 40 to 50 minutes per a pair of participants

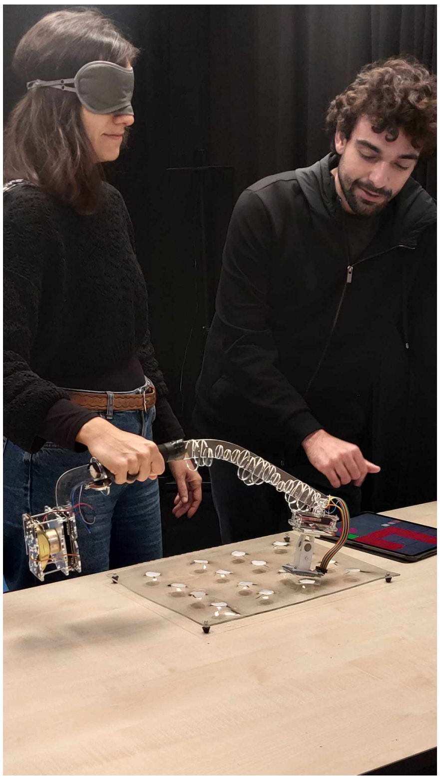

Figure 13. Two participants try the interaction.

5.2 Data Analysis

As a starting to evaluate the usability of the system and create some first insights, we created a score based on the SUS for the first part of the questionnaire. To make it more reliable, 7 answers had positive outcome and 5 negative and for producing the score we alternate the negative Likert scale into a positive one. Above, the calculation of the score is explained.

$$rawSUS = n * (p_n - 1) + w * (7 - n_w) \quad (1)$$

With *n* to be the number of positive questions, *p* to be each score of the positive questions and *w* the number of negative questions, *n* the score of each negative questions. After we calculated the *rawSUS* for each participant, we needed to calculate the mean value, and we created a multiplier to reach the scale of 100.

$$SUS = 1,389 * \frac{rawSUS}{P} \quad (2)$$

The overall score of SUS was 71,74 in the scale of 100 percentiles, and it is graded as **GOOD** in the score table of SUS. Next, some charts and bar diagrams will present to analyze some insights from the answers of the participants. In this questionnaire, a 7-point Likert scale was used.

- In the statement, I would like to use it again. 90.9% of the users had a positive answer (see the Figure 14
- In the statement, I found the overall experience pleasant. 86.4% of the participants stated a positive answer, with 2 of them(9.1%) to have a neutral response.(see the Figure 15
- In the statement, the interaction was too complex for me, 77.3% of the participants responded negatively, with 2 of them have a neutral response.(see the Figure 16)
- In the statement, I perceived both the interactions with the stick and the app unresponsive and without coherence. The participants stated a negative response in a percentage of 81.8%, with 2 of them to have a neutral response.
- In the statements, I prefer the interaction with the cane and I prefer the interaction with the musical application. the participants, had a positive response of 86.4% for preferring with the cane and 54.5% had a negative response for preferring the musical application with 27.3% to have a neutral response.(see the Figure 18)
- Lastly, in the statements, I perceived both the interactions with the stick and the app unresponsive and without coherence, and the interaction was too complex for me, 81.8% responded negatively about the incoherence of the system with 2 individuals to be neutral and 77.3% were negative towards the complexity with again two to be neutral.(see the Figure 19)

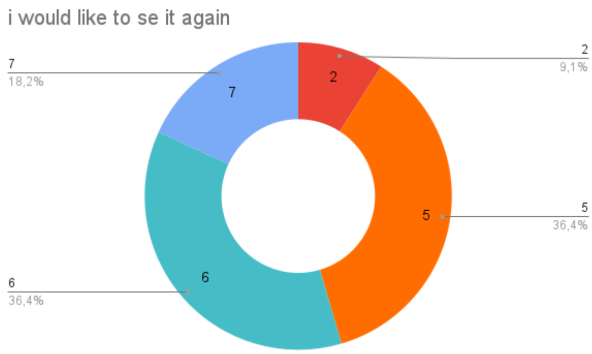

Figure 14. Answers of the question I would like to use it again.

