SUITCEYES

1 Jan 2018 - 31 Dec 2020

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

[Deliverable 5.1]

Report on technologies used for existing (hard) solutions for haptic communication

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

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Dissemination level		
PU	PUBLIC, fully open, e.g. web	x
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CI	CLASSIFIED, information as referred to in Commission Decision 2001/844/EC.	

Deliverable Type		
R	Document, report (excluding the periodic and final reports)	x
DEM	Demonstrator, pilot, prototype, plan designs	
DEC	Websites, patents filing, press & media actions, videos, etc.	
OTHER	Software, technical diagram, etc.	

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Glossary	
Abbr./ Acronym	**Meaning**
Haptics	The application of tactile sensation (touch) and control with computer applications is nowadays designated as the science of “Haptics”. By using input/output devices tactile feedback can be conveyed to the user. This can be used, for example, in gaming or for motor learning. Haptic feedback includes two types of feedback: tactile and kinesthetic. The most widely known feedback modality of haptic feedback is vibration. But, also electro-tactile, ultrasonic and force feedback have been previously applied. Haptic communication is a commonly used modality to convey feedback to individuals with visual and auditory impairments.
Communication	Communication is the transfer of information – namely a message sent from a receiver via a sender. The sender encodes the message and sends it over some distance to the receiver. The receiver encodes and interprets the message and reacts on it via answering or another interaction. In the context of SUITCEYES, this means that garment and deafblind person both need to be sender as well as receiver, to communicate effectively. The intended garment should collect information from the environment, encode it into haptic feedback, and transmits the signal to the deafblind person. The person decodes the haptic signal and interprets its meaning, further, an answer on the message can be encoded and sent back to the garment.
Feedback modalities	Classifies feedback by which sensory modality it addresses, i.e. auditory, visual, tactile, or olfactory.
Virtual Reality (VR)	Artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided through technology

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Introduction

In the past few years, the accessibility of electronic applications and services by disabled users has become a topic of great importance at an international level. Based on the fundamental right of all people for equal access to information and services, and equal opportunities for employment and independent living, a range of modalities and interaction methods have been developed to support interaction with technology for people with physical, sensory, or mental disabilities. The choice of modality depends strongly on the targeted disabilities, and on the environment in which the device is used. An assistive device may offer, for example, visual, auditory or tactile assistance, or combine several modalities. In the case of a person with deafblindness, a major focus has been placed on tactile, and haptic feedback modalities.

This document provides a review of existing hard, haptic devices, used for assisting impaired individuals. We refer to hard haptic devices as devices or physical mechanisms made from materials with reduced flexibility – e.g., steel and plastic, as opposed to foil, paper, etc. With this review, we intended to gain a richer understanding of the techniques applied within this class of devices, and use this knowledge towards inspiring the design of our own haptic solution. We have focused on hard, haptic devices due to their advanced maturity (as compared to soft, haptic devices). We include scientific developments as well as products in the last stage of development and already commercially available products. Whereas cutting edge scientific studies that introduce new haptic devices will help to inform about methods, user acceptance and low-budget technical implementation, more mature products that are ready to be introduced into the market are also worth considering, as they may identify possible future partners and contributors.

Overview

Most currently available hard haptic devices have covered two major areas: Virtual Reality (VR) games and assistive devices. Nowadays, although gadgets for VR gaming are also used for rehabilitation and therapy purposes, their original aim was supporting immersion and fun in games [1]–[3]. Commercially available assistive devices may support people that experience physical or cognitive impairments[4-7]. For instance, in the automotive industry many alert systems using haptic feedback are available, whereas the health sector has established numerous haptic devices supporting people experiencing disabilities. Regarding the scientific developments of the following selection, one focus of haptic devices lies on support devices for people that experience disabilities [8–12]. Other studies have examined the effect of different haptic feedback, and developed application suggestions.

The following review on hard, haptic devices was conducted by two researchers of the SUITCEYES project. An initial search was conducted via Google Scholar, with a focus on keywords *haptic devices*, *accessibility*, *deafblind*, *blind*, and *deaf*. Referenced, and cited articles were also considered.

Structure

In the following two sections, a list of numerous developments of hard, haptic devices in science and for commercial usage are presented. Every device is described in a two-column table. Besides the name, size, weight and cost of the device, the following information is provided:

Commercial availability: States if the device is already available on the market;

Technical Details: Publicly available technical details (e.g. operating system, batteries, physical modules, Software);

Capacity: Power supply of device and potential duration of usage, in hours;

Modality: Modality used in this device (e.g. vibration, thermal feedback, force feedback, pressure);

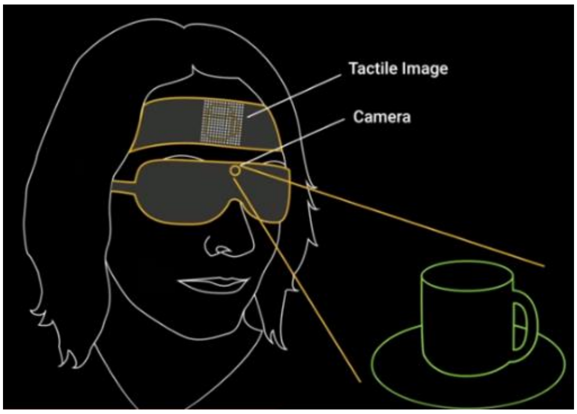
Description: Short description on how the device is assumed to operate;

Potential contribution to the project: An estimation of what aspects of this device could be useful for SUITCEYES;

