SUITCEYES

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Smart, User-friendly, Interactive, Tactual, Cognition-Enhancer, that Yields Extended Sensosphere
Appropriating sensor technologies, machine learning, gamification and smart haptic interfaces

[Deliverable D7.6]

Demonstrators of Gamification and Social Interaction Scenarios: Iteration III

Courtesy of LightHouse for the Blind and Visually Impaired, see http://lighthouse-sf.org

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OTHER	Software, technical diagram, etc.	

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Authors	
Partner	**Name(s)**
HSO	Arthur Theil, James Gay

Contributors	
Partner	**Name(s)**
HSO	Oliver Korn

Internal Reviewers	
Partner	**Name**
TUE	Myrthe Plaisier
HB	Li Guo

Glossary	
Abbr./ Acronym	**Meaning**
Dx.y	Deliverable of Work Package x, Number y
HIPI	Haptic Intelligent Personalized Interface
PCB	Printed Circuit Board

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Executive Summary

In this deliverable, we report on the third round of technical iterations regarding the *Keep Your Distance* gaming wearable and the *Tactile Board* device. Both interactive systems were developed to demonstrate how user-centred, game-based contexts can support accessible and intuitive experiences to individuals with multisensory disabilities. Firstly, we describe a number of technical iterations made to the *Keep Your Distance* prototype in order to provide an improved experience to potential users. Secondly, we describe technical iterations made to the *Tactile Board*'s user interface.

The main contributions of this deliverable are:

- A detailed report on technical iterations in the hardware side of the *Keep Your Distance* wearable.
- A detailed report on technical iterations in the software side of the *Tactile Board* device.
- An updated Bills of Materials for the *Keep Your Distance* gaming wearable.
- A preliminary report on technical evaluation of both systems.
- A set of 53 4x4 haptic signs to be integrated across platforms.

1 Introduction and Rationale

The present deliverable directly builds on the work presented in D7.4 *"Demonstrator of Gamified Scenarios"* and D7.5 *"Demonstrator of Gamified Scenarios: Iteration II"*. As described in previous deliverables, the aim of our work is to report on the design, development and evaluation of accessible, interactive systems for the Deafblind community. Our work in WP7 focuses on developing and evaluating user-centered technologies for gamification and enhanced social interactions using design iteration methods. In that respect, we now present the third of round of technical iterations made to the *Keep Your Distance* gaming wearable and the *Tactile Board* device. These technical iterations were based primarily on direct feedback from users with deafblindness and technical evaluations conducted in the lab.

Our primary objective was to provide users of the HIPI platforms with an intuitive and fun learning process. This was accomplished by implementing gamification scenarios in which users learn different modalities of haptic communication through contextualized and game-based interaction. Haptic communication is mainly consisted of both continuous and event-based vibrotactile signals displayed onto different parts of the body. These vibrotactile signals are then used to support sensory substitution in independent navigation or two-way communication with other persons. In relation to the *Keep Your Distance* gaming scenario, vibrotactile feedback is provided onto the shoulder area, belt and upper back. Different parts of the body are used for displaying signals that mean different information to the user, therefore it was important to us that users were able to perceive and understand different modalities of haptic communication applied to numerous contexts of use. Consequently, the technical iterations presented in this report are meant to improve the feasibility of using the demonstrator in real-world scenarios and increase the overall recognition rates of vibrotactile signals displayed onto the body.

In relation to the Tactile Board, the technical iterations presented in this report mainly focus on improving the communication between the mobile device with the haptic wearable as well as providing a more intuitive and personalized user interface to users with a diverse set of sensory characteristics and different levels of familiarity with haptic communication. In the following subsections, we provide a brief recapitulation of how the *Keep Your Distance* gaming vest and the *Tactile Board* work. Furthermore, this deliverable ends with an outlook discussion on future work related to the technical iterations reported in this document.

1.1 The *Keep Your Distance 2.0* wearable

As detailed in both D7.4 and D7.5, the Keep You Distance[1] wearable (previously called *Follow Your Partner*) [1] provides navigational cues to users with deafblindness by conveying vibrotactile feedback around the waist and shoulder areas. The wearable system translates proximity and directional cues related to objects or other people near the user using a fish-eye camera and vibration motors attached to vest (Figure 1). We aimed to explore intuitive vibration signals that users could easily learn without the need of extensive training. Additionally, we evaluated the suitability of the haptic wearable with a playful interaction scenario where individuals with deafblindness tested and learned how to be guided through haptic feedback in a non-intimidating environment. The iterated version of the wearable was informed by direct user feedback (n=5) and a number of technical improvements described in this deliverable.

[1]**Further reading**: James Gay, Moritz Umfahrer, Arthur Theil, Lea Buchweitz, Eva Lindell, Li Guo, Nils-Krister Persson, and Oliver Korn. 2020. Keep Your Distance: A Playful Haptic Navigation Wearable for Individuals with Deafblindness. In *The 22nd International ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS '20). Association for Computing Machinery, New York, NY, USA, Article 93, 1–4. https://doi.org/10.1145/3373625.3418048

Figure 1: The Keep Your Distance wearable. Continuous and event-based vibrotactile feedback is provided on three areas: belt, shoulders and upper back.