For the mutual engagement and the social impact part of the questionnaire, the quality of the responses was able to give various insights. The bar charts will be presented with the questions of the left vertical axis, and with different color annotation will be presented the Likert 5-points scale.

- Overall, the scores are indicative of a well-defined purpose for the system, a clarity that emanates not only from the explicit description provided but, more significantly, from the seamless interaction observed among the participants. The project's objectives were not only effectively conveyed in its documentation

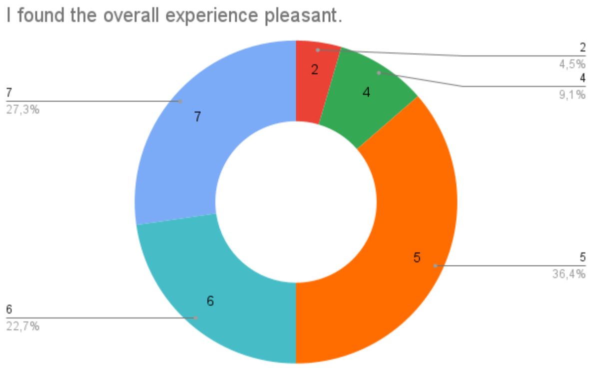

Figure 15. Responses of the statement I found the overall experience pleasant.

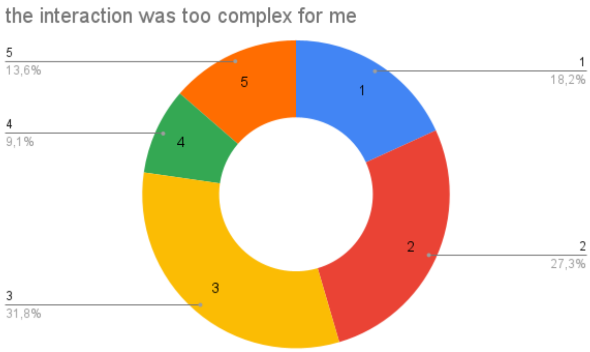

Figure 16. Responses of the statement the interaction was too complex for me

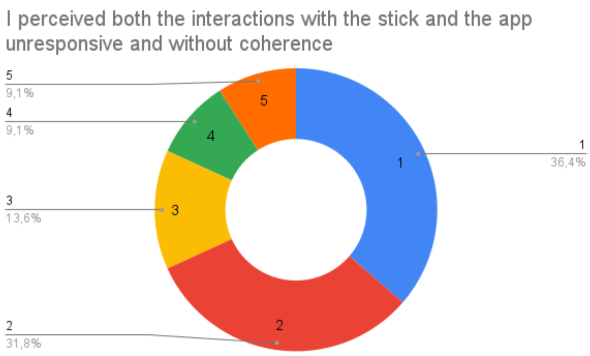

Figure 17. Responses to the statement, I perceived both the interactions with the stick and the app unresponsive and without coherence

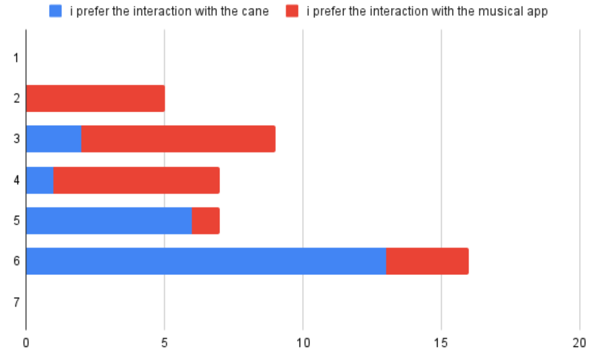

Figure 18. Responses to the statement, I prefer the interaction with the cane, and I prefer the interaction with the musical application

