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Design Guidelines for a Non-Visual AR Gaming Application Using Haptic Feedback

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Abstract of Master's Thesis of Academic Year 2018

Design Guidelines for a Non-Visual AR Gaming Application Using Haptic Feedback

Category: Design

Summary

In recent years, smartphone usage has drastically increased, not only to look up information or talk to friends or colleagues, but also for mobile gaming, which generates 51% of global revenue in the gaming industry as of 2018. GPS, mobile internet and features like motion tracking brought the rise of augmented reality (AR) games, one of the most successful ones being Pokémon GO, released in 2016, which focus mainly on augmenting visual experiences.

However, constant phone usage and the resulting distraction of the visual sense pose dangers for traffic and the pedestrians themselves. Therefore, this project aims to design a concept for a new type of non-visual AR gaming experience inspired by yōkai by introducing a game concept for a smartphone application paired with a wearable device in form of a haptic collar that provides an immersive gaming experience utilizing spatial audio and haptic feedback without distracting visuals. Based on the results of 4 user studies with 2 prototypes focusing on different aspects of the gaming experience, design guidelines for non-visual AR gaming applications are defined.

Keywords:

Augmented Reality, Non-visual, Haptic Collar, Haptic Feedback, Immersion, Yokai, Location-based Gaming

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Chapter 1
Introduction

In 2016, the author found herself among many people who roamed around the streets, explored new neighborhoods and decided to walk an extra mile just to hatch an egg – Pokémon GO was just released and hundreds and thousands of people all over the world fell for the Pokémon frenzy.

While the game itself and its consequences like the mass accumulation of players in city centers were equally praised as well as criticized, the author noticed that something about her perception of the environment had changed. The same streets, the same places she had been walking uncountable times before suddenly were full of wonders. Little things she had never noticed before – small statues on walls of buildings, artful graffiti, little pieces of art and easily overlooked artifacts – suddenly became meaningful by being turned into PokéStops, points of interest in the game that provide the player with useful items. The author was shocked how little she had noticed about her surroundings even in places she thought she knew in and out. The author's desire to share this feeling of a re-connectedness with the environment around her has led to the creation of this research project, which aims to provide an enjoyable and immersive gaming experience, while switching the focus from the smartphone screen to the real world.

1.1. Overview

Contemporary technological advances have led to an increased use in mobile technologies. A statistic from 2017 that summarizes a worldwide survey shows that around half of the respondents spend an average time of 5 or more hours per day on their mobile phones (Statista 2017). This is reinforced by the communications regulator Ofcom, which conducted a study in the UK and found out that 93% of the population owns a smartphone, and users spend approximately 20 hours per week online on their phones, which is more than on any other device, like laptops or desktop-computers (Ofcom 2015). Nowadays, access to the world lies in our pockets. We look up information, consume news and entertainment, communicate with friends, family and colleagues, we purchase goods and transfer money, everything is just one click away. However, those recent changes do not have only positive effects. The World Health Organization even listed addictive phone mobile us as a public health issue (World Health Organization 2015). How addicted people are to their mobile phone screens can be derived from the ongoing campaigns of Japanese train companies to raise awareness of this problem to create a safer environment and prevent accidents by promoting no texting while walking (see fig. 1.1).

Figure 1.1 Campaign poster of the Tokyu Corporation to promote no texting while walking

Research also suggests a correlation between increasing pedestrian distraction caused by mobile phones and increasing traffic accidents (Kuss et al. 2018). Unlike suggested on the campaign photo by the Tokyu Corporation, it is not only texting that is responsible for accidents. A study suggests that the previously mentioned smartphone game Pokémon GO had indirectly caused over 100,000 traffic accidents, with "the likelihood of an accident occurring within 100 meters of a PokéStop was 26.5 percent higher" (Jones 2017).

Mobile games should be fun and entertaining, but if players might endanger themselves and others by being visually distracted, this poses the question of how we can create enjoyable experiences and games that do not distract our visual sense from what is important: our physical surroundings.

1.2. Objectives

This research is aimed to design a concept for a new type of gaming experience in form of a smartphone app paired with a wearable device that generates an immersive experience without using visuals. The overall objective of this research can be stated as follows:

1. To provide an enjoyable gaming experience that users want to engage in
2. To find out whether users can be navigated safely and accurately with haptics and without visuals
3. To explore new ways of immersing the user
4. To find out which combination of sensory stimulation can increase immersion
5. To create a first attempt in defining design guidelines for navigation and immersion for non-visual augmented reality gaming applications

1.3. Contributions

In this thesis the author proposes a concept for a non-visual augmented reality gaming application that uses audio and haptic feedback in form of vibration and thermal sensation to immerse the player multimodally in the game and derives guidelines for the creation of such a game application. The main contributions are the following:

- **Design guidelines** A first attempt at creating design guidelines for non-visual augmented reality gaming application using haptic feedback
- **Game concept** Design of a location-based and non-visual augmented reality game concept that focuses on non-visual stimuli for navigation and to enhance immersion
- **Artefact** A wearable haptic feedback device in form of a collar to be paired with the smartphone game that triggers the haptic feedback synchronized with the audio narrative/sound effects
- **Results of 4 user studies**
- **Social effect** Players are discouraged to look at their phones while playing which is to encourage awareness of their surroundings

1.4. Thesis structure

This work is comprised of 6 chapters.

The first chapter summarizes the author's motivation for conducting this research and creating the game design, as well as lays out the contributions for this field.

The second chapter gives an overview of related concepts and works that were used as inspiration for the research.

In the third chapter, the author describes the final design concept. It contains a description of the the overall game concept, the haptic feedback device and the flow of an example quest to illustrate the concept. In the end of the chapter, the target persona of the proposed design is outlined.

Chapter four lays out the prototyping iterations behind the design decisions for navigation and immersion and describes the experimental setups as well as discusses the results of the user tests.

The fifth chapter is dedicated to a summary and expanded discussion of the user test results.

In chapter six the author concludes this thesis with a first attempt at defining guidelines for non-visual augmented reality gaming applications using haptic feedback and introduces further potential of the work.

1.5. Key Terms

Key terms used in this work are the following. Definitions were taken from or based on the Oxford Dictionary unless specified otherwise.

Location-based gaming, designating a software application/game which identifies the physical location of a computer, mobile phone, etc., and uses this to help determine how it responds to input from the user; relating to or involving such an application.

Augmented Reality, a technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view. This definition will be challenged and expanded in chapter 2.2.

Haptic Feedback, feedback relating to the sense of touch, in particular relating to the perception and manipulation of objects using the senses of touch and proprioception.

Navigation, the process or activity of accurately ascertaining one's position and planning and following a route.

Immersion, deep mental involvement in something. In the gaming context, immersion is related to multimodal perception and interaction and can be achieved by substituting as many real world sensations with sensations that are corresponding to the virtual environment (Mestre 2018).

Chapter 2
Background

The following chapter introduces various concepts that are important for the creation process of the proposed game design. Each chapter gives a brief overview about the concept and selected related work examples where applicable.

2.1. Location-based Games

With the rising popularity of mobile phones, 'mobile gaming' also started to enjoy great popularity. Usually, when using the term mobile gaming, it is referred to games played on the cell phone – or nowadays smartphone – screen (Rodriguez 2006). With the global positioning system (GPS) becoming a staple in mobile phones, the phone screen is turned into an interface for navigating physical spaces (de Souza e Silva and Hjorth 2009). De Souza e Silva and Hjorth refer to Johnson, who already back in 2003 suggested that mobile technologies might add additional value to physical spaces by adding a digital layer of information. As an example he mentions location-based services that could trigger "digital information" to appear at specific locations or places that then can be accessed by the user on their cell phone when they enter the range of the attached information. This vision is now daily reality with GPS equipped smartphones, mobile internet and a variety of smartphone applications including pre-installed mapping apps that let the user not only navigate their surroundings but also add the mentioned layer of various digital information onto the map. Also, mobile gaming has evolved drastically in the recent years, moving from handheld consoles like the Nintendo DS or the Sony Playstation Vita to smartphones. Mobile games made "51% of global revenues in the gaming industry" in 2018 (Go-Globe 2018) and still expect future growth. Many mobile games make use of the GPS feature, linking the game world to the real world. Prominent examples of recent location-based games that introduce concepts similar to the proposed game design concept are *Geocaching*, *Fog of World* and *The Walk*, which will be introduced in the following.

Geocaching Geocaching can be best described as a "GPS-enabled treasure hunt" (O'Hara 2008). Players are hiding a waterproof container in a specific location, publish the latitude and longitude of the container location on a geocaching website for other players, so-called "geocachers," to find. Ever since the first geocache was hidden in 2000, the hobby has grown into an international sensation, counting over 3 million active caches in 191 countries in 2017 (Kettler 2017). Geocaching has evolved over time from a community-run website into a smartphone app by Groundspeak Inc.[1] for iOS and Android, which made Geocaching an even more easily accessible hobby (see fig. 2.1). The app is available for free, however, a subscription-based premium membership can be purchased for additional geocaches and functions.

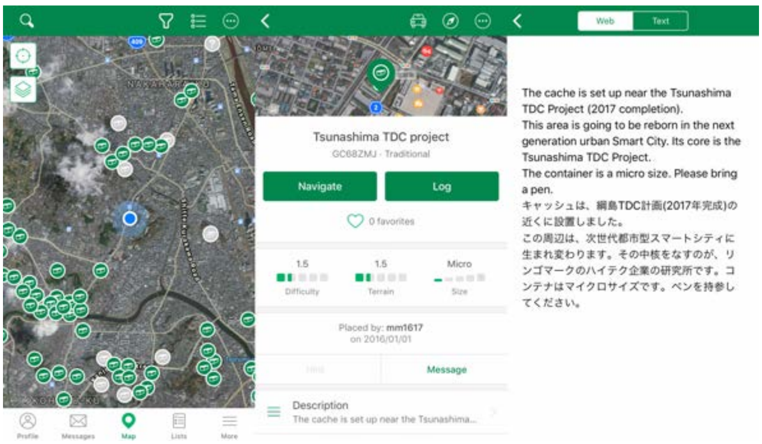

Figure 2.1 Screenshots of the Geocaching App for iOS. Left: "Map" menu; center: selected geocache; right: detailed description of the geocache location

Users can see available geocaches (green) and geocaches only available for premium members (grey) on the start screen, which is the "Map" menu tab. When the user clicks on one of the available caches, various information, like the difficulty to reach the geocache, the difficulty of the terrain and the size of the cache are displayed. Is also shows which user placed it there, when it was placed and when it was first found. Also, additional information can be retrieved, e.g. such as if dogs are allowed in that area, if there is a time constraint as well as information about accessibility by public transport. Geocaching can be a fun hobby, however, sometimes the geocaches are micro-sized and hidden in locations that are difficult to reach like inside of fences or buried in the ground far off the normal streets. Therefore, the game requires a high amount of commitment and might be time consuming if the cache cannot be found at once or is located in more remote locations. This is of course what makes the game more challenging and fun, but might discourage potential users with limited time or more casual gamers to play it.