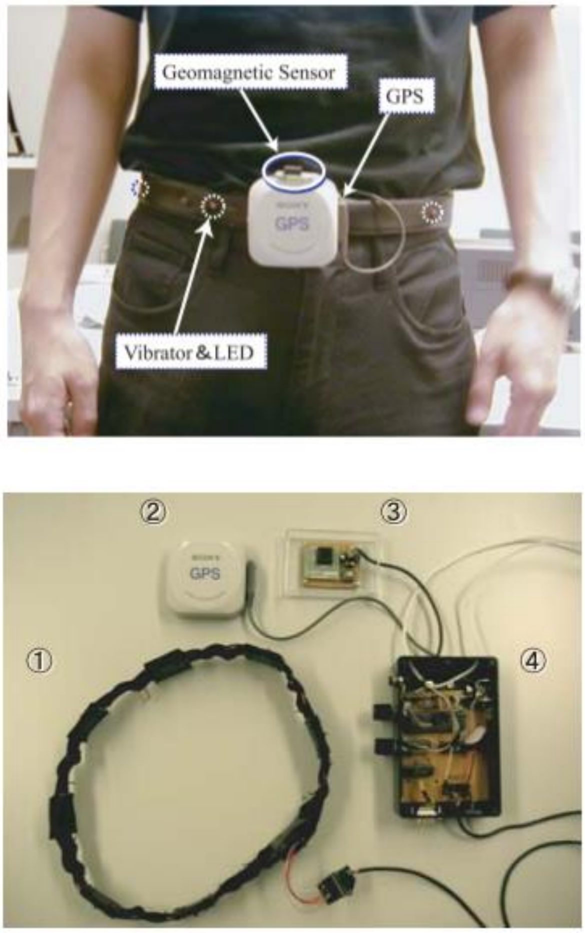
Ranking: The ranking consists of three different levels: low, medium and high. The higher the ranking is, the more important and innovative a device is considered, and the more likely it is that it may contribute to the project and inspire important new approaches and ideas. This estimation is based on potential contribution and judgments, availability, results from user studies, etc;

Comments on Appearance + Handling: A personal judgment on the appearance and potential handling of the device for users and their surroundings. Regarding the appearance, it is judged if a device looks, e.g., good, a little bit scary or futuristic. Further, it is considered, if it seems to be unobtrusive when worn in public or if the device still needs improvements in appearance because it is still on a prototype level. The second criterion refers to handling of the device. Questions on how easy it may be for a user to interact with the device, how fast a confident usage may be learned or how intuitive and comprehensible feedback signals might be, are addressed in this criteria.

An overview of existing Hard Haptic Devices

Name: Forehead Electro-tactile Display for Vision Substitution	 **Figure 1:** Forehead Electro-Tactile Display
Size: normal sunglasses, electrodes: 12 x 6 cm, band: 6cm width	
Source: [8]	
Commercial maturity: not available	
Technical Details: - CCD micro-camera attached to sunglasses (Ajoka Corp., SunGlasses Camera) - Laptop for edge extraction and conversion to stimulation pattern (Pentium-M, 1.1 GHz) - Driver circuit with standard serial port - 512 electrodes	
Modality: Electrical stimulation	
Description: A small camera captures the view, extracts outlines from the view and converts the outlines to tactile sensation by electrical stimulation on the forehead.	
Potential contribution to the project: Stimulations on the forehead, which is normally not needed for any activities (apart from facial expressions). Stimulation patterns are not abstract, provides outlines of objects.	
Ranking: High	
Appearance: The glasses are looking like sunglasses, maybe they can be changed to normal glasses. The band on the forehead looks quite massive and conspicuous, because the electrodes need some space.	

Handling: The correct interpretation of the stimulation on the forehead needs some practice, because the feeling sense on the forehead is normally not well trained. If the pattern recognition is learned, the handling is very easy and important visual cues can be replaced by electrical stimulation. Additionally, the electrical stimulation is individually scalable. The system can be easily turned on and off.	

Name: ActiveBelt	 **Figure 2:** ActiveBelt
Size: 78cm long belt	
Source: [13]	
Commercial maturity: not available	
Technical Details: - 8 vibrating actuators (FM23A by TPC, 18x3mm, distance between 9.75cm) - LEDs - Geomagnetic sensor (TMC3000NF by NEC Tokin) - Acceleration sensor (ADXL202E by Analog Devices) - GPS (IPS-5100G by Sony) - Computation unit (PIC18F452 by MicroChip) - Belt with buckle	
Modality: Vibration	
Description: The ActiveBelt gives the wearer intuitive directional information. It can be worn without any additional device. It has three applications: FeelNavi (navigation), FeelSense (finding lost object) and FeelWave (rhythmic vibration in synch with music)	
Potential contribution to the project: FeelSense implements idea of 'Easter egg hunt' with vibration. FeelWave is implementation of vibrational gamification	
Ranking: High	
Appearance: It still looks like a prototype, but in general it is unobtrusive and discreet **Handling:** When standing, the indicated directions are recognized within about one second. When walking, and for the pulse intervals of more than 1000msec, changes of vibration are recognized within two steps	

Name: TactileGlove

Size: normal glove

Source: [22]

Commercial maturity: not available

Technical Details:

- Unisized fabric glove;
- 10 vibration motors with 10mm diameter, operated up to 3.3V (stitched on inside of glove). Of these, 8 located on dorsum of hand in a radial layout with 45 degrees spacing;
- Control unit: actuators and sensors connected to RedBearLab Duo Arduino microcontroller with Bluetooth support;
- Motion tracking via OptiTrack system. Glove augmented with four retroreflective markers to be recognized as unique trackables.

Modality: Vibration motors

Description: TactileGlove provides vibrotactile guidance for assistive scenarios where individuals have difficulties to navigate in 3D space. Different vibration patterns are provided as individuals approach targets.