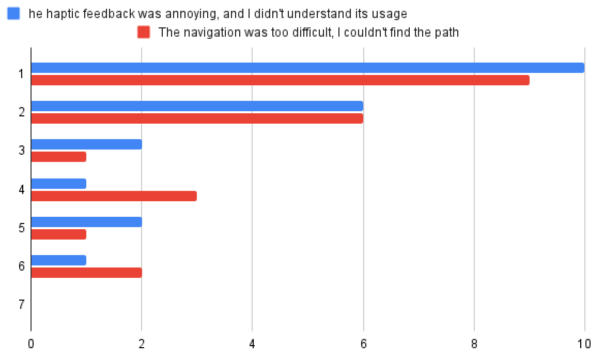

Figure 19. the responses to the statement, I perceived both the interactions with the stick and the app unresponsive and without coherence, and the interaction was too complex for me.

but were vividly demonstrated through the engaged and purposeful participation of those involved. This alignment between the stated goals and the participants' interactive experiences underscores a robust and coherent project design, contributing to the overall success and positive evaluation of the system. The most promising point that 21 from 22 participants responded positive in trying it alongside with a visually impaired person and just 1 responded neutrally. Also, it seems that most of the participants didn't feel discomfort or overwhelmed using it because of the stigma, with 14 from 22 participants to state a negative response 1 participant to be neutral and 6 to be positive to the discomfort. (see the Figure 20)

- The participants seemed to be highly engaged with their partners through the interaction. In the statement, I enjoyed playing together with my partner, 20 from 22 individuals replied positively and 2 replied neutrally. Also in the phrase, I didn't feel like interacting with my partner, 18 people replied negatively and 4 neutrally. And an interesting aspect is that 13 people felt more creative after collaborating with their partner, 5 had a neutral position and 4 negative.

Summarizing, all the participants were able to complete their tasks with both the media of the interaction. Also, seemed to be intrigued by the eccentric appearance and novelty of the interaction. The novelty of the interaction was particularly noteworthy, given the inherently intricate and non-jovial nature of the experimental subject. Despite the challenging nature of the subject, participants in-