1.2 The *Tactile Board* device

As introduced in D7.5, the Tactile Board[2] [2] is a mobile Augmentative and Alternative Communication (AAC) device for individuals with deafblindness. The mobile interface allows multimodal text and speech input to be translated into vibrotactile signs that are displayed to the user via the Keep Your Distance wearable. Users can communicate with non-disabled persons by using dynamic, sequential and 2-dimensional vibrotactile signs that are then translated into text and spoken words (Figure 2). We developed the Tactile Board to facilitate communication for the Deafblind community, creating opportunities for these individuals to initiate and engage in social interactions with other people without the direct need of an intervener. Its design was based on direct feedback from users with deafblindness and the application can be used on smartphones or tablets depending on the user's preference. Users have the ability to draw and create their own vibrotactile patterns on the touchscreen as well as using pre-existing signals. Besides allowing text and speech input, the Tactile Board mimics how persons with deafblindness communicate using haptic signals. The use of user-defined vibrotactile patterns can improve the overall learnability of the system as users need to use the very same patterns they created in order to communicate using the device.

[2]**Further reading**: Arthur Theil, Lea Buchweitz, James Gay, Eva Lindell, Li Guo, Nils-Krister Persson, and Oliver Korn. 2020. Tactile Board: A Multimodal Augmentative and Alternative Communication Device for Individuals with Deafblindness. In *19th International Conference on Mobile and Ubiquitous Multimedia* (MUM 2020). Association for Computing Machinery, New York, NY, USA, 223–228. https://doi.org/10.1145/3428361.3428465

Figure 2: The Tactile Board. The mobile device works with different haptic wearables and allows two-way communication between persons with deafblindness and non-disabled persons through either text, speech or 2-dimensional haptic signs.

2 Technical Iterations: Keep Your Distance 2.0

The haptic wearable was designed to be used in a gamified navigation scenario where a person with deafblindness intends to follow and keep an optimal distance from another walking individual. Independent navigation is support by environmental data that is translated into directional and proximity feedback using multi-point vibrotactile actuators attached to the wearable. The following subsections report on some minor design shortcomings of the third iteration of the Keep Your Distance gaming vest, previously presented in deliverables 7.4 and 7.5, and deals with the technical challenges we faced while assembling it, and how some of these issues have been addressed:

2.1 Hardware Iterations

Initially, we planned to use conductive thread to get the electrical current to the vibration motors. However, with the issue of crosstalk causing the vibration motors to misfire and high resistance limiting their intensity, we decided to use jumper cables throughout the entire vest. While connecting the jumper cables from the custom PCB to the vibration motors proved to be easy, the number of cables required did present some challenges. The high number of cables on the back of the vest (16 wires & one common ground cable) to power the 4-by-4 matrix of vibration creates enough weight to pull the motors down, resulting in incorrect motors placement. This also put strain on the cables, rendering them prone to detaching from the motors. Addressing this matter, we have created various support points for the cables by sewing them down to keep them as rigid as possible. This also made it easier to handle the number of cables involved.

Figure 3: Improved cable management in the Keep Your Distance wearable.

As illustrated in Figure 3, these cables are concealed by the straps for the 4-by-4 matrix and meet at the pocket near the bottom of the vest.

Furthermore, we found that the zipper was not ideally placed on the front of the vest as it caused problems attaching the central vibration motor used for the navigational element of the *Keep Your Distance* game. We were still able to attach the motor with Velcro. However, moving the zipper slightly to the left or right without obstructing other components would solve this problem while also allowing the camera to be mounted at the centre of the user's chest.

Figure 4: *Left*: Frontal view of the Keep Your Distance wearable. *Right*: Side view.

We also identified potential for further improving the design of the vest. We found it difficult to feed the jumper cables through the green pipes (created for concealing the wires), with the cables getting caught by the material used. A material causing less friction could help to resolve this matter. Moreover, the vest could benefit from having slightly larger pockets on the front and back to better accommodate the various components as the current ones are very tight.

Figure 5: Interior view of the 4x4 matrix of coin-shaped vibration motors.

2.2 Raspberry Pi overheating

When running the system for any prolonged period, one other potential drawback may also be seen in the lack of airflow to the Raspberry Pi when it is inside one of the pockets. This will cause the Raspberry Pi to get fairly hot, not only leading to discomfort for the user but also posing problems when running performance-intensive computations (e.g. computer vision algorithms). At a certain temperature, thermal throttling will be triggered, slowing the system down or, at worst, preventing it from responding. Although a passive cooler has been implemented here, we would recommend using an active type, i.e. one with a fan, and consider placing the Raspberry Pi on the exterior of the vest to permit better airflow.

2.3 Textile

In informal tests on persons of various body sizes, we found that placement of the 4-by-4 matrix on the back could be enhanced. In some instances, the vibration motors made insufficient contact with the user's back, resulting in haptic signals being difficult to understand. The side zippers to alter vest size and the straps on the back of the vest did alleviate this problem, but alone are not enough to rectify it fully. In our opinion, the vest would need to be tailored to the user's exact body contours.