Potential contribution to the project: Vibration patterns and ideal number of actuators on performance have been explored.

Ranking: High

Figure 3: *TactileGlove* prototype showing the (a) dorsum, and (b) palm of a user's hand. Red circles highlight the positions of the vibration actuators and blue indicates the position of the microcontroller.

Appearance: The glove is visible if worn, but its appearance is quite ubiquitous. **Handling:** Through a field study, the authors found that the use of a higher number of actuators leads to better performance. Further, vibration patterns seem to work better when using a pull metaphor (i.e. triggering actuators that are closer to a target) as compared to push (i.e. triggering actuators that are further to a target). However, the hand is blocked for any other activities and both hands are needed to communicate messages.	

Name: HapticHead

Size: Velcro, adjustable size

Source: [23]

Commercial maturity: not available

Technical Details:

- Adjustable Velcro batching cap, with chin strap
- 24 Actuators on outside of Velcro (see Fig 5. For placement). Precision Microdrives 310-117 pico Vibe, 10mm diameter x 3mm height, 150HZ frequency at 3.3V
- Rasberry PI 2 board with wi-fi dongle and standard 5V USB battery pack

Capacity: Connection to USB battery

Modality: Vibration

Description: *HapticHead* consists of a bathing cap with 24 vibration motors distributed in three concentric ellipses around the head to give intuitive haptic guidance hints and to increase immersion for VR and AR applications.

Potential contribution to the project: Through a user study, *HapticHead* led to more precise and accurate results than auditory feedback for the purpose of finding virtual objects in 3D space, but – as expected, less precision than visual feedback.

Ranking: Medium

Appearance: Not very ubiquitous. Actuators and connector cables are visible as they are placed outside of band.

Handling: Low learning effect, as shown in a field study. Participants took half the time to understand the vibration patterns as compared to auditory feedback.

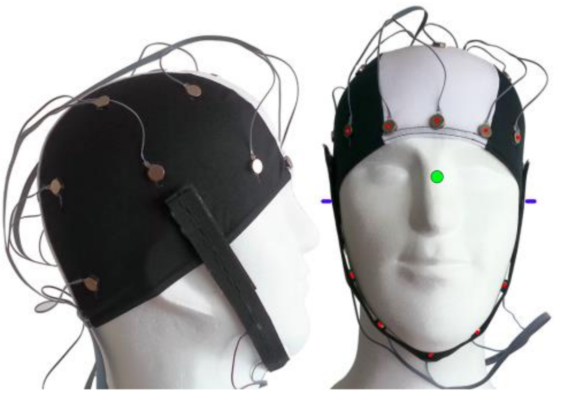


Figure 4: *HapticHead* prototype, side and front view.

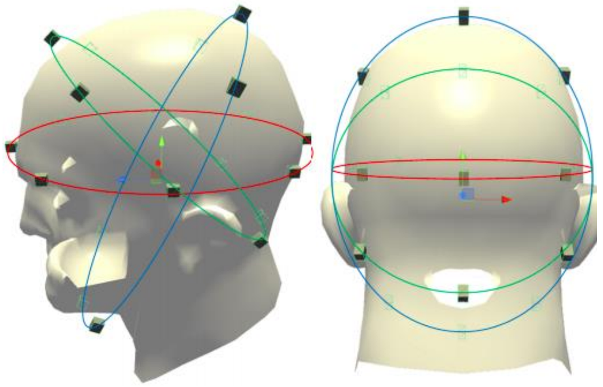


Figure 5: Placement of actuators in *HapticHead*. Note the three concentric ellipses around the user's head and no actuators close to the ear openings. The red ellipse contains 10 equidistant actuators, the green and blue ellipses each contain 7 actuators.

Name: FOLDAWAY

Size: 72 x 66 x 1.7 mm

Source: [15] http://www.foldaway-haptics.ch/index.html

Commercial maturity: not available

Technical Details:

- Actuators at the extremities: two planar layered coils
- Permanent magnets

Capacity: Connection to tablet/laptop etc. needed

Modality: Vibration, Force Feedback

Description: The device has three degrees of freedom and can interact with human fingers by tracking their motion and providing force, stiffness and texture perception. It can be used as a computer mouse, for interaction in virtual environments and can be connected to tablets and laptops using common communication protocols

Potential contribution to the project: It offers interaction with various different devices, which could be beneficial for deafblind persons to use a known device to interact and communicate with various devices. Very portable and cost-effective combined with individual usage.

Ranking: Medium

Appearance: A very small device, looking a bit futuristic. It seems to be delicate in handling

Handling: The handling may be very sensitive, which would need some experience and training for proper usage. It is very handy and can be taken anywhere without any problems.

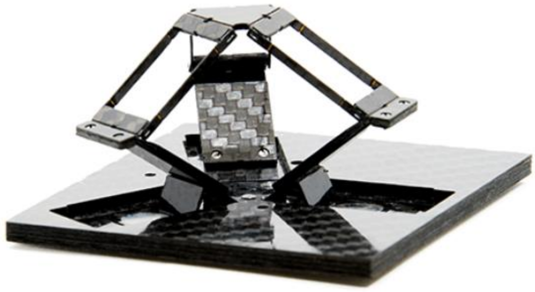


Figure 6: FOLDAWAY popped-up for usage

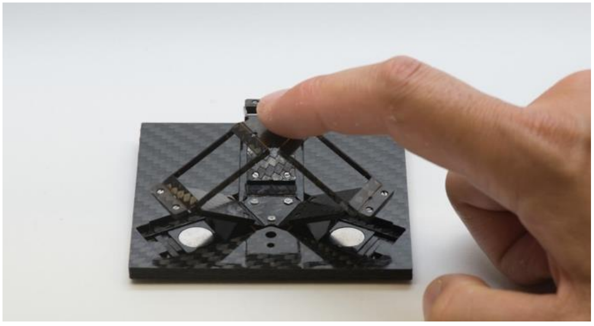


Figure 7: Interaction with FOLDAWAY

Name: Dexmo

Size: slightly bigger than a hand

Source: [16] http://www.dextarobotics.com/

Commercial maturity: not available, but preorders possible

Technical Details:

- Main controller
- Force feedback units (sensor and actuator)
- Upper and lower connectors
- Finger caps
- Compatibility: Oculus, HTC Vive, PSVR, Hololens (among others).