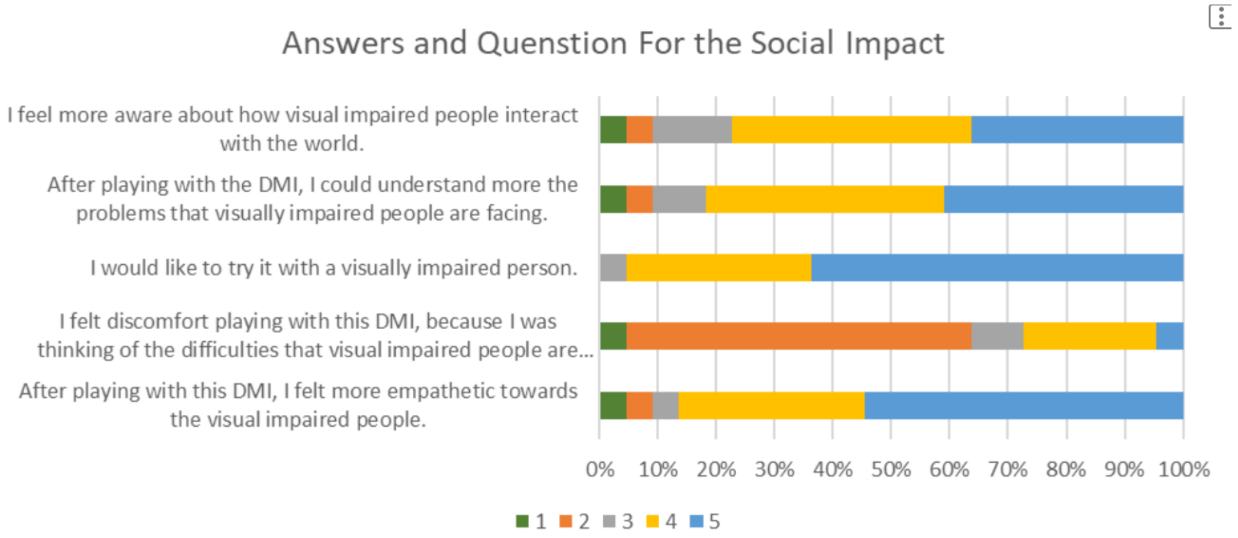

Figure 20. All the responses from the questionnaire for the social impact of the system. On the left side, the statements are presented and with different color annotation the 5-point Likert scale, where 1 indicates Strong Disagreement and the 5 Strong Agreement.

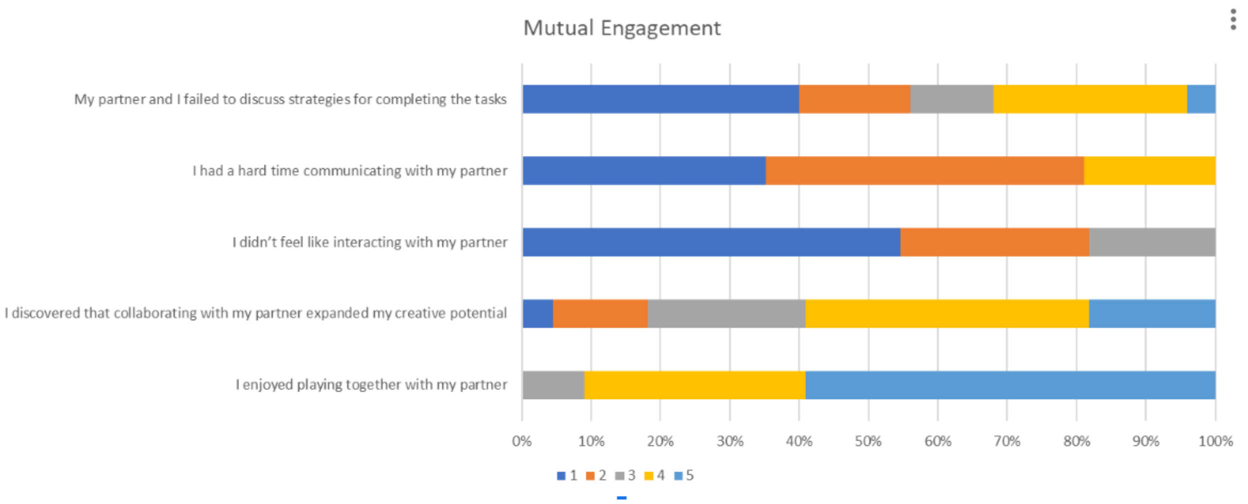

Figure 21. All the responses from the questionnaire for the mutual engagement of the system. On the left side, the statements are presented and with different color annotation the 5-point Likert scale, where 1 indicates Strong Disagreement and the 5 Strong Agreement.

vested a significant amount of time actively engaging with it, striving to become more familiarized. From the feedback that was taken from the questionnaire, the discussion and by observing the pairs to interact with the device, the concept can st

6. DISCUSSION

While the points that made in the Section **BACKGROUND** haven't been fulfilled, the first iteration of this prototype gave insights about the next designing steps, and shown the potentials of the interaction. The resulted work was evaluated in the form of a custom device and a musical application developed using the framework *MobMuPlat* and tested only by sighted people. This decision has taken due to the complexity of the subject and technological constrains. Then main concerns were that people with visual disabilities couldn't use the touch screen on the iPad to interact with the musical app. And having visually impaired people interacting only with the cane was cancelling the designing purposes of this idea and put the blind people in a position of magnifying their negative experiences of excluded designs (like the touch screen). When the technical issue will be resolved, it is planned to test it with mixed groups of sighted and visually impaired people.