2.4 3D-Printed Cases for Components

Finally, the pockets designed to hold cylindrical motors on the shoulders were too loose, failing to prevent them from falling out. We addressed this issue by creating custom-made 3D printed cases which give the vibration motors a tight hold and can be sewn onto the garment. Figure 6 shows the 3D printed case holding the cylindrical vibration motor. Additionally, we designed an enclosure with a snap-fit cover for the custom PCB (Figure 6), with small openings for the connections, to better contain the PCB and improve overall robustness.

Figure 6: *Left*: 3D-printed case for cylindrical vibration motor. *Right*: 3D-printed case for the custom Printed Circuit Board (PCB).

2.5 Iterated Bill of Materials

Based on hardware iterations reported in this deliverable, we propose a new Bill of Materials necessary for prototype development. Table 1 shows all hardware components used within the Keep Your Distance wearable. The list excludes software components.

Table 1: Iterated Bill of Materials for the *Keep Your Distance* wearable.

Item	Description	Manufacturer	EAN	Quantity
430450800	Molex, 8 Way, Dual Row PCB Header, 5A	MOLEX	9900001861758	1
430452000	Molex, 20 Way, Dual Row PCB Header, 5A	MOLEX	9900002366498	1
FE1B	Diode Standard, 100V, 1A	DIOTEC	2050001282774	23
BC548C	NPN Transistor, 100 mA, 30V, 3-Pin	DIOTEC	2050000029462	23
BL LP 1/ 36/Z	36 Female Header Vertical	FISCHER	2050001685704	3
PCA9685	16-Channel 12-Bit PWM/Servo Driver, I^2C	ADAFRUIT	9900002355256	2
PO1636	Shaftless Vibration Motor, 0.75g, 60mA, 3V	POLULU	4060137018442	16
307-103	9mm Vibration Motor, 7g, 100mA, 3V	PRECISION	-	7
RP-4B-8GB	Raspberry Pi 4B 8GB 4x1.5GHz	RASPBERRY PI	0765756931199	1
K10	Flex Cable 50cm	AZDELIVERY	7426817666902	1
EB6923	Passive cooler, Armor Case “BLOCK”	JOY-IT	4250236819365	1
LC20	Wide Angle 160° Fisheye Lens HD Camera	LONGRUNNER	6932083818088	1

3 Technical Iterations: Tactile Board

The haptic wearable was designed to be used in a gamified navigation scenario where a person with deafblindness intends to follow and keep an optimal distance from another walking individual. Independent navigation is supported by environmental data that is translated into directional and proximity feedback using multi-point vibrotactile actuators attached to the wearable.

3.1 Software Iterations

In this section, we present the improvements we have made to the software of the tactile board. Since deliverable 7.5, the software of the tactile board has undergone a design overhaul, with the application being split into four separate screens, all accessible via a bottom navigation tab bar. These screens are *Home*, *Create*, *Library* and *Settings*.

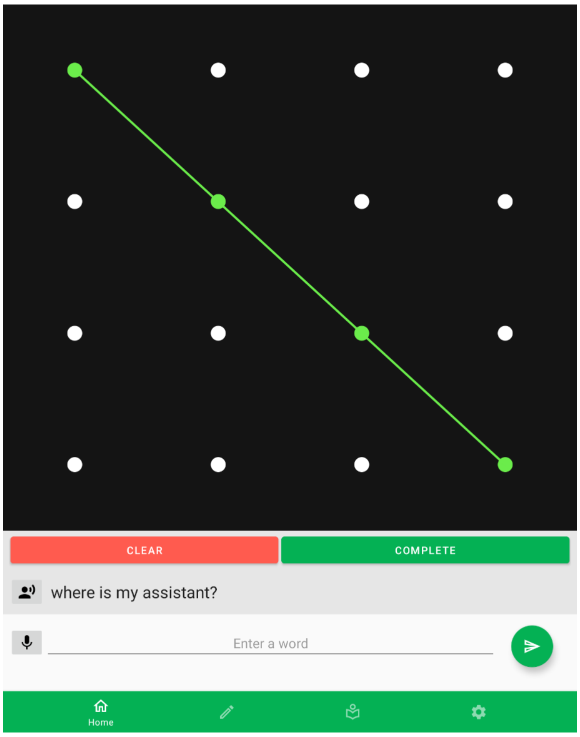

Figure 7: The Tactile Board's Home screen.

The *Home* screen is designed to allow the user to form a message in a multitude of ways. The top portion of the Home screen contains the grid which is used to encode haptograms by drawing a pattern. In addition to single strokes, the newer version of the software now provides the capability of drawing multiple single-touch strokes, e.g. it is now possible to draw a cross or any patterns that require more than one stroke. Along with drawing patterns, the user is now able to type messages via an input field which autocompletes words or phrases that are known to the local library of word-haptogram pairings. Alternatively, the user can press a button next to the input field, which activates speech-to-text, enabling the user to speak a word or phrase. When using the input field or speech-to-text, the system will draw the corresponding haptogram pattern on the grid if the pattern is known.