Fog of World Fog of World is a location-based game for iOS and Android by Ollix, that encourages the player to explore new areas, cities and even countries [2]. The world map is covered in fog, similar to the so-called 'fog of war'[3] that lifts over the paths that the player has walked. Over time they create their own map of trails that reflect their personal journey and memories. While exploring streets and areas and thereby leaving new trails, the user gains levels and receives badges for certain achievements (e.g. the 'Roman Empire' badge for visiting 10 countries that were invaded by the Roman Empire). Also, it keeps track of countries the user has been to. The price is with 10,99 EUR (approx. 12.53 USD) quite high.

(Source: Apple App Store)

Figure 2.2 Screenshots of the Fog of World app for iOS. From left to right: user profile, world overview, Europe overview, detail view of Germany

Fog of World is a rather passive game that tracks the user's location information and presents it in a gamified way, however, there is no real active gameplay other than walking around and exploring the area. Also, since it works in the background, it is a nice record to have, but might not necessarily encourage users to go out over a longer period of time.

The Walk The Walk by Six to Start and Naomi Alderman created in collaboration with the NHS (the National Health Service of the UK) is a gamified fitness tracker game. The player finds themselves in the role of an involuntary undercover agent who has to fulfill a secret mission on which they are guided by their personal assistant, who speaks to them over a special earring. The story is divided into 65 chapters and challenges, which share a common goal: to make the player walk 10,000 steps per day. The chapters are unlocked one by one by walking for a certain amount of minutes and the player receives badges by fulfilling certain criteria, e.g. finishing one chapter within a day. The game is not so much location-based in the sense that it reflects the current location of the user, but uses the amount of steps the user took in the real world to proceed the game. However, the app only counts the steps once a mission is started, which results in no progress if the user forgets to do so. Sometimes the user has to choose which way to proceed when they reach a fork in the game, which increases the value of repeating a chapter. The chapters can be played in the background and do not require any action so they can be listened to while walking or running just like audio books and are best experienced with earphones since it adds to the secret agent flair of the game. The visuals except for rough stylized pictures of the chapter area are left to the user's imagination (see fig. 2.3) and therefore the game solely relies on audio to immerse the player and keep them motivated to walk more.

The first five chapters and challenges are free to play, the remaining chapters can be unlocked by a one time purchase of 5.49 EUR (approx. 6.26 USD). While The Walk is praised for its engaging storyline and voice acting, it is basically an enhanced version of an audio book that unlocks its chapter after a set amount on steps is reached.

As described earlier, many location-based gaming applications add a digital layer onto the real world, which can simply be a narrative, but also other virtual game elements. A more recent development or evolution of this are augmented reality (AR) apps and games. AR is defined by the Oxford Dictionary as "a

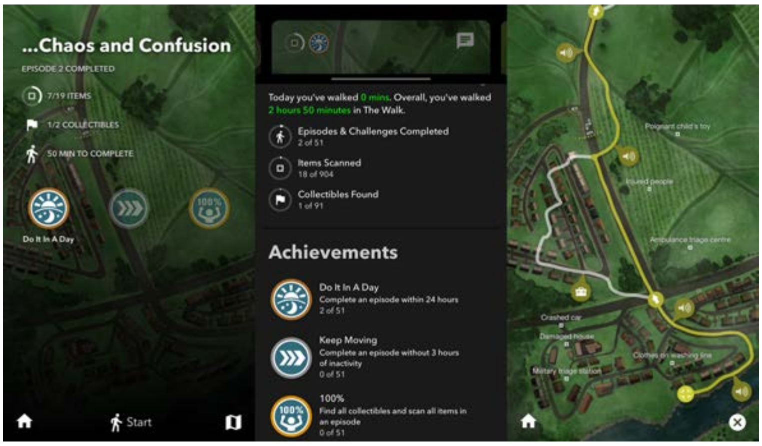

Figure 2.3 Screenshots of The Walk app for iOS. Left: chapter overview, center: current challenge and achievements, right: area map of a chapter including fork

technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view." (Oxford English Dictionary 2018). The following chapter will provide a deeper understanding about what AR is and will challenge the notion of AR as a solely visual concept.

2.2. (Non-Visual) Augmented Reality

Augmented Reality can be more than meets the eye.
– Schraffenberger, H.; van der Heide, E.(2016)

As stated above, AR is oftentimes seen as a solely visual experience, overlaying virtual images onto the real world. Coming from this point of view, most existing research about AR is focusing on the visual element of AR. In 1990, when Caudell and Mizell coined the term 'augmented reality,' they explicitly referred to the visual component, proposing a Heads-up display in order to "augment the worker's visual field of view" (Caudell and Mizell 1992) by overlaying virtual imagery on the worker's visual reality. This view is shared by many other researchers. Piekarski and Thomas see AR as "the process of overlaying and aligning computer-generated images over a user's view of the physical world" (Piekarski and Thomas 2002). Similarly, Reiners et al. claim that "Augmented Reality is a technology that integrates pictures of virtual objects into images of the real world" (Reiners et al. 1998). Likewise, Doyle, Dodge and Smith describe AR as "a technology in which a user's view of the real world is enhanced or augmented with additional information generated from a computer model" (Doyle et al. 1998). AR was first used for navigation in NASA's X-38 spacecraft in 1998, but soon found its way into the gaming sector. The first AR game AR Quake was launched in 2000. Back then, the player had to wear a head-mounted display as well as a backpack with a computer and gyroscopes (Piekarski and Thomas 2002). The first mobile AR game was AR Tennis, a game for 2 players for Nokia phones released in 2005 (Yianni 2018). In the following years, AR technology has been made widely available by the spread of smartphones and the development of more powerful chips that enable motion tracking for more immersive AR experiences (Apple Inc. 2018). Selected AR games – Pokémon GO and Zombies, Run! – will be introduced in the following.

Pokémon GO Pokémon GO is an AR game by Niantic Inc. released in 2016 based on the popular video game franchise Pokémon and its pocket monsters. In contrast to their handheld console games, players have to wander around their physical neighborhoods, collecting Pokéballs and other necessary items at PokéStops, encounter Pokémon on their way and fight in virtual Pokémon gyms. Players are divided into 3 different teams that fight about ruling over the gyms, which – same as PokéStops – are places from the real world like landmarks or buildings that players have to go to in order to be able to interact with it in the game. As Hjorth describes it, "[t]hrough this augmented layering of the digital onto place, banal and familiar surroundings are transformed to become significant game loci" (Hjorth and Richardson 2017). Pokémon can therefore be found in one's living room, in a cafe, the library or even a graveyard and enabling the AR mode during wild Pokémon encounters (see fig. 2.4) makes it look like they are appearing right in front of us. Although Niantic had launched its first AR game Ingress that follows similar principles back in 2012, it was not until Pokémon GO was released 4 years later that AR had a breakthrough in the mass market and became a widespread concept not only in research, dubbing Pokémon GO the "first ever really successful location-based game" (Hjorth and Richardson 2017). Since its original release in 2016, various updates introduced new generations of Pokémon, weather effects that are based on the real world weather, being able to add friends, fulfill missions to find rare Pokémon and – recently – to trade Pokémon and battle other trainers.

Figure 2.4 Screenshots of the Pokémon GO app for iOS. From left to right: start screen, PokéStop, Pokémon gym, encounter with a wild Pokémon in AR, mission menu

Although Pokémon GO has lost a lot of its hype compared to when it was first released in 2016, according to analyst firm Superdata, Pokémon GO had 147 million active users in May 2018, which are more users than it ever had back in 2016 (Tassi 2018). Although Pokémon GO still seems to be popular, it mainly relies on the same features as its predecessor Ingress (now "Ingress Prime") as well as recent 'competitor' games featuring other famous titles like "Harry Potter Wizards Unite" (also by Niantic)[4] and "Jurrassic World Alive" (by Ludia) [5], which also use mapping data and visual overlay on the physical world accessed through the smartphone's camera.

But how can we experience augmented reality non-visually? Although the visual element of AR has been the prominent one in research, other researchers like Schraffenberger and van der Heide are challenging this point of view, making a case "for an experience-focused and modalities-encompassing understanding of AR" arguing that "multimodality in AR is the norm rather than the exception, as AR environments consist of both virtual content and our real, physical, multimodal world." (Schraffenberger and van der Heide 2016) The notion of AR not being exclusively limited to the visual sense but combining the visual and other senses is not entirely new. Already back in 1997 Azuma proposes in his review of AR that "Augmented Reality might apply to all senses, not just sight" (Azuma 1997). As an example he suggests that "AR could be extended to include sound," namely synthetic spatial sound that might cancel out real world sounds. Azuma et al. then expanded this image of AR by emphasizing that "AR can potentially apply to all senses, including hearing, touch, and smell" (Azuma et al. 2001). Unfortunately, most possibilities for multimodal or crossmodal AR are described as ways to support the vision-focused AR research rather than substituting it.

Zombies, Run! One common approach is to tell a story via audio, similar to the concept described in The Walk. The self-dubbed "augmented audio" (Six to Start 2011) game Zombies, Run! by Six to Start and Naomi Alderman, the same team who developed The Walk, released Zombies, Run! as a fitness app in 2012. The player takes on the role of Runner 5, one of the few survivors of the zombie epidemic, on the way to one of the last remaining outposts of humanity in order to help them rescue survivors and gather supplies as well as to defend their home base. Also, there is another secret mission that they do not know about, which unfolds throughout the game. The concept is to mix the post zombie epidemic storyline with the player's own music to create an immersive experience that encourages them to jog or run. For completed runs and missions the player gains objects and supplies to build his base. However, if the player runs too slowly, they will hear zombies coming after him and contact with the zombies will result in losing objects. The "Zombie Chase" mode triggers random zombie groups chasing the player even at normal running speed so they have to increase their speed for additional workout[6].

Although Zombies, Run! adds a layer of immersion onto the real world not only by providing a storyline that the user unfolds while running, by giving it an extra connection to the real world by adding zombies to chase the player as an immediate reaction to their performance this game can be seen as more augmented than its successor. However, immersion is still mostly generated by audio and not by any other feedback mechanism.

Which other ways can be used to enhance immersion that surpass the common audio approach? In the following, two haptic devices for enhanced gaming, *Pokémon GO Plus* and *OmniWear Arc*, are presented.