Capacity: Battery power approx. 4hrs

Modality: Force Feedback

Description: It is an inexpensive and lightweight mechanical exoskeleton for usage in VR. Dexmo provides motion capture and force feedback. The hand in the virtual environment is moving according to the movement of Dexmo. If a collision in the VR world is detected, the force feedback units of Dexmo are activated. They lock the joint in point and simulate a grabbed rigid body. The force applied on the users' hand to stop the grab-movement is adjustable, depending on the material of the grabbed object. During motion capture, the exoskeleton is not restricting the movement of the hand.

Potential contribution to the project: Creating the illusion of holding an object, by being stopped by a mechanical exoskeleton. Although, this seems to be strange, the feeling is very natural and intuitive. The result of new and strange things might be beneficial.

Ranking: Low

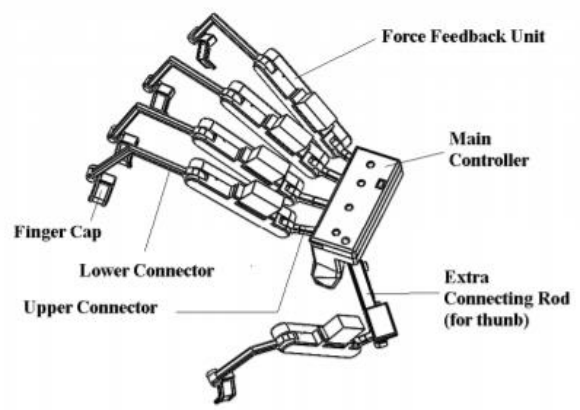
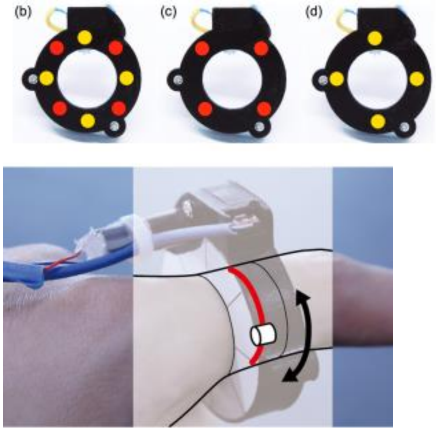


Figure 8: Dexmo mechanical exoskeleton, offering motion capture and force feedback

Appearance: It looks very futuristic and really like a skeleton, not like a glove. It is very conspicuous. **Handling:** The feeling of being stopped by the skeleton may be irritating and a little bit scary. Although, the handling is easy, because grabbing objects and performing movements feels very intuitive and natural.	

Name: Mobile Lorm Glove	 **Figure 9:** Mobile Lorm Glove
Size: normal glove	
Source: [9]	
Commercial maturity: not available	
Technical Details: - Glove of stretchy fabric - 35 round shaped pressure sensors made from piezoresistive fabric, 10mm diameter (input on the palm) - 342 shaftless coin vibrating motors, 8mm diameter, 200Hz (output on the back) - Control unit: actuators and sensors connected to it, 8-bit shift registers and 4 darlington transistor arrays, microcontroller ATmega328 - Bluetooth module	
Modality: Pressure sensors, Vibration motors	
Description: The Mobile Lorm Glove is a mobile communication and translation device for the deafblind. The glove translates the hand-touch alphabet Lorm into text and vice versa. It enables deafblind users to compose messages via fabric pressure sensors to be transmitted as an SMS. Initiated by small vibrating motors located on the back of the glove, tactile feedback patterns allow the wearer to perceive incoming messages.	
Potential contribution to the project: Direct translation of pressure patterns into Lorm alphabet, which forms a very intuitive and straightforward way of encoding information. Vibration and pressure, two modalities combined, one used for encoding, one for decoding	
Ranking: Medium	

Appearance: The glove is visible if worn, but its appearance is quite ubiquitous. **Handling:** The Lorm alphabet needs to be known to interact with this device. If this skill is available, the interpretation of the vibration patterns and the generation of pressure patterns seem to be very intuitive and easy. However, the hand is blocked for any other activities and both hands are needed to communicate messages.	

Name: TactoRing	 **Figure 10:** TactoRing
Size: 20,68mm diameter	
Source: [17]	
Commercial maturity: not available	
Technical Details: - Small DC motor (LCP06-A03V-0136) - 3 spur gears (0,5 module) - Tactor - Infrared sensor G-2BC) - Arduino UNO connected to a PC	
Capacity: power-hungry therefore connected to laptop	
Modality: Pressure	
Description: It is a ring with a tactor dragging on different locations around the users' finger. The pressure felt on different locations can encode different information.	
Potential contribution to the project: Quite a large variety of different patterns on a very small part of the body. Challenge of intuitively encoding useful information into abstract patterns	
Ranking: Medium	
Appearance: The appearance of TactoRing is very unobtrusive, although, a finger and maybe also the whole hand is blocked for other activities. **Handling:** The interpretation of abstract patterns can be tricky and needs practice and individual adjustments. If all 8 locations can be distinguished properly a high flexibility is offered. Still the whole hand with the TactoRing may be blocked during receiving and interpreting the pressure patterns	