Below the grid are two buttons: The *Clear* button is used to erase the current pattern formed by any of the above three mentioned methods. This is particularly useful if the user makes a mistake when drawing a pattern consisting of multiple strokes. The *Complete* button must be pressed to confirm any drawn pattern. Upon doing so, the software checks if the pattern is known. If the pattern can be found in the local library, the word or phrase appears below the two buttons and is spoken via text-to-speech, also added in the new version. The spoken phrase can be repeated by pressing the icon next to the text. Additionally, a new button appears in the bottom right corner. Pressing this will publish a message via the message broker to the vest wearer or the ontology. Once sent, the screen resets to its default state, allowing a further message to be constructed. Conversely, if the pattern is not known, the system informs the user by displaying a message accompanied by text-to-speech output.

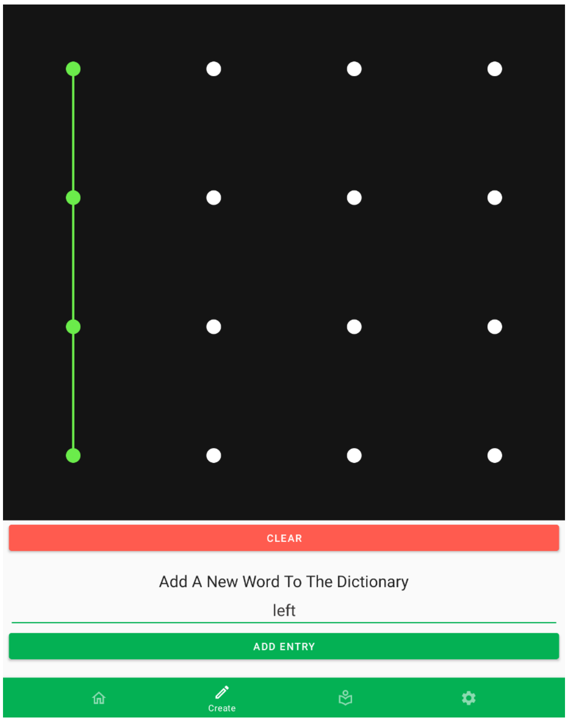

Figure 8: The Tactile Board's Create screen.

The *Create* screen enables the user to add a new haptogram-word pairing to the local library. This is accomplished by first drawing a pattern (single stroke or multiple strokes), followed by entering a text via the input field. Pressing the *Add Entry* button will validate the user's entry and add the word-haptogram pairing to the local library if a series of tests are successfully passed. If any part of the validation fails, a relevant error message is displayed to the user (e.g. empty entry, a haptogram already exists etc.).

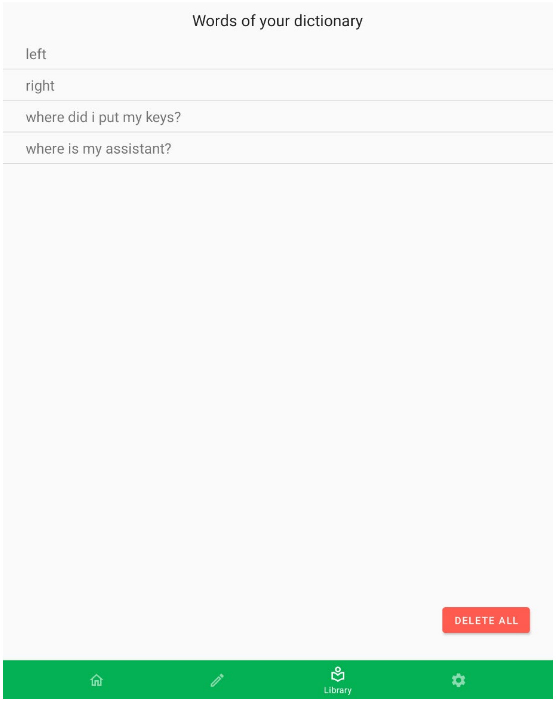

Figure 9: The Tactile Board's Library screen.

The *Library* screen displays a list of words known to the system. Keeping the *Delete All* button pressed removes all words from the library.