Pokémon GO Plus Pokémon GO Plus (see fig. 2.6) is small wearable device to

Figure 2.5 Screenshots of the Zombies, Run! app for iOS. From left to right: introduction, own base, next mission screen, screen while running

enhance the experience of the aforementioned AR gaming application *Pokémon GO* and was launched in September 2017, one year after the launch of the game itself (Nintendo 2016). The device can be worn as a wristband, lapel or brooch and is to be connected to the phone via Bluetooth low energy and notifies the player by vibration and a flashing LED light if a PokéStop or wild Pokémon is nearby. The player can then press the button to spin the PokéStop to collect items or throw a Pokéball to catch the Pokémon. In contrast to playing Pokémon GO by itself, it tracks the distance walked even when the app runs in the background, which is useful to hatch eggs, which need a certain amount of distance walked in order to hatch. However, the Pokémon GO Plus comes with various limitations, e.g. the player can only throw a regular Pokéball in a one chance approach. Better Pokéballs cannot be used and neither berries, which are used to make catching Pokémon easier or gaining additional candies to evolve Pokémon. Also, only one ball is thrown. If the Pokémon is not caught at the fist attepmt, it escapes automatically. It can therefore be said that the device enhances the gaming experience and lets the player enjoy the game without having to look at their phone, but it cannot be used by itself and comes with limitations that might diminish the gaming experience of the players, e.g. when rare Pokémon escape using the one chance method of the Pokémon Go Plus but might have been caught easily by using a berry or a better Pokéball. Vibration feedback, however, can not only be used for simple notifications, but also for the indication of location.

(Source: www.nintendo.com.au/goplus)

Figure 2.6 The Pokémon GO Plus

OmniWear Arc OmniWear Arc (see fig. 2.7) is a Kickstarter-funded neckband that provides the player with location information of enemies by vibration to warn the player e.g. about enemies approaching from behind, in other words, outside of the player's view in the game (Naudus 2016). The OmniWear Arc is currently compatible with popular online games like Counter Strike or League of Legends. It does not have to be connected to the computer, but to a smartphone app that is clipped to the monitor and reads the minimap – a small map of the player's surroundings featured in may games – just like the player would, and gives vibration feedback accordingly.

Because of the spread of smartphones, vibro-tactile feedback is almost ubiquitous in our daily life. It is often used notify us – about a new message, a reminder, an incoming call or a friend request. While most of these triggers also have accompanying audio or visuals, it is used as a more unobtrusive and discrete 'nudge' to direct one's attention towards something without anyone else noticing. This can be seen as one of the reasons why vibro-tactile feedback is often used when visual feedback is hard to process or when no visual sense is available. Since this thesis is aiming to find an non-intrusive way of navigating users to a certain location or point of interest that is relevant for the game that does not include the

(Source: Online Article by Kris Naudus on www.engadget.com (Naudus 2016))

Figure 2.7 The OmniWear Arc

visual sense, inspiration can be drawn from those approaches for the navigation of visually impaired people.

2.3. Haptic Feedback

Haptic feedback in form of vibration has been used on the skin since the 1960s, when it was considered to be a potential future form of communication (Geldard 1960). Since then, vibro-tactile feedback has been used extensively for various purposes, including navigation and gaming.

Haptic Feedback for Navigation According to the latest information by the World Health Organization, there are 217 million moderately to severely vision impaired people worldwide. Out of those, 36 million people are blind (World Health Organization 2018). Visually impaired people and especially blind people are less capable of perceiving their environment. There are many existing aids which aim to substitute the missing or reduced sense of vision, the most well-known ones being the white cane and guide dogs. Since guide dogs are very expensive, many blind people rely on the white cane, which can detect obstacles on the ground but not on chest height or hanging from above. The white cane is also limited by its length and therefore its field of "view" (Adame et al. 2013). Many different approaches have been proposed, one of the first one being the Laser Cane by Benjamin in 1965 (Malvern Benjamin Jr and A. Ali 1973), which underwent several iterations. However, many of those aids are not widely accepted and used by visually impaired people. Other then the generally high price, one of the main reasons is that they often use the auditory channel for information transfer. The auditory channel, however, is usually one of the primary senses used for spatial orientation, path finding, collision and others that might be disturbed when overlaid with additional acoustic signals (Möller et al. 2009). For this reason Geldard already back in 1960 argued that vibro-tactile skin stimulation can be used as substitution for the visual sense, not only because of the large surface area of the skin but also the fact that those are "practically unused" (Geldard 1960).

The use of vibro-tactile stimuli of the skin in order to convey spatial information to visually impaired or blind people has been investigated by many other researchers (Geldard and E. Sherrick 1965, Lechelt 1986, Zöllner et al. 2011, Velazquez et al. 2005, Johnson and Higgins 2006, Nagel et al. 2005, Bach-y-Rita, Paul et al. 1969, van Erp 2005). For guidance and navigation applications many researchers use head mounted or belt devices. Vest and Torso based feedback is also used (Jones et al. 2004). Zöllner et al. (Zöllner et al. 2011) proposed an indoor navigational aid for the blind using the Microsoft Kinect and optical marker tracking. They suggest a hybrid approach, which relies on voice instructions for point-to-point navigation (macro navigation) and vibro-tactile feedback on the waist for micro-navigation like obstacle detection. Their system consists of a waist belt containing three pairs of Arduino LilyPad boards, located on the left, right and center of the waist.

Johnson and Higgins (Johnson and Higgins 2006) made use of two webcams attached to a belt and created a computational stereo algorithm that detects obstacles through the visual input by the camera and transfers their position to another belt, on which 14 vibration motors give vibro-tactile feedback about the obstacle's location. A spacing of 2cm was used in accordance with van Erp's measurements of the perception of the waist for vibro-tactile stimuli (van Erp 2005).

Nagel et al. (Nagel et al. 2005) proposed a quite unique goal by trying to induce new sensorimotor contingencies by giving users orientation information about the magnetic north using 13 vibration motors on a belt. Although navigation was not its primary purpose, user tests throughout a training phase of six weeks showed a boost in performance of the test persons.

Rantala et al. present a headband with vibrotactile feedback for cueing in virtual reality applications (Rantala et al. 2017). Berning et al. translate ultrasonic distance information to pressure on the head as well (Berning et al. 2015). Other research focuses on improving spatial awareness and improving 3D guidance in VR using haptic feedback on the head (Jesus Oliveira et al. 2017, Kaul and Rohs 2017). Kaul and Rohs, however, also mention that thick hair can lead to weakened stimuli and a longer time needed for the detection of the vibration location (Kaul and Rohs 2017). Considering guidance applications, Niforatos et al. augment the peripheral vision of skiers using vibrotactile actuators (Niforatos et al. 2017). Two other examples of recent designs for navigation of the visually impaired are *Wayband* by WearWorks and *Maptic* by Emilios Farrington-Arnas, who received the Haptic Design Award 2017 for it[7]. *Wayband* is a haptic wristband that pairs with a smartphone app to guide blind users in an non-instrusive manner by turn-by-turn vibration, which is currently in the beta testing phase and was funded on Kickstarter[8] (see fig. 2.8).

(Source: WearWorks homepage: www.wear.works/wayband/)

Figure 2.8 Wayband by WearWorks

(Source: Haptic Design Awards 2017 homepage: http://hapticdesign.org/award/)

Figure 2.9 Maptic by E. Farrington-Arnas

Maptic is a combination of a visual sensor worn like a necklace and two feedback units that can be worn around the wrist like a bracelet or clipped onto clothing 2.9. The sensor then communicates with an iPhone app to use the GPS data to navigate the wearer by a series of vibrations to the left or right (Tucker 2017). So far, the author is not aware of other research work exploring several vibrotactile actuators for navigation/guidance applications on the neck.

Haptic Feedback for Games Haptic Feedback has become an essential component in video games. It increases the immersive user experience of the player by providing an additional modality in form of touch to visuals and audio (Deng et al. 2013). For learning and training purposes, haptic feedback provides users with a better and more intuitive understanding of their performance. Also, visually impaired or blind users, who can usually hardly play visuals-heavy video games, can enjoy gaming by the substitution of visuals by haptic feedback. The main output for games for visually impaired people are audio and haptics and existing literature suggests satisfaction by the gaming performance. Yuan and Folmer created a glove that lets visually impaired users play the popular music game Guitar Hero. Visual information was transformed into haptic stimuli that activated haptic motors attached to the tip of each finger to vibrate before the corresponding button had to be pressed (Yuan and Folmer 2008). Haptics as an approach to interact with virtual environments is also beneficial for the game industry since it has the potential to enlarge their market to new user groups that were previously not reachable (Derryberry 2007). Compared to research-oriented haptic devices, haptic feedback devices for entertainment and gaming are devoted to generate an immersive gaming experience while being affordable and more portable. Standard vibration motors can be found in various game controllers like mice, joysticks, vest/jackets, gamepads, mobile phones etc. The rumble feedback became a standard feature in console game controllers like XBox or Playstation. In recent years, haptic vests and jackets have emerged for immersion purposes as well (Al-Sada et al. 2018, Mosca 2017). Another example is the 3RD Space Vest commercialized by TN Games[9] or the Tactile Gaming Vest introduced by Saurabh Palan et al. in 2010 (Palan et al. 2010). The probably most recent example is the Synethesia Suit by Enhance Games created to embody the multi-sensory experience of Rez Infinite[10] (Konishi et al. 2016).

While there are various products and research approaches that focus on various parts of the body, no one so far has tried the approach of a collar-like device. Compared to the widespread approach of using the belt, the neck is usually free from clothes or other layers that might disperse vibration or make it more difficult to access depending on how many layers of clothes one wears. In contrast to using a cap or other head-mounted approaches the vibration cannot be dispersed or becomes indistinguishable by thick hair or curls. The neck also is on the vertical axis of the body and the collar approach tight to the skin of the neck ensures that the device will rotate with the rotation of the head.

While this chapter explored haptic feedback in form of vibration used for navigation and gaming without using visuals, the next chapter will give a brief overview and historical explanation for the popularity of yōkai and why they were chosen to be the protagonists of the proposed game concept.

2.4. Yōkai in History and Present

The term 'yōkai' describes an uncanny or supernatural appearance and can relate to sensations, sounds as well as animals or humans. After the introduction of the term in the Meiji era (1868-1912) by scientist Inoue Enryō, 'yōkai' became the gerenal term for all supernatural phenomena in Japan (Foster 2009, Papp 2010). The term is also used for anthropomorphized characters throughout history and folklore. One widely known example is the *kappa*, a river goblin with a turtle-like shell and a bowl on his head, who is known to be mischievous and for pulling children into rivers, but also for his politeness and for being fond of cucumbers (Foster 1998). Its history can be tracked back to the Nihon Shoki, one of the oldest Japanese scripts from the Nara era (710-794).