6.1 Implementation

The overall building of the cane was sturdy and all the parts in hardware and in software were responsive without any serious bugs or arbitrary behaviors. The Bluetooth communication was reliable without causing unreasonable latencies and disconnections. Also, none of the participants complain about latency in the haptic feedback and the audio. The LiPo batteries were a good choice for powering the microcontrollers, although the *AudioKit* needed to be charged regularly because of the high power consumption of the speaker in high volumes. In the musical app, the response of the GUI was very established, and only minor bugs can be reported concerning the scaling of the GUI elements to the parameters of the subtractive synthesis. The audio synthesis responded well without any sonic or control issues (no distorted sounds or artifacts were reported or found during internal testing).

Improvements can be realized in the UID to MIDI conversion. The current midi on/midi off implementation can be significantly improved by programming the midi off information when the card isn't detected. Also, it could be very interesting to investigate how to store midi information as UID information directly to the passive tag and find a way to add MIDI velocity or through the detection of the distance between the antenna and the tag or by adding a second sensor.

6.2 Evaluation

User feedback, gathered through questionnaires and oral interviews, proved encouraging, motivating further implementation of new ideas. The objectives of fostering mutual engagement in music-making practices, introducing novices to electronic music, and exploring potential social impacts were successfully achieved. Observations highlighted the enjoyment users experienced, emphasizing the collaborative and unconventional nature of the interaction, forcing the users to 'rediscover' affordances, discuss them and make a musical output out of them. While acknowledging the positive outcomes, the technical aspects of the evaluation were recognized as areas for improvement, suggesting opportunities for refining testing methodologies and questionnaire frameworks. A participant's unique perspective, from his experience with his parent's visual impairment, expressed that the statements about the social impact didn't make sense to him, although he found the whole interaction interesting and would use it together with his parent. Also, the haptic feedback even in this simple form was found helpful for the navigation, and it made sense in the interaction (see Figure 23), furthermore the density of the vibration were found pleasant. Overall, the user-driven insights obtained from this evaluation provide a solid foundation for advancing and refining this novel musical interaction platform.

6.3 Future Research

In terms of completing the initial idea, there are plenty of steps towards, although a careful step by step design to eliminate unresolved issues where initially didn't exist is needed and especially when it comes to designing for people with different abilities than the norm that maybe experienced stigma. The challenge of identifying crucial information for the vitality of the product (ontological uncertainty) is known as *unknown unknowns*. The strategy to bring them into light is making low-functionality prototypes with focusing on one key feature of the design following an iterative prototype procedure [25]. This idea followed intuitively for designing this interaction and making sure that no vital problems will occur, especially when high levels of complexity exists (lots of different components and technologies, poor literature etc.). Thus, more exploration and prototyping in terms of RFID technologies needs to take place in the future. The long range RFID technology with Ultra-High Frequencies (UHF) have to be tested and calibrated for the needs of this interaction. Moreover, making tactile layers for the touch-screen is an idea that will be tested in the near future. It is planned to start experiment with conductive and flexible filament for 3D printers (TPU) and create 3D printed designs firstly for the GUI Grid. To continue with, the idea of adding more sensors to the cane like a gyroscope for more expressiveness will be implemented after the evaluation of the current prototype from visually impaired people.

For software improvements, more abstractions with different sound synthesis can be created. In addition, music game abstractions can be made with various levels of difficulties or musical training goals. The interaction is multipurposed and musical training-specific abstractions, social awareness-specific abstractions, electronic music exploratory abstractions and more can be made with the possibility of overlapped focuses. And lastly, but very important idea that came from a participant in the evaluation during the interview, is to create a heatmap-like map for vibrations. The idea behind that is to create amplitude sensitive haptic feedback depending on the distance that the tiles/steps outside the desired path have compared to the tiles inside the path. By selecting a specific path, the tiles that are besides to the path will have stronger haptic feedback and the ones that are far away will have a weak vibration sense.