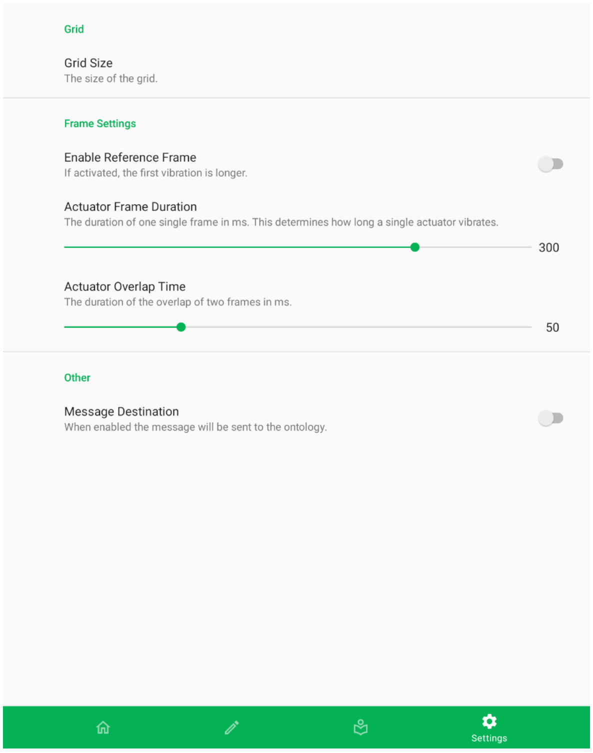

Figure 10: The Tactile Board's Settings screen.

The addition of the *Settings* screen enables the user to configure various features:

- ***Grid Size***: Modifies the size of the grid to make it uniform (e.g., 3x3, 4x4, 5x5 etc.). The default value is 4.
- ***Enable Reference Frame***: A toggle which, when enabled, lengthens the first vibration. In this instance, it sets the first vibration to a length of 500ms. When disabled, this defaults to the time set by *Actuator Frame Duration*.
- ***Actuator Frame Duration***: This setting determines the duration for which a single vibration motor is activated. Defaults to 300ms with a maximum duration of 400ms.
- ***Actuator Overlap Time***: Determines the duration of activation overlap of two consecutive vibration motors. This overlap is intended to create the illusion of a continuous motion. This is a value between 0ms (no overlap) and 200ms. Defaults to 50ms.
- ***Message Destination***: A toggle determining the destination of the message. When enabled, the message is sent to the ontology in the form of a query. For example, a deafblind user could ask "Where is my assistant?". If this setting is disabled, messages are sent to the vest wearer, triggering the vibration pattern on the back where the matrix of vibration motors is located.

3.2 Message Bus

The *Realtime Framework Message Bus*, which was used to broker messages between the HIPI, Tactile Board and ontology, stopped operating in mid-2020. For this reason, we had no other option than to find an alternative for communication between HIPI, tactile board and ontology. We replaced the *Realtime Framework Message Bus* with *MQTT (Message Queuing Telemetry Transport),* an open OASIS and ISO standard publish-subscribe network protocol. The MQTT protocol comprises two entities: the MQTT broker and a variable number of MQTT clients, permitting one-to-many communication. MQTT clients can publish and subscribe to certain *topics* (in Realtime Framework these were referred to as *channels*). In our case, Ably.io assumes the role of the online broker. Initially written in Python, C# and Java for the Tactile Board and the Keep Your Distance game, the existing code has been adjusted accordingly to use the MQTT protocol as a means for communication.

4 Preliminary Evaluation

In this section, we briefly report preliminary results from pilot studies conducted prior to the COVID-19 pandemic with the aim of obtaining general user feedback and testing technical feasibility of our haptic wearable.

Participants

Five individuals with acquired deafblindness were recruited for this study (2 female; mean age = 48 years old). All five participants were fully deaf, however, three participants communicated verbally with the help of cochlear implants (CIs). Participants who used Sign Language were accompanied by professional interpreters, who assisted with communication throughout the study.

Furthermore, participants presented varying eyesight characteristics: one participant was fully blind; one participant had a field of view of 100 degrees and a visual acuity of 2% to 5%; while the other three participants had tunnel vision with fields of view between 3 to 7 degrees and a visual acuity of up to 70%. Either written or verbal informed consent was given by all participants and their interpreters.

Navigation

The haptic feedback modality consists of continuous vibrotactile signals provided by five vibration motors around the waist area. These vibrotactile signals use cylindrical shaped Precision Microdrives vibration motors (307-103, 25mm) on voltage of 3V, delivering vibrational amplitudes of 7G when attached to the vest. For the *Keep Your Distance* user evaluation, we used pulse frequencies of (a) 100ms when the user was too close to the other person (up to 0.5 meters), (b) 500ms when the user was within the optimal distance of 0.5 to 1.5 meters to the other person, and (c) 1000ms when the user was getting too far from the other person (more than 1.5 meters apart). Figure 1 shows preliminary accuracy rates based on data from five individuals with deafblindness playing the *Keep Your Distance* game. Our findings suggest that 5-point vibrotactile signals are suitable for providing orientation guidance to users with deafblindness. Furthermore, users were able to complete the orientation task efficiently and independently after only three trials.