Another historical example of anthropomorphized characters is the *Chōjinbutsu Giga* ('animal caricatures') from the 12th century, which Takahata Isao, co-founder of the popular Studio Ghibli, described as the predecessor of contemporary manga and anime (Papp 2010). It shows various scenes in which animals like frogs, rabbits and monkeys behave like humans and are depicted swimming, shooting with bow and arrow or dancing. In many scenes they even wear human clothes and conduct Buddhist ceremonies (Occhi 2012). A different form of anthropomorphized entities in a Shingon Buddhist context appears in the *Tsukumogami Emaki*[11], a picture scroll from the Muromachi era (1333-1573). *Tsukumogami* are objects or utensils that gain supernatural power after turning one hundred years old. However, if they are discarded or mistreated after 99 years, they will seek vengeance from their owner, while their wrath first transforms them into yōkai, then humans, then demons (*oni*) and eventually into Buddha as seen in the *Tsukumogami Emaki* (Papp 2010). The probably most widely known depiction of *tsukumogami* is the picture scroll *Hyakki Yagyō Emaki*, as well from the Muromachi era, in which anthropomorphized music instruments, umbrellas and kitchen utensils march over the pictures (Foster 2009). While in literary works of the late Heian and early Kamakura era the term Hyakki Yagyō describes a procession at nighttime, which was considered dangerous since just a look upon the procession might lead to the death of the observer, *tsukumogami* were depicted rather humorous than dreadful in the *Hyakki Yagyō Emaki*. Foster mentions: "Ironically, through expressions such as the comical Hyakkiyagyō Emaki, an inversion occurs, and that which should not be gazed upon is rendered visible – and gazed upon with pleasure. The unseen (unseeable) is transformed into spectacle; the mysterious spirits of untamed nature are transmuted into familiar everyday objects; terror turns into humor; pandemonium becomes parade" (Foster 2009).

Transmutability can be considered as one of the core elements of yōkai (Papp 2010). Both Reader and Komatsu see worship as the decisive factor for differentiating between yōkai and the *kami* ('gods') worshipped in Shintoism[12], whose distinguishing features are usually quite vague (Komatsu 1994, Reader 1998). By deciding to worship a certain yōkai, it is up to humans whether they lift it up to the status of a *kami*. Yanagita also describes yōkai as 'fallen' *kami* (Foster 2009).

Tsukumogami as well as yōkai, however, were robbed of their claws and fangs and banned into the realm of cute *kyarakutā*[13] decorations or *kyarakutā* merchandise (Occhi 2012). For example, one of the modern incarnations of the kappa can be found in form of the city mascot *unagappa* of the city Tajimi in Gifu prefecture, which enjoys *zazen* meditation and classical music and can also be found on downloadable smartphone games (Foster 1998, Occhi 2012). Their latest (and maybe cutest) representatives can be encountered in the hugely successful video game series Yokai Watch, which led some into thinking that they might be the successor of Pokémon (Orisni 2015). Indeed, many of the currently 807 Pokémon can be traced back to yōkai and also Nagao explicitly uses the term yōkai for the cute entities that populate the Pokémon world (Nagao 1998). Although Pokémon were created by humans, mainly by Tajiri Satoshi, the inventor of Pokémon, they do not significantly differ from traditional yōkai. Allison therefore concludes: "In both cases – the game space of Pokémon and a cultural milieu that accommodates yōkai – an animist logic prevails in which the borders between human and nonhuman, this-worldly and otherworldly, are far more permeable than fixed" (Allison et al. 2006).

From the combination of play, entertainment and worship, Occhi draws parallels to events in which *kyarakutā* in form of *kigurumi* spread admonishing messages of their sponsors (Occhi 2012). The above-mentioned permeability between the human and the non-human, the this-worldly and other-worldly promoted by Shintoism for hundreds of years that is also present in the example of yōkai could be one reason for their modern incarnations in form of *kyarakutā*. Jun Miura appropriately said "Give something a set of eyes and a mouth and it takes on a life" (Arakawa 2009).

Because of the close connection of yōkai to Japanese history and culture as well as their well accepted ubiquity in form of mascots, *kyarakutā* or other video game characters like Pokémon, yōkai were chosen as the main characters for the proposed game design concept. However, instead of presenting a cutified version of yōkai, which many contemporary games and media do, yōkai will be used in their original form, as a sound, an uncanny feeling and something that cannot and maybe should not be looked upon.

Notes

1 https://www.geocaching.com/play

2 https://fogofworld.com/

3 'Fog of war' is a concept commonly used in video games. The player can only see the immediate environment around them and is therefore reliant on the limited information the uncovered area provides. While this mechanism encourages exploration, however, the fog possibly does not only hide treasures but also enemies.

4 https://www.harrypotterwizardsunite.com/

5 https://www.jurassicworldalive.com/

6 https://zombiesrungame.com/

7 http://hapticdesign.org/award/

8 https://www.wear.works/wayband/

9 https://tngames.com/

10 http://rezinfinite.com/synesthesia-suit/

11 The word *tsukumogami* ('ninety-nine gods' includes the word *kami* ('god') in a complex word-play. Phonetically it can also be read as 'ninety nine hairs,' which implies old age – associated with an old woman with long white hair. One one hand, can be explained by the difference of only one stroke in the kanji for 'white' 白 and 'one hundred' 百, on the other hand by the homonym of '*tsukumo*,' which can mean 'ninety-nine' as well as refer to a certain kind of sea grass, similar to hair (Foster 2009).

12 The Shintoism-inspired animism states that not only humans, but also animals, plants and even human-made objects have a soul or that a *kami* ('god') lives inside of them (Kalland and Bruun 1995).

13 '*Kyarakutā*' or short *'kyara'* stands for numerous and usually cute looking characters from nameless creatures in shape of animals that promote good manners on posters, over characters as Hello Kitty created by companies like Sanrio, to characters from manga and anime or even human characters, that take on representative roles as *imēji kyara* ('image character') (Miller 2010, Occhi 2012). Another subcategory of *kyara* are so-called *yuru kyara* ('loose' or 'wobbly' characters). The term was coined by culture critic Miura Jun and describes *kyara* that are frequently used for PR of municipalities or regional specialties and whose designs are often chosen based on amateur design and name contests. Because of this they usually rely on a strong narrative to be competitive in contrast to professionally designed characters for commercial purposes like Hello Kitty (Peil and Schwaab 2013, Occhi 2012). For more information about *kyarakutā* as part of Japan's cute culture and their implications for online communication and messenger marketing, see the bachelor thesis of the author (Schaack 2016).

Chapter 3
The Proposed Design

The following chapter gives an overview of the proposed game concept based on the explorations in the previous chapter. This section is divided into the presentation of the concept and the accompanying hardware, an example quest of the game, as well as a description of the target persona for this gaming application. It is emphasized that this concept is merely what the finished game and its hardware should look and feel like and does not represent the final prototype of this thesis.

3.1. The Concept

The game design concept is influenced by previously introduced AR games like Pokémon GO and Ingress, however, instead of adding another experience to the visual sense, the concept of the proposed game is centered around transferring the gaming experience from the usually utilized visual sense to a multimodal level, which excludes the visual. In order to deliver a multimodal, yet non-visual experience, an external device is necessary since the desired level of immersion cannot be delivered with a smartphone alone.

Required Hardware The game is to be run on a smartphone in combination with a haptic feedback device in form of a collar, which utilizes 8 LRA (linear resonant actuators) for vibration feedback and 1 4x4 cm Peltier element for cold thermal feedback, that can be connected to the smartphone via Bluetooth. The collar is also equipped with an accelerometer and a digital compass so the player position is not dependent on the GPS sensor in the smartphone but can be retrieved directly from the collar, which ensures a more accurate direction of where the user is looking at than using the phone as a reference point, which might be located in the user's bag or pocket and might not point into the same direction the user is facing. By attaching the accelerometer to the collar the neck movement can also be tracked, which is used for interaction with the yōkai and the spatial audio generation in reference to the emitting source. Since the game heavily relies on audio, using headphones – ideally noise canceling ones – is advised. The collar is to be made flexible so it fits various neck sizes and comes in different colors to match the user's taste. The mini controller responsible for the Bluetooth connection as well as the communication with the sensors is stored in a shell that is attached to the collar as a pendant, which also comes in various forms and colors to make it more customizable and therefore can be used as a fashion accessory rather than a mere haptic device for gaming.

The Story The story of the game is centered around the player, who happens to be one of the few humans able to sense the yōkai in the real world. Some usually peaceful yōkai have turned exceptionally malicious and do no longer keep their actions to the spiritual world, but paranormal activities have been reported in the real world as well as an uncanny fog that seems to have covered the whole world. Upon noticing that the player is perceptive of the other world, they are asked for help and the player embarks on a journey to find out how to lift the fog, what happened to the yōkai and why they are transcending the boundaries of their world and the world perceptible by humans.

Gameplay The flow of the game action is as follows: The user opens the app and is presented with the start screen, which shows a zoomed-in version of the world map around the user's current GPS location. The map itself is covered in a 'fog of war' (see chapter 2.1 for explanation) and one of the goals of the game is to lift the fog over the map by clearing quests in the designated area. Available quests are indicated by a quest symbol that, when pressed, gives the user a brief description of the requirements of the quests, a teaser of what to expect as well as an outline of the area that the quest takes place. If the user is close enough to a quest mark of an available quest, they can accept and start it. Starting the quest will cover the whole screen in fog so that the user receives no visual information from the screen, which functions as a way to discourage the user to look at their phones while playing. Returning to the home screen of the phone pauses the game so the user does not receive information on where to go or whether they have reached their destination while not having the game as their active window. The game can still be played if the phone goes into standby mode as long as the setting for it has been activated and the quest can be paused of given up anytime from the screen displayed during the quest. The user will then be navigated to their next destination by haptic feedback in form of vibration from the collar. A 200ms short vibration pattern is used for the initial indication of direction. A second vibration pattern of 2 vibrations of 200ms are used when the turn is closer than 20 meters, and a final vibration of 3 vibrations of 150ms are triggered when the distance to the turn is closer than 5 meters. A tilt of the head to the left or right for 3 seconds repeats the vibration into the direction in which the player has to go if they are unsure about their next step or forget where to go. If the player enters a 50m radius of the yōkai's location, the player will feel a cold sensation and start hearing spatial audio of the yōkai's characteristic sound accompanied by synchronized vibrations from the collar. The music becomes louder and the vibration becomes stronger the closer the user gets to the yōkai until they feel another cold sensation, notifying them that they have reached their destination. When the user is ready to proceed and e.g. talk to the yōkai they have just reached, they have to give an elongated nod of 3 seconds, which will then trigger the next sequence. Sometimes the player has to use the accelerometer of the collar by nodding or tilting their had in order to to interact with the yōkai, answer questions collect or use items. Completing all tasks of a quest usually results in lifting the fog in the designated quest are and befriending the yōkai met in this area. New quests can be unlocked by clearing neighboring areas or collecting certain key items as a reward for clearing missions.

3.2. Example Quest

The example story takes place in Hiyoshi, part of Yokohama City in Kanagawa Prefecture. Human children have been reported missing and rumors suggest they were kidnapped by a *kappa*, a yōkai in form of an "aquatic reptilian humanoid" (Meyer 2018b), which inhabits rivers and streams throughout Japan. For illustrations of the mentioned yōkai see fig. 3.2 and for the locations of the respective yōkai in this example quest see fig. 3.2. While being known for being mischievous, they are also said to sometimes befriend lonely children. This poses the question of what happened to the children and if they are in immediate danger, since *kappa* are also known for eating human flesh. The quest is triggered close to Hiyoshi station (1), when the player is asked by Fukuzama, the ghost of Keio University founder, Fukuzawa Yukichi, who turned into a yōkai, to find out what happened. The first hint leads the player to *yonaki babā*, the yōkai of an old woman who can usually be found close to where a tragedy happened (Meyer 2018e).