Name: A(touch)ment	 **Figure 11:** A(touch)ment, share haptic experiences on social networks
Size: approx. the size of a smartphone, slightly smaller	
Source: [10]	
Commercial maturity: not available	
Technical Details: - DCDC converter (LM27735) - Audio amplifier (AMP15W-8006) - Tactile microphone (PRIMO MX-M4758) - Voltage divider - Haptic actuator, vibration (Tactile Lab Haptuator Mark-II)	
Capacity: Gets power from smartphone	
Modality: Vibration	
Description: The A(touch)ment device is attached to the audio jack and the visual and tactile experience can be recorded simultaneously. The tactile microphone detects vibro-tactile wave data, which is translated into vibration patterns, if requested by a user. Experiences on social networks can be shared visually, but also enhanced with haptic stimuli of the content.	
Potential contribution to the project: Sending haptic signals over a larger distance is very beneficial for deafblind persons! It is not limited to sensations, but also communicative information could be sent.	
Ranking: High	
Appearance: Since a smartphone is hand-held, the attached A(touch)ment is not visible to others. If the prototype is packed into a small box, it is very unobtrusive.	

Handling: The recording and sensing is very easy and intuitive, also the handling with plugging the device into the audio jack is straightforward. For visually impaired people it may be a lot more difficult, since finding the audio jack needs fine motor skills and recording of tactile experiences is more difficult, is the visual cue of the video is missing.	

Name: Tickler

Size: approx. a large band on the forearm

Source: [18]

Commercial maturity: not available

Technical Details:

- Laterally moving, rigid tactile bars
- Compliant frame modulated from Vytaflex 60 rubber
- Shape Memory Alloys (SMAs)
- Strap

Modality: SMAs moving laterally against skin (pressure)

Description: The Tickler is a compliant, wearable, tactile display that creates natural-feeling stroking sensations. It could be used for mediated social touch, to express emotions and affection. The Tickler could also be used as a gentle and unobtrusive means of communicating non-urgent alerts. When the attention of the user is free, the alert gets recognized, if the user is busy, the alert can be easily ignored without finding it annoying.

Potential contribution to the project: Another way of communicating that a loved person has arrived. An actuator which creates a new and unobtrusive modality of sensation.

Ranking: High

Appearance: Currently it looks like a not-finished prototype, but if it is covered somehow, it may look like a normal, unobtrusive band on the forearm.

Handling: Putting the device on and off seems to be easy, even for visually impaired persons. Handling seems simple, as it encodes specific information, but without a lot of variations.

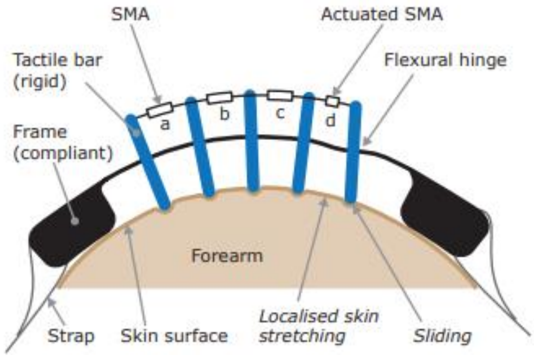


Figure 4: The Tickler simulates stroking

Name: Haptic device for upper limbs rehabilitation

Size: height: approx. 40cm, width: approx. 50cm

Source: [11]

Commercial maturity: not available

Technical Details:

- 5 degrees of freedom (opposition, translation, pitch, yaw and rotation)
- Motors by Maxon (opposition: RE30-268214, others: RE36-118798)
- Sensors: HEDS 55

Modality: Force Feedback

Description: The device can be used for 5 different rehabilitation exercises: rotation, translation, opposition, pitch and yaw. Further, different exercise modes are offered by the device: active, passive, power-assist and hindering mode. Depending on the disability of the patient and the training level, the modes can be adjusted. Active mode stops all motors of the device, the patient need to exert the exercises by own force. Passive mode enables the motors which then perform the exercise without the help of the patient. A partially supported mode is the power-assist mode, where the device helps to perform the exercise, if needed. If the patient is already well trained, the hindering mode needs the most skills: the device tries to discourage the patients' movement.

Potential contribution to the project: The device offers 4 different modes of haptic feedback. Depending on the abilities of the user, the mode can be adjusted and regularly changed to the mode needed at a specific

Figure 5: Haptic device for rehabilitation

moment. The modular design is very important and beneficial.	
Ranking: Medium	
Appearance: The device is stationary and quite large. It looks very technical and is not easy to transport anywhere. **Handling:** The handling of the device seems quite complex. Before using it properly, detailed instruction is required. If active or hindering mode is active, it is necessary to already know the movement.	

Name: The Haptic Chair

Size: Size of a chair with footrest

Source: [19]

Commercial maturity: not available

Technical Details:

- ‘Poäng’ chair by IKEA, with footrest
- 4 Contact speakers (SolidDrive™ SD1 and Nimzy™ Vibro Max)
- Wooden domes on the armrests
- Accelerometer (3041A4, Dytran Instruments, Inc.)
- Data acquisition module ((USB-6251, National Instruments)
- Laptop with LabVIEW™ 8.2

Capacity: Connected to a laptop

Modality: Vibration

Description: The Haptic Chair generates vibrotactile stimuli according to audio signals (music). The vibrotactile stimulation is applied on different parts of the body, such as palm, feet or the head. Deaf users reported to enjoy the experience of feeling music.