Also in a more general framework for developing further this idea, a dialogic design strategy needs to implemented and design along with people and therapists that experienced blindness and work with it in dally basis.

7. CONCLUSIONS

This work aimed to develop a first prototype of an ADMI inspired by conversations with blind people and focusing on collaborative music making practices between blind and sighted people. Firstly, the interaction consists of a cane, a surface and a musical app, where the users could mutually in pairs to interact with a subtractive synthesizer built with the *Pure Data* framework *MobMuPlat* by creating and finding paths in the surface. The main goal of its pair of individuals was to create and find the path by activating MIDI notes a then play with parameters of the synthesis to familiarized with it and create electronic music together.

Secondly, an experiment was contacted to assess the usability of this creation, the mutual engagement and the potentially social impact in the users. The valuation contacted with 22 sighted participants in pairs of 11.

The present study contributes then to a relatively new interdisciplinary research field, covering the areas of inclusion practices and NIME. It is hoped that the research done during this study can work as a foundation for future investigations in these fields and could create new engaging musical experiences, resulting in new perspectives in musical expression and create a framework for music collaboration between visually impaired people and sighted people.

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9. APPENDIX

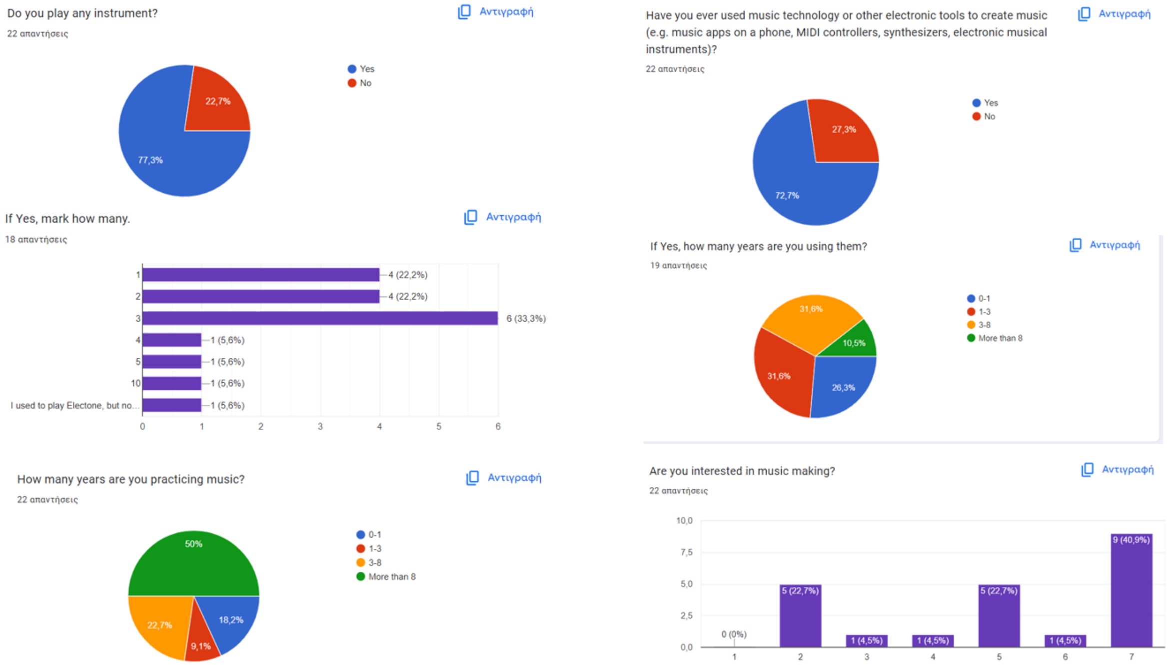

Figure 22. Responses from question concerning the musical background of the participants