(Source: Yōkai online database yokai.com. Used with permission of the illustrator. Copyright: Matthew Meyer)

Figure 3.1 Illustrations of the yōkai appearing in the example quest. From left to right: yonaki babā, yama oroshi, tengu daoshi, kappa.

Her weeping is said to be contagious and it is not sure whether her weeping indicates shared sadness with humans or if she is mocking the ones who truly cry out of sadness. She can be found in front of an abandoned clothing store in Hiyoshi (2). The player listens to her weeping and only when they listen to her for a longer period of time, they find out what she saw in the night the children went missing. She then suggests the player to find *yama oroshi*, the yōkai of a metal grater that has not been properly taken care of and therefore turned into a yōkai in shape of a porcupine, who supposedly knows more about the matter (Meyer 2018d). *Yama oroshi* can be found at an elderly couple's miscellaneous shop close to Hiyoshi station (3). When the player approaches she shop they hear the dull grating sound with accompanying vibrations from left to right. When the *yama oroshi* notices that the player can sense him, he asks for help by sharpening his dull slicers. The player has to decide to fulfill him this wish by repeatedly tilting their head from left to right in sync with the grating sound. After doing this favor to the *yama oroshi*, he will tell the player how he saw the children going close to a park accompanied by a yōkai, but he could not see the yōkai properly. Therefore he suggests to visit the nearby park to find further clues. The player then is navigated to the nearby park (4), where they start hearing timber fall. This is the work of *tengu daoshi*, a yōkai that is mostly known as an audio phenomenon of giant trees falling down in the woods (Meyer 2018c). The sounds of the trees falling gradually becomes louder when the player approaches the park. In order to attract his attention, the user has to stand still for its loudest tree fall, after which the *tengu daoshi* speaks to them. It reports that he saw a yōkai leading the children in the direction of the river, but it could not follow then since it needs to stay close to the trees in order to move around. The player is then guided towards the river (5), where they first hear water splashing accompanied by laughter. They are confronted with a *kappa*, just as the rumor suggested. However, something seems to be wrong. The *kappa* asks the player for a duel that the player accepts by nodding. The trick to defeat the *kappa* is to bow to it when it is about to start the duel. Since *kappa* are very polite yōkai, it has to bow back to the player, which leads to the water in the depression of his head to spill. This can lead to the death of a *kappa*, but in this case, the evil spirit that possessed the *kappa* escapes, leaving the *kappa* clueless about what it did. It then promises the player to bring the children safely back to their parents. The player then returns to Hiyoshi station (6) to report back to Fukuzama, who expresses his gratitude for the help. This results in lifting the fog over the Hiyoshi area of the world map and Fukuzama becomes the player's friend.

Figure 3.2 Location of the yōkai encountered in the example quest

3.3. Target Persona

Since this game does not only require a smartphone, as many even younger people own nowadays, but also a collar-based wearable haptic device, the target group of potential users differs from players of casual smartphone games. This game requires a higher amount of commitment by wearing the device and by having to take the time to explore an area in the real world. Since older smartphone users might be more reserved about wearing the haptic device, the target group can be identified as females and males aged 15-35 who belong to one of the following types of gamers:

- **Technologically enthusiastic gamers**: Smartphone users who are enthusiastic about new technology and want to be among the first to try it
- **Curious gamers**: Curious smartphone users who like playing games on their phones and are interested in new and usual experiences
- **Hardcore gamers**: Players who are willing to spend a fair amount of time and money in playing and completing a game.

Chapter 4
Design Decisions

The following chapter elaborates on the reasoning for the respective design choices that were described in the previous chapter. The two major categories for which design decisions were made are navigation and immersion, hence they will be discussed in separate chapters. Each chapter includes the setup, the user test and a discussion of the results of each user test and their implications.

4.1. Navigation

4.1.1 Approach and Prototype

In order to find out whether haptic feedback in form of vibration can be successfully utilized to navigate users without visual input, e.g. looking at a map or a phone, a haptic collar prototype was built using off-the-shelf components.

The prototype consists of a velvet collar, similar to the recent fashion accessories called chokers, with Velcro tape attached to its perimeter, which also serves as the closure of the velvet ribbon and makes it adjustable to the test subject's neck size as seen in fig. 4.1.1. 8 eccentric rotating mass actuators (ERM) (Shicoh C1034, Japan) with attached Velcro tape can be flexibly affixed to the collar. The actuators are driven using a PN2222 transistor. The vibration motors can be accessed programmatically over the Arduino UNO and the processing programming GUI. For tests, 4 hardware buttons were used to trigger the individual vibration patterns.

The prototype was used in combination with 2 different files for code, which were used for different parts of the test. One file was used for the testing of the different vibration patterns and one file for the different configurations of number

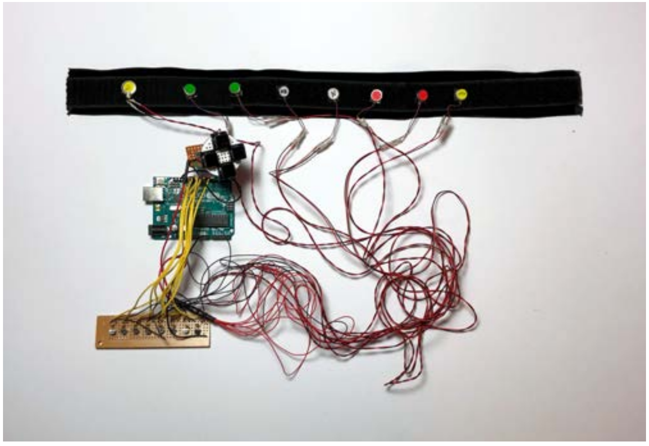

Figure 4.1 Prototype version 1: The Haptic Collar used for the experimental setups

of motors.

The research questions for this study were:

1. Can you navigate with haptics instead of visuals?

2. How many actuators are necessary for intuitive direction localization of 8 directions?

The corresponding hypotheses were:

1. You can navigate safely, accurately and with little effort using haptics and no visuals.

2. 8 actuators are the most accurate in localizing directions intuitively for 8 directions.

4.1.2 Experimental Setups

Subsequently, the two experimental setups conducted with the Haptic Collar prototype are described: First, a ”vibration pattern study” that focuses on qualitative feedback on how easy and understandable the vibrations of the system are. Second a ”number of actuators study” to evaluate direction encoding and the sensitivity of the participants using 4, 6 and 8 actuators around the neck. After the two studies followed the third part of the user test, a haptic walk as a practical use-case. The test lasted around one hour per test subjected and the studies were conducted in the same room for all test subjects to prevent environmental bias. All experiments followed the same flow and were audio-recorded while in the room. The questionnaires used can be seen in appendix A.

Subjects The proposed guidance system was tested with a test population of n = 11, five males and six females. The age range was 24 to 34 (mean 28.09 and standard deviation 3.30) and had 7 different nationalities. They gave their written consent to participate in this experiment, and did not receive compensation. All of them use mapping apps for navigation, with Google Maps being used by 100% of the population. 9 out of 11 participants previous played location-based games like Pokémon GO before, but none of the subjects had prior experience with Pokémon GO's haptic feedback device, Pokémon GO Plus. However, all but 2 of them were familiar with the concept of haptic feedback (n = 6) or had an idea of what is was (n = 3).

Vibration pattern study The collar was put on the participant's neck and the vibration modules were adjusted to the participant's neck size with one vibration module on each straight axis[1] and one actuator on each diagonal axis in the middle between the straight axes. The subject then was exposed to two clockwise rounds of the same vibration pattern and then – also to give their necks a break – asked questions about the comfort of the vibration pattern and the clearness of the direction. Then the next vibration pattern was introduced. The same questions were asked for each pattern and in the end questions about the overall comfort and clearness of direction were stated. The four vibration patterns tested were in this order:

- sustained short: a short vibrations of 200ms
- multiple long: two vibrations of 250ms
- multiple short: five vibrations of 50ms each
- sustained long: one long vibration of 500ms.

Number of actuators study In order to find out whether 4, 6, or 8 motors are needed for users to be able to accurately point out 8 different direction of the vibrations on their neck, three different setups were created that use 4, 6, and 8 vibration motors respectively (see fig. 4.1.2). For the 4 motor setup, vibration modules were used on the straight axes and vibrating two motors at the same time was used to indicate diagonal directions, e.g. the front and right motor vibrating at the same time indicated a front-right direction. Each direction is triggered twice during each setup to eliminate guessing alone as the reason for successfully identifying the direction. The order of the 16 directions in total was randomized using the Latin Square model. The experimenter triggered the directions manually by pressing the buttons on the device and compared the direction the participant indicated and the direction triggered. Whether the right direction was triggered was confirmed by a printout in the serial monitor of the Arduino software.

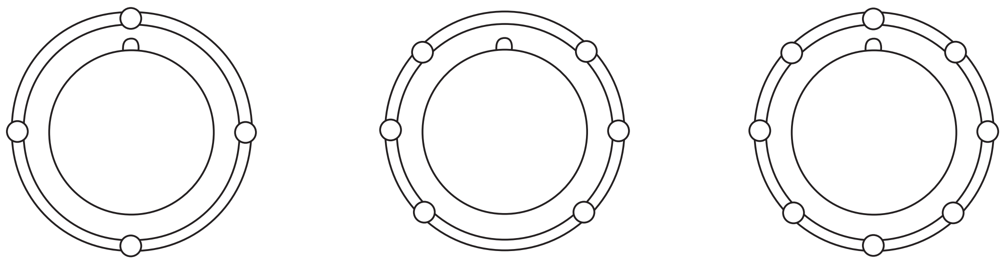

Figure 4.2 Schematic view of the arrangement of the 4 (left), 6 (center) and 8 (right) motor setup

For the 6 motor setup, all directions except for front and back were controlled individually. A vibration of the front-left and front-right motors indicated a forward direction and back-left and back-right a backward direction. Front and back were chosen as the directions to be indicated by this compromise because they were considered to be the ones to be used the least for navigation purposes, where the focus lies on indicating turns.

The 8 motor setup does not require compromising in the the directions since every vibration module is assigned to one direction. This is why the hypothesis is that this setup is the one that is the clearest in terms of direction localization.

In-between the different setups, the participant was asked questions about the comfort and the clearness of the direction of the vibrations as well as had to give a qualitative and subjective evaluation of how well they think they did on the test and which directions were easy or hard for them to understand. These short breaks also served as a break for their necks to make them more receptive to the new setup. The vibration pattern that was used for this part of the test was the short-multiple pattern.