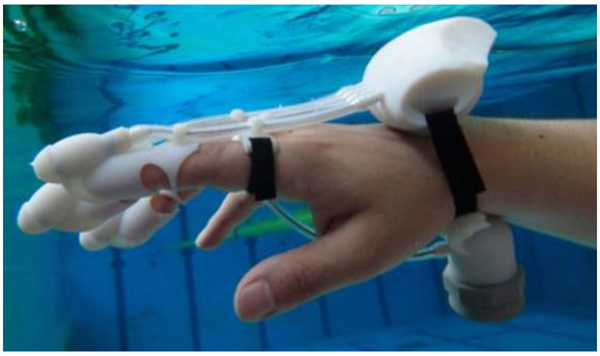
Potential contribution to the project: Making something which relies on the visual or hearing channel assessible for deafblind persons, by translating the signals into vibrotactile stimuli.

Ranking: Medium

Appearance: It looks like a normal chair, the domes on the armrest are not obtrusive. With a nice textured cotton cushion it even looks nice and comfortable.

Handling: The plugin of audio devices may be a little bit tricky for deafblind persons. If the music is turned on, the user just have to enjoy the vibrotactile version of his favorite music.

Figure 6: Haptic Chair

Name: IrukaTact	 **Figure 7:** IrukaTact
Source: [12] http://www.aisencaro.com/iruka.html	
Commercial maturity: not available, but DIY toolkit provided	
Technical Details: - Arduino Pro Mini 5v - FTDI cable 5v - MaxBotix Sonar sensor (MB7066) - 3 mini Motors - NPN Transistor - LiPo Battery - Silicone Tubing - Rainbow wiring cable - Header Pins - Velcro - Motor Waterproofing grease - Silicone O-ring - Detecting range: 2 feet - Do-it-yourself instructions	
Capacity: LiPo Battery	
Modality: Pressure	
Description: IrukaTact uses a combination of sonar and haptic feedback to detect distant objects underwater. It was inspired by echolocation of dolphins. When approaching to an object, the pressure on the fingertips increases.	
Potential contribution to the project: Obstacle detection of distant objects via pressure and sonar localization	
Ranking: Medium	
Appearance: The device looks very futuristic and strange. It is small and portable, but not unobtrusive.	

Handling: IrukaTact can be used by moving the hand and feeling differences in pressure feedback. Although, the handling seems to be quite easy, the glove is covering the hand and blocks any other activities using this hand. The device can be very useful in surrounding with bad visual conditions.	

Commercially available haptic devices

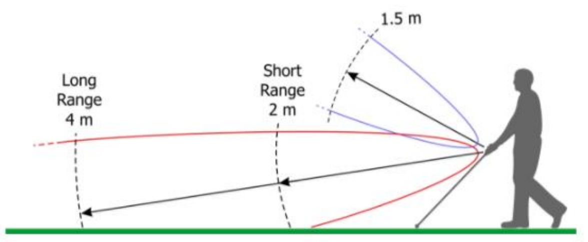


Figure 8: UltraCane

Name: UltraCane
Size: 110 – 150cm (packed 25 – 30cm)
Source: https://www.ultracane.com/ [4]
Cost: ca. 720€
Commercial maturity: available
Technical Details: - Ultrasonic sensor - Vibration actuators - Different tips (rolling ball and roller) - 2 AA batteries
Capacity: 2 AA batteries
Modality: Ultrasound and vibration
Description: The UltraCane permits navigation around obstacles both in the user's forward path and just as importantly, giving valuable protection at head/chest height. By emitting ultrasonic waves from two sensors the UltraCane detects obstacles up to 1.5 metres ahead at chest/head height and 2 or 4 metres on the ground. To inform the user of an obstacle the UltraCane gives tactile feedback through two vibrating buttons on the handle over which the user places their thumb.
Potential contribution to the project: Navigation device using ultrasonic sensor, encoding information from two directions with vibration, but on different locations. One-handed device
Ranking: Medium
Appearance: The UltraCane looks like a cane indicating a person with visual impairments. **Handling:** Information extraction with one hand, but two vibrating buttons need some practice

Name: TeslaSuit	 **Figure 9:** TeslaSuit for VR and AR experiences
Size: full-body suit	
Cost: estimated approx. 1340 – 2340€	
Source: https://teslasuit.io/ [1]	
Commercial maturity: not available, but preorders possible	
Technical Details: - 46 haptic points - Electro-tactile stimulation: TENS (Transcutaneous Electrical Neural Stimulation) EMS (Electrical Muscle Stimulation) - Weight simulators - 14 motion capture sensors - On-board data processing - Offline animation recording - Compatibility: Unreal Engine, Unity 3D, MotionBuilder - 4-10 thermo climate points - Temperature range: 20 - 40°C	
Capacity: 3-4 days of gaming	
Modality: Thermal, electrical stimulation, pressure	
Description: Different actuators are imitating soft touch, warm rain, heavy impact, cold, … 46 haptic points, weight simulation and motion and location capture for virtual environments. The user can also define custom animations. TeslaSuit is a thermo controlled, motion capturing, full-body haptic feedback suit which should enhance the user experience of AR or VR environments	
Potential contribution to the project: The suit gives completely new insights in different sensations which can be simulated on the	

body by electrical stimulation. Get inspiration by the electrical and thermal stimulation	
Ranking: High	
Appearance: It looks like a superman or military suit, kind of futuristic and a little bit scary. Of course, a head-mounted display (HMD) for VR or AR needs to be worn which makes the awareness of the real-world environment difficult, but enhances immersion **Handling:** It will be introduced into the market around next year. The handling will be very easy, since it only need to be put on and all haptic feedback and motion capture will be triggered according to the Application used with the suit. The user only has to feel and maybe edit custom stimulation or change stimulation strength.	