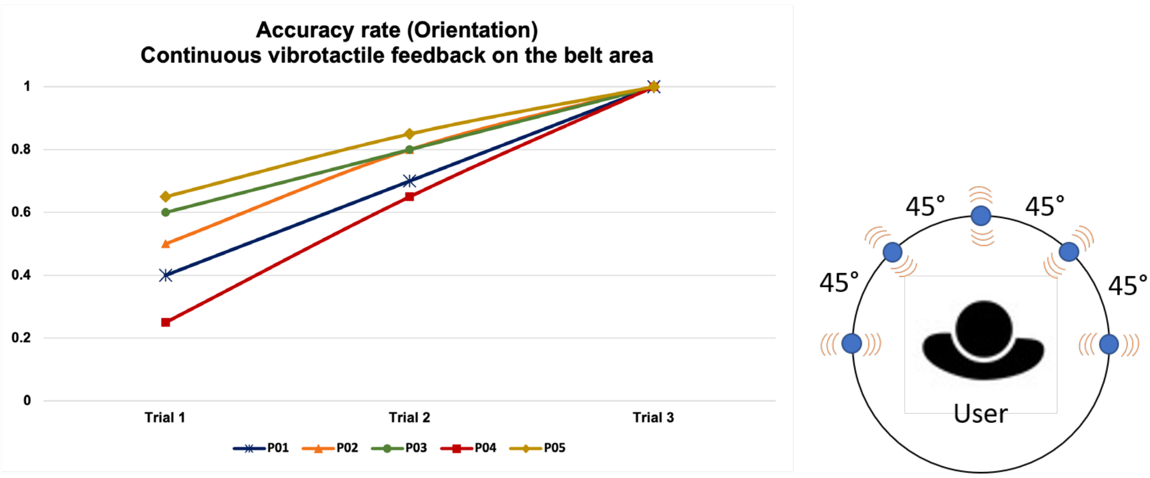

Figure 11: Navigation and orientation accuracy rates for first, second and third trials. Orientation was provided using 5 vibration motors on the frontal side of the belt area.

Pattern Recognition

We conducted a preliminary test with the aim of assessing the feasibility of different haptic patterns for in-game communication. A full list of currently available haptic patterns is available as an appendix. These patterns are essentially based on existing Danish Haptic Signals but are coded as 2-dimensional, dynamic and sequential vibrotactile patterns displayed on the upper back of the user through an array of 16 coin-shaped vibration motors. The available set can be integrated into different interaction contexts using the Tactile Board or can be included in gamified scenarios using the *Keep Your Distance* wearable. In our experiment, each vibration unit was activated for 400ms with an overlap of 50ms.

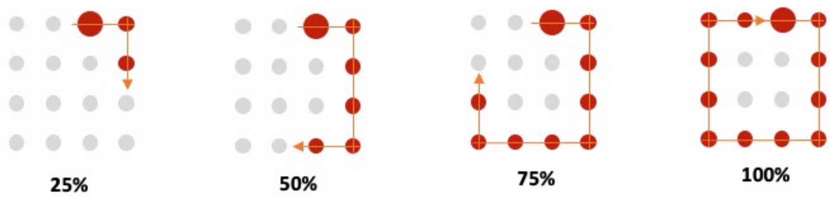

Figure 12: Haptic patterns designed to present in-game progress indication to users. Patterns are displayed using a 4-by-4 matrix of vibration motors placed onto the upper back of the user. The first vibration unit is activated 100ms longer. Percentages represent the walking status until the end of the *Keep Your Distance* game.

For instance, we tested recognition rates of four in-game progress indication messages with different individuals (n=7). Figure 12 shows visual representations of the four haptic progress indication patterns designed by us based on user feedback. In our pilot study, participants wore the Keep Your Distance vest while being provided with a visual representation of those haptic patterns. Then, they were asked to point to the correct pattern once it was displayed with vibration motors on their upper back. As shown in Table 2, all patterns presented a high recognition rate without formal training and participants were generally able to distinguish different patterns with no difficulties.

Table 2: Recognition rates for progress indication messages using haptic patterns.

Haptic pattern	Progress indication **25%**	Progress indication **50%**	Progress indication **75%**	Progress indication **100%**
Recognition rates	100%	100%	92%	100%

5 Outlook

This deliverable reported on technical iterations made to the *Keep Your Distance* game scenario and to the *Tactile Board* device with the goal of refining our final prototype design in WP7. As part of our iterative design process, we focused on incorporating user feedback to ensure that our system requirements meet user needs. Furthermore, we aimed to conduct a series of performance tests to validate the robustness of our prototypes. Due to the current COVID-19 pandemic, we were unable to conduct further testing with users with deafblindness. However, users were actively involved in testing during the early stages of research, in which we were able to evaluate our proof-of-concept effectively (see D7.4, D7.5 for more details).

5.1 Open Platform

As a direct product of our iterative design process of prototyping, testing, and refining, we share an extensive documentation of hardware and software components on an open platform This platform will allow stakeholders and other researchers to access to the technical documentation related to the *Keep Your Distance* wearable and the *Tactile Board* device.

The platform is available on the project's website http://suitceyes.eu/ as well as on the project's GitHub page: https://github.com/Suitceyes-Project.