Figure 23. all the statements and the responses from the usability questionnaire

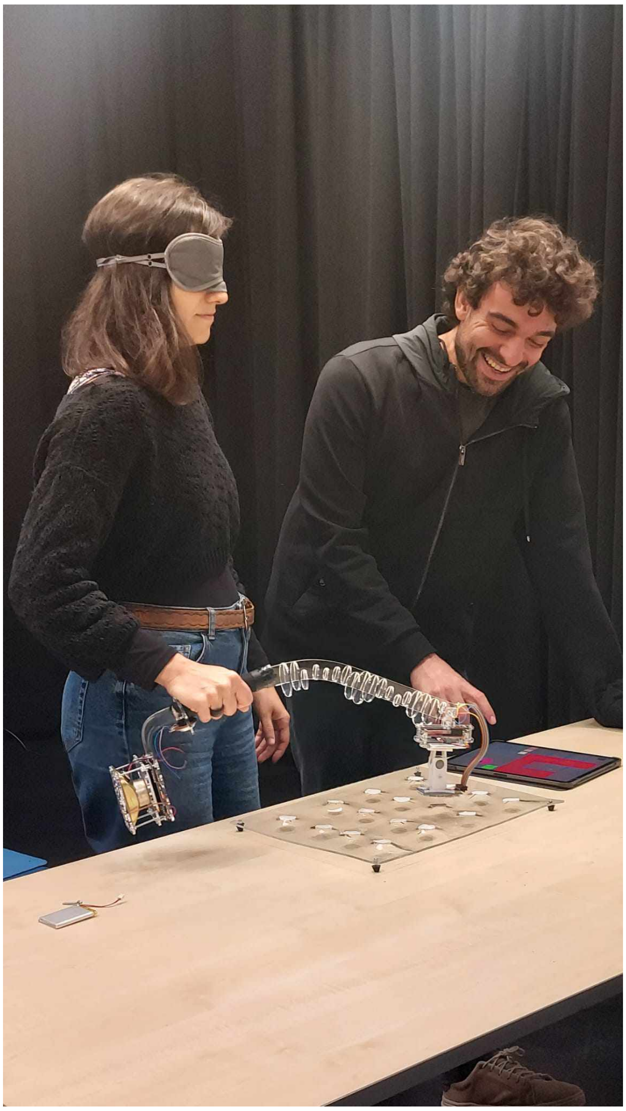

Figure 24. A pair of participants trying the ADMI

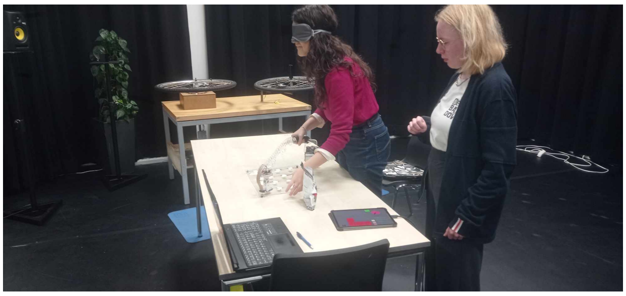

Figure 25. A pair of participants trying the ADMI

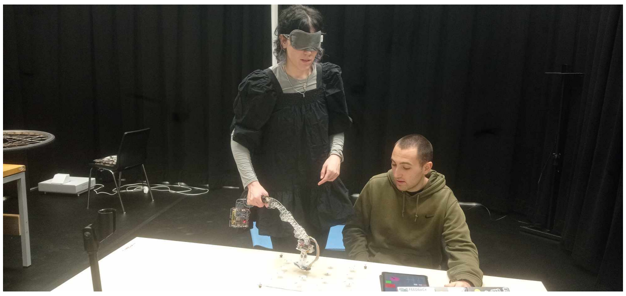

Figure 26. A pair of participants trying the ADMI

Figure 27. A pair of participants trying the ADMI