Name: Lane Departure Warning System (LDWS)

Size: approx. 35-40 cm outer diameter

Source:
https://www.hyundai.news/eu/model-news/genesis-active-and-passive-safety-features-protects-and-assists/ [6]

Commercial maturity: available

Technical Details:

- Vibrational elements in steering wheel
- Light
- Camera at the top of the windshield recognizing an unintended lane crossing

Modality: Vibration

Description: If the driver crosses lanes without indication (blinking), two types of feedback are provided: a warning light and vibration from the steering wheel. The attention and the eyes of the driver should focus on the road and not on visual cues. Vibrational feedback is also used for the Blind Spot Detection System (BSD).

Potential contribution to the project: Important information is intuitively translated from visual cues to haptic feedback.

Ranking: Medium

Appearance: The LDWS is not visible, it can only be felt if lane crossings are detected

Handling: Vibrations in the steering wheel may be surprising and confusing. Redundant information (vibration and visual cue) are beneficial for fast processing, which is needed in dangerous situations.

Figure 10: Vibrating steering wheel of Hyundai Genesis

Name: Taclim VR Shoes	 **Figure 11:** Taclim VR Shoes
Size: (300-360) x 100 x 140 mm	
Weight: 950g	
Cost: estimated approx. 800 – 1200€	
Source: https://taclim.cerevo.com/en/ [2]	
Commercial maturity: not available, but preorders possible	
Technical Details: - Batteries - 9 axis sensors (acceleration, gyroscope, geomagnetism) - Pressure sensor - Walking detection sensor - 8 tactile motors - WiFi	
Capacity: approx. 5hrs	
Modality: Vibration	
Description: Taclim Shoes give tactile feedback to your feet and transmits foot movements via 9-axis sensors. Additional trackers for different VR devices can be attached (e.g., HTC Vive). Real-world walking is transferred into the virtual world and soil conditions, such as water, grass or sand are simulated by the shoes.	
Potential contribution to the project: Considering several body parts, not always torso and upper-limbs, also feet could offer beneficial information.	
Ranking: Medium	
Appearance: The shoes look clumsy and not very comfortable. Instead, if they are designed like normal shoes, they are really inconspicuous.	

Handling: The handling should be straight forward. Because of the clumsy design, the shoes are easy to put on and off and you just have to feel what they are simulating. Maybe it takes some practice to recognize what is simulated.	

<table>
<tr><td>Name: White Falcon 3D Haptic Controller</td><td rowspan="13">
Figure 20: The White Falcon</td></tr>
<tr><td>Size: 22 x 28 x 24 cm</td></tr>
<tr><td>Weight: 2.8kg</td></tr>
<tr><td>Cost: approx. 230€</td></tr>
<tr><td>Source:
https://hapticshouse.com/products/white-falcon-3d-touch-haptic-controller [20]</td></tr>
<tr><td>Commercial maturity: available</td></tr>
<tr><td>Technical Details:
- USB 2.0
- 1000Hz output forces
- 3 arms to move in and out the body
- 3 motors</td></tr>
<tr><td>Capacity: Connected to laptop/PC etc.</td></tr>
<tr><td>Modality: Force Feedback, touch</td></tr>
<tr><td>Description: It is a device offering 3 degrees of freedom and force feedback. The Falcon can be plugged into a computer, which can keep track of the handles’ movement. It can simulate a detailed sense of touch including surfaces and textures, game effects like gun recoil or impact forces, and even medical simulation</td></tr>
<tr><td>Potential contribution to the project: The device can be individually used. It is just plugged in to a computer and everyone can use it for different tasks ranging from games, over VR, 3D modelling and animation, visualizations to medical simulations</td></tr>
<tr><td>Ranking: Low</td></tr>
<tr><td>Appearance: The Falcon looks very futuristic and seems to be a large version of a normal mouse. It is not handy and certainly not very easy to transport.</td></tr>
</table>

Handling: Handling seems to be very precise, which also means that practice is needed to adequately use the highly precise performance of the Falcon. The feeling of surfaces, textures and game effects is very beneficial for different uses.	

Name: Brailliant BI 32	 **Figure 21:** Brailliant BI 32 for communication for deafblind persons
Size: 26 x 8,7 x 1,8 cm	
Weight: 524g	
Cost: approx. 2100€	
Source: http://www.humanware.com/en-usa/home [5]	
Commercial maturity: available	
Technical Details: - USB 2.0 - Bluetooth V2.1 - 4 thumb keys - 6 command keys - 8-key braille keyboard - 2 spacebars - Cursor router keys - Compatibility: Windows, Jaws, Windows-Eyes, iOS, Mac, NVDA, System Access - Lithium-ion polymer battery	
Capacity: approx. 20 hrs	
Modality: Tactile	
Description: Communication device for reading and writing on a computer or smartphone for blind or visually impaired persons. It can be paired via USB or Bluetooth. Every document, text message or webpage is displayed in Braille at the lower Braille display and entered Braille texts via the keys are translated into normal text on the screen	
Potential contribution to the project: A haptic device making normal internet browsing and work on a computer assessible for deafblind persons.	

Ranking Medium	
Appearance: The Brailliant BI 32 is portable and handy, but not too small for good usability. The keys are very tactile and structured **Handling:** The device can be connected to various systems and a wide variety of interactions can be performed. Learning all feature certainly needs some time and needs regular practice. Understanding the different concepts of documents, browsing, webpage layout and interactions are complex and need higher-level cognitive abilities and understanding.	