Appendix 1: Full set of haptic signs

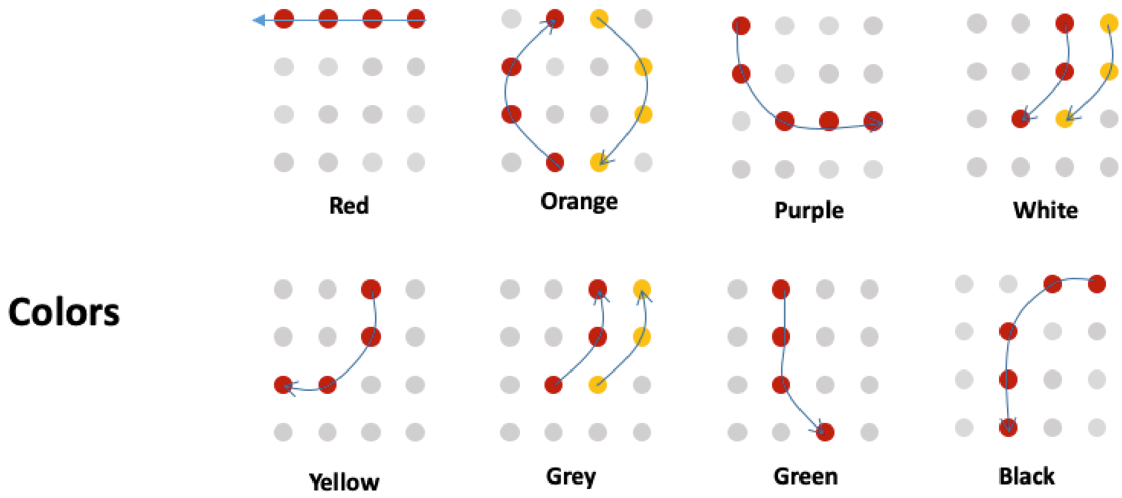

Figure 13: Dynamic 2-dimensional haptic signs for communicating colors. First sequence is shown in red, second sequence is shown in yellow.

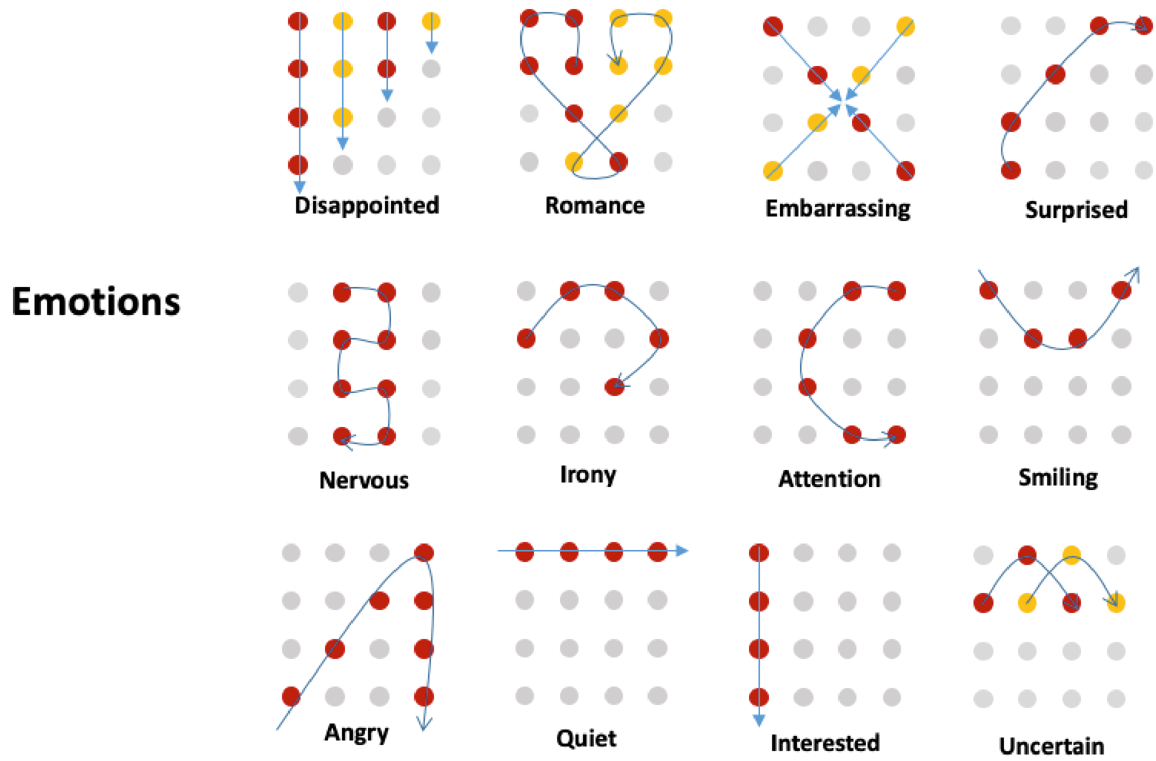

Figure 14: Dynamic 2-dimensional haptic signs for communicating emotions. First sequence is shown in red, second sequence is shown in yellow.