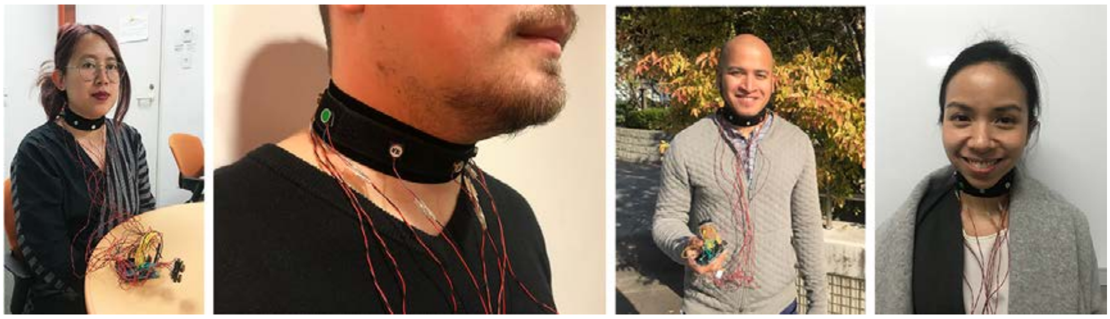

Figure 4.3 Users wearing the first Haptic Collar prototype during user tests

Haptic walk The test subjects were asked to go on a walk outside together with the experimenter. Each subject started from the same starting location toward the same final location. They were asked to follow the direction of vibration they assumed they were supposed to go based on the haptic feedback they received. All subjects were guided on the same path and GPS data of the route was recorded during the walk. When an error occurred, the test subjects were not notified of it, but guided along the set trail. The specific route that the test subjects were supposed to walk can be seen in fig. 4.1.2 and was chosen since it includes 7 out of all 8 vibration directions in a condensed and easily accessible area. The test subjects were engaged in casual conversation with the experimenter to make the setting as natural as possible to see how natural and intuitive the haptic navigation process could work in a real life situation. After the test the participants were asked questions from a survey about the walking experience that the experimenter read out and filled in for them.

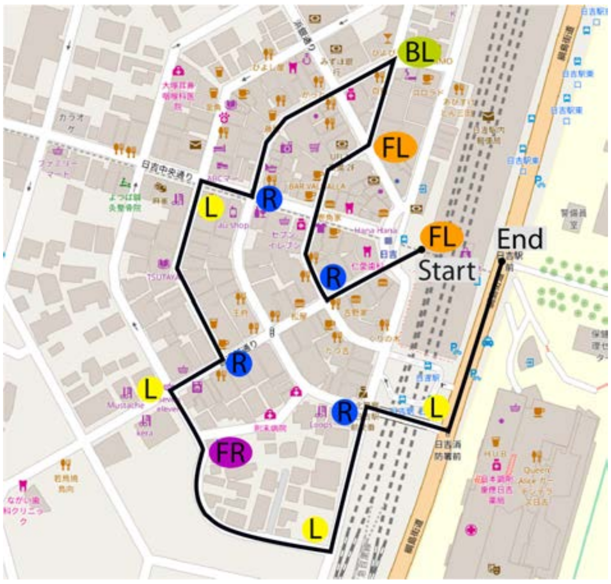

Figure 4.4 Original route for the haptic walk

4.1.3 Results

Vibration Pattern Study The qualitative feedback survey focused mainly on the level of comfort and the clearness of direction of the vibration. In terms of comfort, the means of the different vibration patterns are as follows: sustained short = 6,00, multiple long = 5.36, multiple short = 5.90, sustained long = 5.50. The means in terms of clearness of direction were: sustained short = 8.82, multiple long: 8.73, multiple short = 8.09, sustained long = 8.18 (see fig 4.1.3. One of the reasons for the shorter vibrations being generally more comfortable were that shorter vibrations did not feel too strong, but rather like a 'nudge' towards the right direction. The sustained long vibration pattern was perceived as more intruding and therefore more uncomfortable. One participant mentioned that the long duration of the sustained long vibration pattern made the vibration disperse along the collar so the location of the vibration source was harder to determine. While repetition of the vibration was appreciated since it made it easier for users to verify that there was a vibration and also its location, the short version caused a sense of alarming urgency for some. The short sustained vibration pattern ranked first both in clearness and comfort on the linear scale and shared the top rank in comfort with the multiple short pattern when asked for the most comfortable pattern. However, in the qualitative feedback the sustained short pattern was seen as the most unclear in terms of direction, which stands in contrast to what the participants replied in the scale questions in the survey in-between the different vibration patterns. This might be explained due to ordering effect. It can be summarized that although short vibrations seem to be more comfortable, a repetition is helpful for input and location verification.

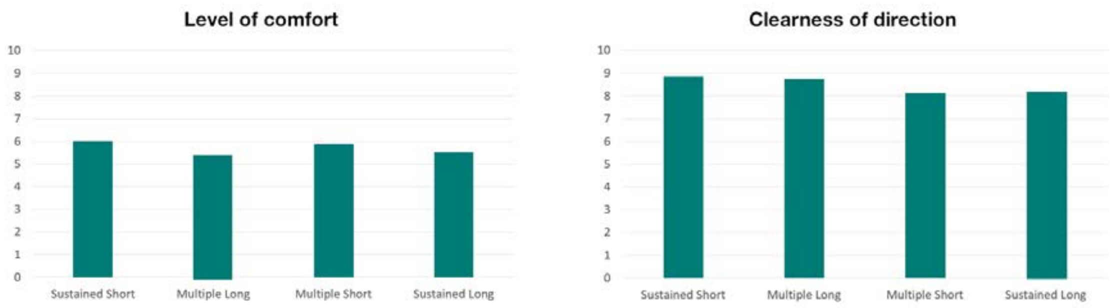

Figure 4.5 Level of comfort and clearness of direction of the different vibration patterns

Number of actuators study The directions of the vibration indicated by the participant were compared to the actual direction that was triggered to find out how reliably the participant could identify the different directions and to find out differences in the amount of errors for each subject in-between the different setups. The full list of errors per setup and direction per subject can be seen in appendix B. The recognition rates based on the responses of the participants are as follows, for 4 motors 72%, for 6 motors 81% and 8 motors 95% correctly identified. The detailed confusion matrices can be found in fig. 4.6.

In order to find out whether the errors in indicating the triggered direction for each setup merely happened by chance or if there is an actual correlation between

perceived as:	F	FR	R	BR	B	BL	L	FL
F	21	0	0	0	0	0	0	1
FR	3	9	10	0	0	0	0	0
R	0	3	16	3	0	0	0	0
BR	0	0	1	11	10	0	0	0
B	0	0	0	0	21	1	0	0
BL	0	0	0	0	4	11	5	1
L	0	0	0	0	0	2	19	1
FL	1	0	0	0	0	0	3	19

perceived as:	F	FR	R	BR	B	BL	L	FL
F	12	1	0	0	0	0	0	9
FR	0	19	3	0	0	0	0	0
R	0	4	18	0	0	0	0	0
BR	0	0	3	19	0	0	0	0
B	0	0	0	0	21	1	0	0
BL	0	0	0	0	3	19	0	0
L	0	0	0	0	0	0	20	3
FL	2	0	0	0	0	0	3	19

perceived as:	F	FR	R	BR	B	BL	L	FL
F	22	0	0	0	0	0	0	0
FR	0	22	0	0	0	0	0	0
R	0	0	22	0	0	0	0	0
BR	0	0	1	11	10	0	0	0
B	0	0	0	0	21	1	0	0
BL	0	0	0	0	4	11	5	1
L	0	0	0	0	0	2	19	1
FL	1	0	0	0	0	0	3	19

Figure 4.6 Confusion matrices for detected actuations based on number of motors (4 left, 6 middle, 8 right). On the left down are the actual directions: Front (F), Front Right (FR), Right (R), Back Right (BR), Back (B), Back Left (BL), Left (L), and Front Left (FL) respectively.

the number of errors and the chosen setup, a number of tests were conducted on the data sets. Firstly, a Shapiro-Wilk test was conducted to find out whether the number of errors for each direction per setup is distributed normally. Since later on the datasets for diagonal and straight axes are to be compared, the Shapiro-Wilk test was conducted on each condition separately. All of them showed a p-value of <0.001. Hence, none of the data sets is distributed normally, so they are nonparametric. To compare nonparametric data sets, a Friedman test was conducted, whose result showed that there is a statistically significant difference in the amount of errors for each direction per setup, $\chi\ 2(2) = 30.194$, $p = 0.000$. Since the Friedman test is an omnibus test, post hoc Wilcoxon signed-rank tests were conducted to pinpoint the significance. Tests between the diagonal axes of the 4 and 6 motor setup showed a significant difference in the number of errors ($Z = -3.381$, $p = 0.001$), as well as the test between the diagonal axes of the 4 and 8 motors setup ($Z = -3.953$, $p = 0.000$). A test between the diagonal axes of the 6 and 8 motor setup did not lead to a significant difference ($Z = -1.658$, $p = 0.097$). This was expected since the same vibration motors are triggered for the diagonal directions of the 6 and 8 motor setups. The test between the straight axes of the 4 and 8 motor setup also did not lead to a significant difference for the same reason ($Z = -1.941$, $p = 0.052$). Since the only difference between the straight axes of the 4, 6 and the 8 motor setups lies in the N and S directions, the W and E directions are ignored for their Wilcoxon signed-rank test. The tests shows a significant change in the number of errors for those directions between the 6 and 8 motor setup (Z = -2.392, p = 0.017 for) as well as the 4 and 6 motor setup (Z = -2.495, p = 0.013).

From these numbers it can be inferred that the 8 motor setup is the most clear in terms of directions. This also correlates with the results of the qualitative feedback by the participants provided between the different setups. Comfort levels were the highest for the 8 motor setup as well as the perceived clearness of direction (see table 4.1). However, also the 4 motor setup has only confusions between the adjacent directions. It seems the diagonal directions are the most difficult for users to point out.

Table 4.1 Level of comfort and clearness per motor setup

Number of Motors	Mean Comfort	Mean Clearness of Direction
4	6.72	6.45
6	6.91	6.09
8	7.63	8.00

Since the participants were not informed about how the directions were compromised by the fewer available motors in the 4 and 6 motor setups to see if the directions can be guessed intuitively, some participants did not understand from the beginning how to interpret vibration feedback that came from two sources at the same time. For the 4 motor setup, 2 participants explicitly pointed out that the straight axes were easy to understand, but the diagonal ones were quite hard. 4 participants stated that they probably did terrible on the test, and only one person being confident of having guessed 80% of the directions correctly. For the 6 motor setup, 7 participants reported being very confused and expecting a bad result in general or worse than the 4 motor test. The other 3 participants reported a slight improvement in comparison to the 4 motor setup and one was confident of having a much better result this time. Overall, most participants were still confused about the directions, especially in the front and back. For the 8 motor setup, 9 participants reported a much better feeling about the test scores for this setup, 5 of them even confidently. Only 2 of them reported mediocre expectations for their results. This correlates with 8 participants stating they did not have to guess the directions at all or only a little and 9 participants stating that the direction were the clearest ones in this setup.