Name: UltraHaptics (TOUCH and STRATOS)	 **Figure 12:** Array with ultrasound speakers by Ultrahaptics
Size: approx. the size of a hand, slightly larger	
Cost: approx. 2300€	
Source: https://www.ultrahaptics.com/ [21]	
Commercial maturity: development kit available	
Technical Details: - Leap Motion camera for hand tracking - Ultrasound speakers (14x14 or 16x16 transducer array) - Control board - 5 frame mounted cover materials (2 metals, 3 acoustic fabric) - Software Development Kit - Support for Windows, OSX, Linux - Multi-region power supply	
Modality: Ultrasound	
Description: An array of ultrasound speakers is used to create a noticeable pressure difference on a users' hand. This creates a feeling of touching something which is not actually there. Every interaction which can be done on a touch pad is theoretically also manageable with the devices from UltraHaptics. Possible application areas: industry, medicine, smart home, education, entertainment, …	
Potential contribution to the project: The device creates the haptic feeling of anything which is not there and normally cannot be seen	
Ranking: High	
Appearance: The device looks unobtrusive, but also does not offer a hint what it is	

doing. A detailed introduction is needed to get the functionality and usage. It is small and portable **Handling:** It can be quite difficult to recognize the actual shape of the object a user is 'touching'. Placing gestures of interactions on the correct position also needs some practice. UltraHaptics introduces a totally new modality which needs learning and practice to interact with it properly.	

Name: Tactus Technology Tactile Touchscreen	 **Figure 13:** Tactile touch screen of Tactus
Size: Size of a touch display	
Source: http://tactustechnology.com/ http://tactustechnology.com/wp-content/uploads/2014/08/White-Paper-New-Tagged-PDF.pdf [7]	
Commercial maturity: not available	
Technical Details: - Fluid for raising the keys - Flexible covering - Polymer base	
Capacity: No batteries, works with a pump	
Modality: Tactile, touch	
Description: In normal use, the touch display is just flat. If the user needs a keyboard, tactile keys are raised, offering haptic feedback while typing. It works by having some fluid between a polymer and the elastic covering.	
Potential contribution to the project: The tactile buttons make normally only visually perceivable touchscreen keyboards tangible	
Ranking: Medium	
Appearance: The touch display looks normal and the tactile buttons are only tangible and visible when needed. Otherwise, they are hided and not present. **Handling:** The user can interact normally with the touch display the visual cues of the keyboard keys are supported by tangible keys. Usually the tangible keys are triggered automatically, it would be useful to have the opportunity to also trigger them manually.	

Conclusion

Hard, haptic devices are developing very quickly. One major reason is the developing technology of Virtual Reality (VR). Haptic gadgets supporting immersive gaming experiences, innovative therapy approaches, and new marketing strategies emerge continously. Especially, in VR games, haptic feedback is a valuable method to enhance immersion and user experience. As previously presented in this list of hard, haptic devices, the predominant modality used for haptic feedback is vibration. Vibration marks a common way to communicate alerts to users, such as a vibrating smartphone when a call comes in, or rumbling controllers marking violations in a console game.

By now, an increasing number of other haptic feedback modalities, such as thermal, ultrasonic and electro-tactile stimuli, are tested. Potential fields of application for those modalities are examined by numerous scientists. There are already great approaches of hard, haptic devices combining easy and classical components to clever and innovative devices with great results in user studies (e.g., Electro-tactile stimuli on the forehead [8], TeslaSuit or Haptic chair [19]). However, most of the devices seem to get stuck on a prototype level and never reach the maturity for market introduction. But even if the developments are not yet as promising as expected, it is necessary to improve the field of haptic feedback and to extend the range of its application. Although, gadgets offering haptic feedback enhance immersion and fun in games, there are groups of persons who rely on haptic feedback completely. For example, for rehabilitation purposes and for persons with visual impairments or deafblindness tactile feedback is mandatory. SUITCEYES tries to forward the level of development in haptic feedback and aims to extend the range of its application on persons with deafblindness.

A great advantage of devices offering haptic feedback, is the intuitive control. Many devices do not need any control or command, they usually just translate some recorded signal into haptic feedback (ActiveBelt [13], IrukaTact [12], Tactus Technology Tactile Touchscreen [7], ThermoReal [20], and many more). The only requirement for users is the ability to interpret and understand the transmitted feedback and eventually react on it.

Another development, which is especially favorable for the SUITCEYES' project, is the rising importance of design. Nowadays, not only functionality, but also design and appearance of a technical device matters, e.g., DuoSkin [14]. If persons that experience disabilities use good looking, or at least, unobtrusive assistive devices, they feel much more self-confident and maybe even proud to use it. Although, some assistive devices inform their surrounding about a specific disability (e.g., white cane), it may be preferable in some cases to support people that experience disabilities in a discrete way. The rising importance of design is a beneficial development in this case, offering SUITCEYES the opportunity to support persons with deafblindness in an unobtrusive, but highly effective way. In parallel with the rising importance of design, also functionalities increasing fun and user experience are gaining more attention. Today's devices need to be more than just functional. They need to also enhance user experience and offer entertainment (ActiveBelt [13], Haptic Chair [19]). This is especially relevant for devices which are natively not designed for games and entertainment.

To summarize, there is already a large number of highly promising developments in hard haptic devices, representing mainly scientific results or products which are not yet commercially available. Further, there are several attempts to extend the range of haptic feedback modalities to thermal, electro-tactile, pressure and ultrasonic stimuli. And even though, many areas may profit from further developments, such as therapy, game industry and marketing, there is still need for improvements.

As next steps, we intend to draw inspiration from the elaborated review to design our own haptic device. A main focus will be placed on drawing insights from the devices identified as having a potentially high contribution to our project. We intend on deepening our understanding the potential, and limitations of these devices, and understand how these devices can be extended from being hard to soft - with the aim of being ubiquitous, and serving as a communication tool.

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