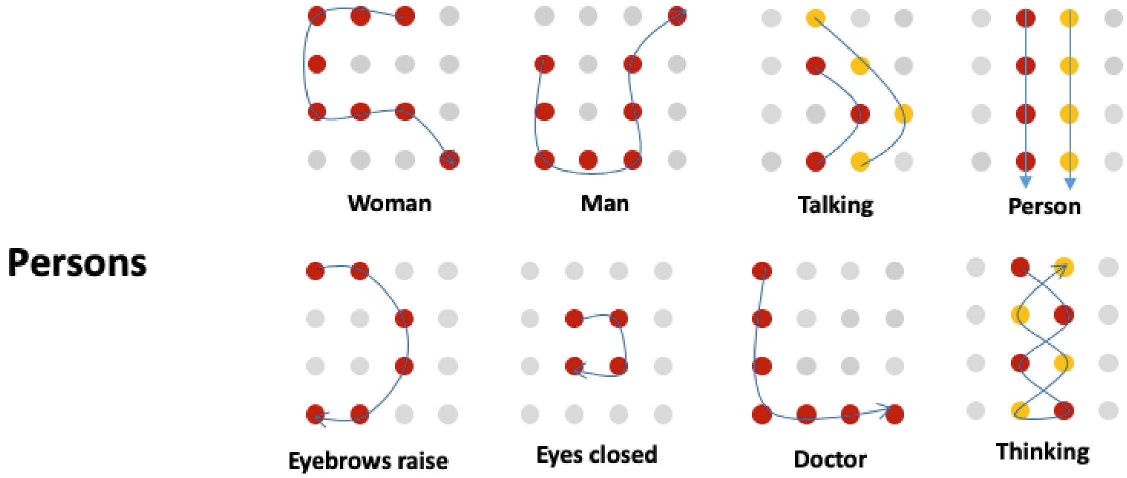

Figure 15: Dynamic 2-dimensional haptic signs for communicating persons. First sequence is shown in red, second sequence is shown in yellow.

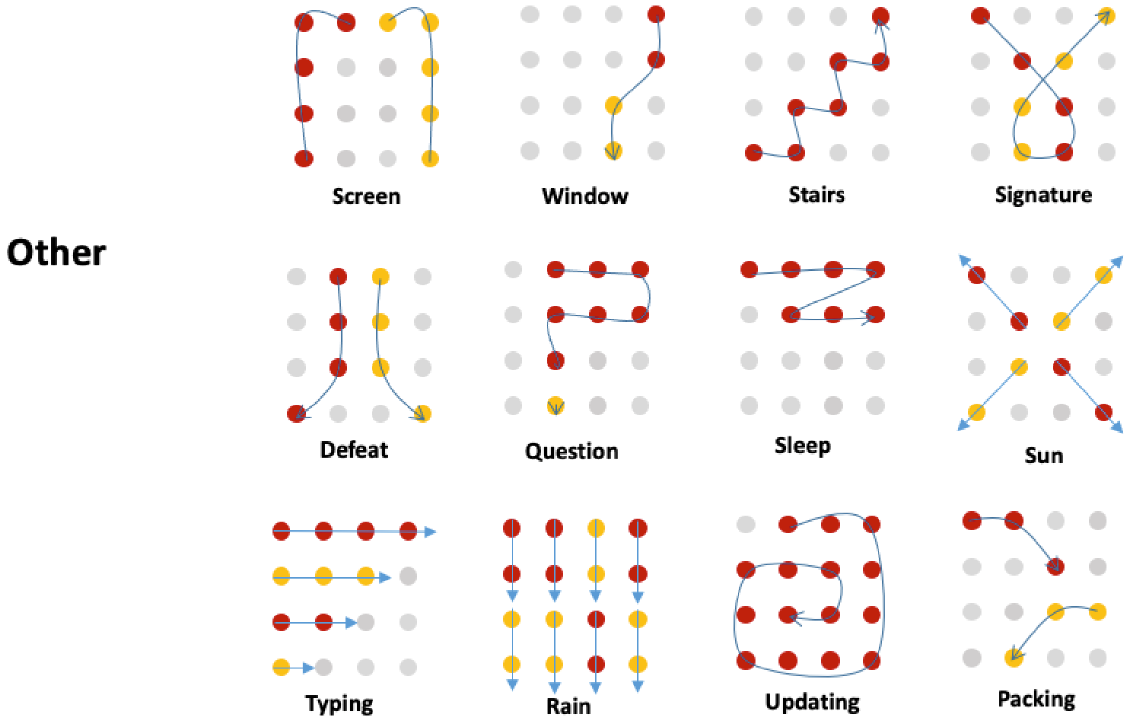

Figure 16: Dynamic 2-dimensional haptic signs for communicating other messages. First sequence is shown in red, second sequence is shown in yellow.

References

[1] Gay, J. et al. 2020. Keep Your Distance: A Playful Haptic Navigation Wearable for Individuals with Deafblindness. In The 22nd International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '20), October 26-28, 2020, Virtual Event, Greece. ACM, New York, NY, USA, https://doi.org/10.1145/3373625.3418048

[2] Theil, A. et al. 2020. Tactile Board: A Multimodal Augmentative and Alternative Communication Device for Individuals with Deafblindness. 19th International Conference on Mobile and Ubiquitous Multimedia (New York, NY, USA, Nov. 2020), 223–228.