Haptic walk The haptic walk took around 15 minutes per participant. The path of the GPS data of each walk can be seen in Appendix C. From the path data it is evident that navigation along the straight axes, e.g. a turn right or left was easy to perceive since no errors were made for those directions, except for once, when one of the participants asked for a direction at a crossing and mistakenly perceived the front nudge as a left nudge, probably because they looked into a different direction than the street in front. The FL direction, however, had a total of 8 errors out of 20 occasions, which is an error rate of 0.4 or 40%. One reason for this high error rate could be that missing the second FL turn automatically results in missing the BL turn. From the survey it can be derived that directions were fairly easy to understand (mean = 7.36) and quite sure about being on the right track (mean = 7.36). The overall feedback was positive, one participant mentioned that they were surprised how little effort it took to process so they could "intuitively" follow the directions while talking to someone, which made it feel very "natural." Walking itself, however, also causes vibrations so sometimes participants were not sure whether they had been given a direction or if it was just the vibration of their steps. There were also other comments that will be discussed in the following chapter.

4.1.4 Discussion

The perception of haptic feedback especially on the neck is a very subjective matter. Preferences and perception of vibration patterns differed among subjects. A repeating 'nudge' not long enough to be intrusive or dispersing the vibration along the collar seems to be preferred. Overall, the system works well (73 - 95% accuracy) with short vibration patterns. 8 vibration motors seem to work best for the applications (yet 4 and 6 also performed ok, disregarding the diagonal directions) since, as expected, compromising directional haptic feedback by using fewer vibration motors than directions available can lead to confusion. For making the device as intuitive as possible, 8 motors are the preferred choice. Also, by taking the device outside of a controlled environment and into the real world gave further insights into which circumstances might need to be taken into consideration for future implementation. One participant mentioned that since the navigation so far works similar to a car navigation, special attention has to be brought to pedestrian needs e.g. changing the side of the street. 2 participants reported that they would appreciate a feedback mechanism to confirm whether they were on the right track or not. Regarding the problem of a high error rate of diagonal navigation, one participant suggested to use different vibration patterns for diagonal and straight axes navigation. Furthermore, the appearance of the wearable device also needs to be considered. While most subjects were not opposed to wearing a collar-based wearable device like the introduced prototype for navigation or gaming purposes, 2 participants uttered potential gender issues of men maybe not wanting to wear a choker, which so far is mostly associated with a female fashion trend, and suggested more explored device implementations such as belts or wristbands. Also, keeping the prototype phase of the choker in mind, walking outside with long cables hanging from your neck might be uncomfortable for some, as one participant mentioned. Making the design simpler and less intimidating would make the wearable device more widely acceptable.

As for the research questions in the beginning of this chapter, it can be concluded that 1) users can be navigated with haptics instead of visuals and 2) 8 actuators are the most accurate for intuitive direction localization of 8 different locations. The hypotheses are therefore confirmed.

4.2. Immersion

The following chapters focus on the first iteration of the collar and the experience provided for the user to evoke the sense of presence of a yōkai in the real space through crossmodal experience design combining vibration, audio and cold thermal feedback.

4.2.1 Approach and Prototype

Hardware A 45cm velvet collar was made in similar fashion as the previous one with Velcro tape around its perimeter. Based on the user test results of the previous prototype, 8 vibration motors were used for this model. Instead of ERM actuators, however, 8 LRA (Linear Resonant Actuators) (Nidec Copal LD14-002, Japan) were used for this prototype for their capability of enhanced vibration modification. Instead of simply being able to turn them on and off for a set period of time, the intensity of the vibration can be controlled via code, which was a desirable feature for this prototype. In this prototype the vibrations no longer indicate directions on where to go, but they had the function of generating a sense of spatial location of an audio feedback. In addition to the vibration as haptic feedback, a 4x4cm Peltier element was used to induce a cold sensation below the participant's neck. To make the device more portable, a Redbear BLE Nano v2 replaced the much bigger Arduino UNO, not only because of the significantly smaller size but also its Bluetooth capability. Connecting the Redbear BLE Nano v2 by Bluetooth made wires from the board to the control unit unnecessary and ensured remote activation of the haptic and thermal modules that were used in this prototype. In order to connect the Redbear BLE Nano v2 with all the necessary components, a custom PCB board was designed using the Diptrace software and cut out by a CNC machine (see fig.4.7 and fig. 4.8). The board was used to connect the 8 actuators, 1 Peltier element and a digital compass (model GY-271 QMC5883L) to the Redbear BLE Nano v2.

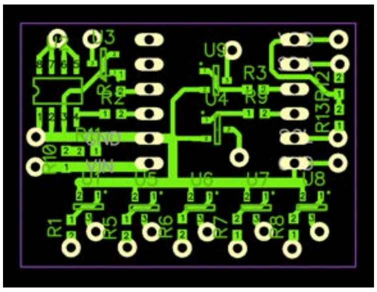

Figure 4.7 PCB Layout Version 1

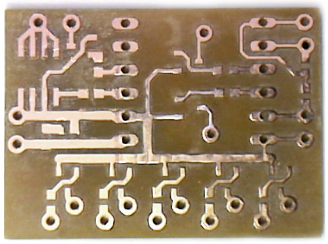

Figure 4.8 PCB Board Version 1

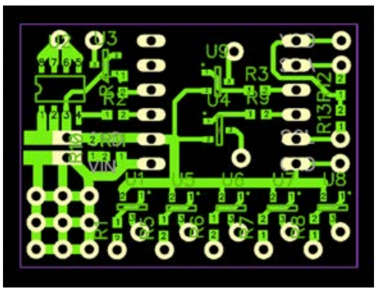

Figure 4.9 PCB Layout Version 2

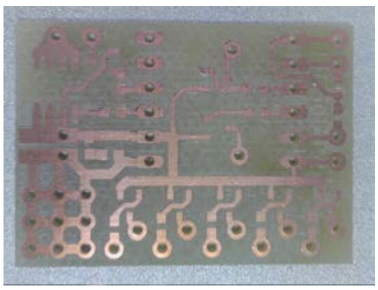

Figure 4.10 PCB Board after CNC

Each vibration module required a transistor and one resistor; a bigger transistor and resistor were used for the Peltier element and a capacitor as well an an LED were added to the board. The LED was used to show current on the board. After attaching the necessary transistors and resistors and the capacitor however, having a combined place for the power seemed more practical, so the PCB board was redesigned and cut again using a CNC machine (see fig. 4.9 and 4.10). The other components including a connector for a battery or another power source and headers for the Redbear BLE Nano v2 were soldered to the board and the compass and then connected to it with wires (see fig. 4.11 and 4.12).

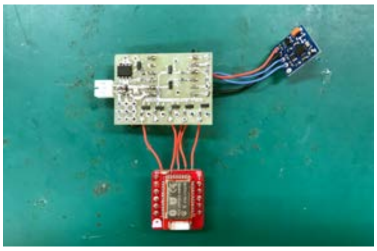

Figure 4.11 PCB connections front

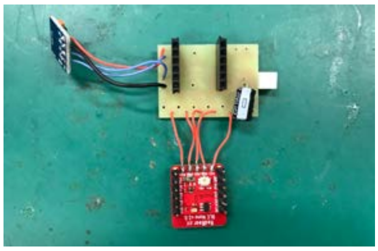

Figure 4.12 PCB connections back

The 8 LRA were attached to the board as well as the Peltier element and a onnection for 2 18650 batteries as a power source. The prototype included Bose QueitComfort 35 noise canceling Bluetooth headphones for audio output. The complete prototype can be seen in 4.2.1.

Mobile application To communicate with the Redbear BLE Nano v2, an iPhone application was coded using Xcode that served as the mediator between the audio and the haptic feedback. While the User Interface (UI) was kept simple by only including 3 buttons, a "Connect" button for the Bluetooth connection to the Redbear BLE Nano v2, a "Start" button for initiating the experience, and a "Stop" button to be able to interrupt the experience when needed. The application encompassed the code to connect to the Redbear BLE Nano v2 via Bluetooth and made use of Xcode's SpriteKit to create different audio nodes and move them along the x axis to give the user the impression of spatial audio. To make the movement of the audio possible, the audio files had to be mixed down to mono. The total of 24 functions for the audio nodes and haptic events were put into a sequence that was played in order with delayed execution commands to create a coherent sequence

Figure 4.13 Prototype version 2: Velvet collar with vibrotactile actuators and one Peltier element on the far left

of events. Each function that included vibrations or thermal feedback also fired a command to the Redbear BLE Nano v2 to trigger the desired haptic feedback, if necessary synchronized to the audio. The experience is centered around *bakezōri* (see fig. 4.2.1) – yōkai resembling straw sandals that were "mistreated or forgotten by their owners" (Meyer 2018a), who tell the user their story in a semi-coherent narrative that was recorded for this experience. Audio feedback accompanying this narrative were step sounds, laughter and exhaling. The total duration of the whole sequence was 145.3 seconds. A detailed description of the complete sequence can be seen in appendix D.

4.2.2 Experimental Setup

The main goal of this user test was to find out 1) how users react to a non-visual AR experience and 2) which combinations of modalities enhance the sense of presence and immersion. Therefore, the research questions for this study were:

1. Can users feel immersed without visuals?
2. Which combinations of modalities are successful in creating the sense of immersion?

(Source: Yōkai online database yokai.com. Used with permission of the illustrator. Copyright: Matthew Meyer)

Figure 4.14 Illustration of bakezōri

The corresponding hypotheses were:

1. Users can feel immersed without visuals.
2. Multimodality enhances immersion.

The user test was divided into 1) the experience and 2) a qualitative survey in which participants reflected on the experience. Since most existing scales for measuring immersion (Witmer and Singer 1998, Mestre 2018) focus on the realism of the visual components and interactiveness, which are both not applicable for the provided experience. Therefore, the survey for this user test was created based on potential emotional impact of the experience and can be seen in appendix E. The test itself lasted about 15 minutes per subject and were conducted in a quiet room. All experiments followed the same flow and comments of the test subjects after the questionnaire were audio-recorded.

Subjects The multimodal immersion experience was tested with a population of n = 21, seven females and fourteen males. The age range was 20 to 38 (mean = 28.57, standard deviation = 4.11) and had 12 different nationalities. Participants were brought into a quiet room and gave their written consent to participate in this study, and did not receive compensation. They were given a brief explanation about the research but without concrete details of what to expect.

Haptic Immersion The collar was put on the participant's neck and the actuators were adjusted to the participant's neck size with one vibration module on each straight axis and one actuator on each diagonal axis between the straight axes. The Peltier was put approx. 5cm below the collar under the clothing on the skin of the back of the participant. To begin the experience the light in the room was turned off to eliminate the visual sense for the experience and make the participants focus on their other senses. The rooms were completely dark except for light that fell into the room for a window to the hallway in some cases. During daytime, users were blindfolded to eliminate the sense of vision. The experimenter left the room so the subjects were not biased by her presence and could focus on the experience. The sequence of events was triggered by the experimenter via the smartphone app from outside the room. After the sequence finished the experimenter went back to the room and the test subjects were asked to fill out a qualitative survey to report their feedback of the experience.

Figure 4.15 Users wearing the second Haptic Collar prototype during user tests

4.2.3 Results

The qualitative survey after the end of the experience can be divided into 2 different topics, the emotional impact on the participant and the feeling of presence, which includes feedback about the different combinations of multimodal stimulation and giving suggestions on what would help generating the feeling of presence and immersion.

Emotional impact 71.4% of the participants felt scared by the experience, with 52.4% being a little and 19% very scared. 76.2% of the participants felt very startled (47.6% very much and 28.6% a little), whereas 23.8% reported not feeling startled. 85.7% felt surprised, 57.1% very much and 28.6% a little, and only 14.3% felt not surprised at all. When asked whether they expected this to happen, 23.8% said yes, with 76.2% of the participants did not expect this experience to happen in this way. This correlates with 28.6% reporting feeling very calm throughout the experience, with 33.8% feeling somewhat calm and 38.1% feeling not calm at all. 95.3% of the participants reportedly had fun during the experience (81% very much and 14.3% a little) and only one participant reported they did not have fun during the experience. Likewise, one participant reported not enjoying this experience with all other participants saying they enjoyed it (95.2%). 85.7% said they would like to engage more into this experience and 14.3% answered with "maybe," no participant answered that they were not interested in engaging more into this kind of experience.

Presence 33.3% of participants reported feeling like "something was in the room," 57.1% somewhat felt so and only 9.5% did not feel like there was something sharing the space with them. To the question which of the elements of the experience helped in making them feel like something was in the room, the majority felt that the audio contributed greatly to the sense of something being in the room. 81% felt it helped "a lot," 19% "a little" and no one reported it had no effect on their feeling the presence of something in the room. Vibration made the second strongest element for inducing the feeling of presence, with 42.9% of the participants reporting it helped "a lot," 38.1% "somewhat" and 19% felt it didn't help their sense of presence at all. The cold sensation provided by the Peltier element was the most ambiguous modality. Exactly one third, or 33.3%, of the participants reported it helped them "a lot," "a little" or "not at all." When asked about combinations of sensations that were the most effective in creating the feeling that something was in the room, 9 reported that a combination of audio and vibration was the most effective, 5 reported that the combination of audio and cold thermal sensation was the most effective, one participant gave the combination of vibration and thermal sensation as an answer and 2 participants reported the combination of all 3 elements to be the most effective. One participant reported that "no" combination was the most effective. When asked about the in their opinion least effective combination 9 participants reported that there was none,

one participant said the combination of vibration and cold thermal sensation, 3 answered the vibration by itself, two participants said the vibration together with the step sound and one participant said the least effective combination for them was the cold sensation combined with any other feedback. One participant also reported that the audio and voice acting did not make them feel like something was there.

When asked about what the participants thought might increase their feeling of presence, technical issues like not hearing the vibration sound were mentioned, one person suggested stronger vibrations, one person suggested thermal sensation inside the ear to be combined with the audio and two participants suggested adding the olfactory sense as well as adding more zones on the body for vibration and thermal sensation as well as the sensation of wind. One participant suggested using a warm instead of a cold sensation to make it feel like something more "alive" was in the room. Another suggestion was to have a constant background music like the sound of wind to not interrupt the feeling of immersion caused by noise from the headphones shortly before each audio track started to play. This correlates with two participants reporting the sound was a little too "cut-off" and therefore suggested softer transitions between audio pieces. 2 participants also requested more spatialized audio that moves with the movement of the participant's head. To the question whether adding visuals would help the immersion into this experience, 66.7% replied with "yes," 4.8% with "no," and 28.8% said they did not know.

When asked about what they liked about this experience, 4 participants mentioned the audio, mainly its high quality, the sound design in general and the voice acting. One of them mentioned the spatial audio and two participants mentioned the cold sensation. One participant mentioned the vibration and two participants referred to the combination of vibration with audio, four of them labelled this kind of crossmodality as a "new sensation." One of the participants said it gave them a pleasant feeling of ASMR (autonomous sensory meridian response) and said that it took them "away from the 'normal' place." Two participants said they were impressed by how immersive this experience was. One participant described it like "a good thriller book came true." When asked about if there was anything about the experience they disliked, 10 participant replied with "no."

One participant mentioned the audio being too loud, three mentioned the sound of the vibration bothered them and three participants did not like being scared. Only one participant disliked the vibration around their neck and one participant reported that at first they did not like the device around their neck since it is a sensitive area, but grew to like the sensations after a few seconds. When asked to quantify their feeling of something being in the room and feeling immersed into this experience, the mean for the feeling of presence was 2.86, the mean for the feeling immersion was 3.71.

4.2.4 Discussion

Sensing presence is a very subjective matter and especially when it comes to supernatural or maybe even superstitious matters like yōkai. For inducing the feeling of presence the analysis of the result shows that audio was the most important element, which might be dependant on its sound quality and whether the voice acting is convincing or not. Since both factors were positively mentioned by participants it can be assumed that the audio quality and the voice acting were at a sufficient level for creating the sense of presence within this experience. The multimodal haptic feedback combining audio and another modalities (vibration and cold sensation) were the most successful combinations to further enhance the feeling of presence, with audio and vibration being perceived a little more effective. One participant noted that they felt more like the haptic feedback gave the more a sense of location rather than presence and one participant mentioned, "I felt like I was more transported to a new place than inhabiting the room I was physically in," which also suggests a sense of immersion into the experience rather than creating the sense of presence in the physical space that the participant is in. This might be explained by the lack of visual sense in this experience, which makes it easier to believe to be somewhere else rather than being constantly confronted with the visual reality of their location. Another indicator for the enhanced sense of immersion is the emotional response by the participants. Most participants reported being scared by the experience, but still enjoyed it. An equal amount of participants reported being startled and surprised, which together with a 99,2% not having expected this kind of experience suggests that the surprising element also enhanced their sense of immersion. The fact that only one participant negatively addressed the vibration on the neck suggests that the notion of something around the neck itself is not weird or scary for potential users in this age group. It is noteworthy that the participant who uttered these concerns was the oldest one among the test subjects. One younger participant did not like the notion of something around their neck at first, but grew to like the feeling within a few seconds, which implies that haptic feedback around the neck is something that people might become used to within a short time frame. Furthermore, suggestions of adding more senses to this experience and expanding the field of the haptic feedback generally advocates a demand for more crossmodally immersive experiences. The research questions at the beginning of this section can therefore be answered as 1) yes, users can be feel immersed using visuals, and 2) the most successful combinations in creating the sense of immersion are audio combined with vibrotactile feedback, followed by audio together with thermal feedback. The hypotheses have therefore been confirmed.

To improve the sense of immersion, however, technical issues have to be addressed as well, e.g. the vibrations should be noticeable, but the sound of the vibration should not be overshadowing the feeling of the vibration. Also, a total of 5 participants mentioned during the survey that they did not feel the cold sensation at all, while it was very noticeable for other participants. Using either a higher number of Peltier elements or making the intensity adjustable to the user seems to be a reasonable feature to consider. Also, one of the participants reported having "aphantasia" – a condition that deprives the person the ability to voluntarily visualize and create images in their mind[2]. Since a non-visual experience can be said to be highly dependant on the mental imagery it evokes in the user, users with this condition can presumably only enjoy this kind of non-visual experience to a limited extent.

Notes

1 In this experiment the straight axes are front (F), right (R), back (B), left (L) and the diagonal axes are front-right (FR), back-right (BR), back-left (BL), and front-left (FL).

2 The name "aphantasia" was first coined by a team led by Professor Adam Zeman of the University of Exeter (Zeman et al. 2015) in 2015, but the phenomenon itself was first described in 1880 by Francis Galton (Galton 1880) and has been scarcely researched so far.

Chapter 5
Discussion

5.1. Evaluation Summary

Over the course of this project, two iterations of the collar-based haptic have been prototyped and tested with their respective field of application (navigation and immersion) in mind. This section lists the key outcomes of each user test round and the implications for the final game concept.

The first version of the Haptic Collar prototype was used to gather insights about the level of comfort and clearness of different vibration patterns, the number of vibration motors necessary to adequately and intuitively guess directions as well as how non-intrusive and intuitive the haptic navigation works in a real-life setting. The system was found to work well (73% - 95% accuracy) and works best with short vibration patterns. 8 vibration motors seem to work best for the applications, however 4 and 6 also performed ok, disregarding the diagonal directions. While participants reported a smooth navigation that took "little effort to process," further considerations have to be made for pedestrian navigation. Issues with this prototype were the non-responsive vibration according to the test subject's head movement and the fairly short cables from the controlling device to the collar, which sometimes made triggering the vibration difficult.

The second version was built based on the feedback gathered from the first user test. 8 vibration motors were used and instead of cables to the control device, the collar was wirelessly connected to the smart phone app via Bluetooth, which made remote interaction possible. Considering the feeling of presence and immersion, the spatial audio was created by movement of the audio on the x-axis, which means that the illusion of the yōkai's presence could be easily broken by totating the head to the left or right. In terms of multimodal feedback, the most important features were high-quality audio and voice acting together with vibrations, while the cold thermal sensation made for a good surprise effect.

It might be asked whether the two prototype designs fulfill the goals set in the beginning and if the desired results were met. Therefore, let us recap the set objectives. First, the author aimed to provide an enjoyable gaming experience that users want to engage in. This objective was met: the crossmodal, but non-visual experience provided in the second prototype gained mostly positively feedback and all users uttered the wish to engage more in such an experience and only around half of the participants felt like visuals would add to the sense of presence. The second objective was to find out whether users can be navigated safely and accurately with haptics and without visuals. Since participants who tested the first prototype reported easy to understand navigation that took "little effort" even when distracted by casual conversation, this objective can be considered to be met as well. The third objective was to explore new ways of immersing the user. Haptic feedback was found to be able to create the sense of immersion even without visuals. Since several participants called this crossmodal experience a "new sensation," this objective is met as well. This is related to the fourth objective, which was to find out which combinations of sensory stimulation can enhance the user's immersion into the game. The answer to that is a combination of high-quality audio and vibration was the most successful crossmodality for immersion, but the cold thermal sensation added an element of surprise that was effective for some and was considered by them as a "new sensation" as mentioned above. The fifth and last objective was to create a first attempt in defining design guidelines for navigation and immersion for non-visual augmented reality game applications. The key findings and guidelines for a non-visual AR gaming application using haptic feedback can be summarized as follows:

- **Audio**: Audio should be spatialized to give a sense of location and presence. The sound effects and voice acting need to be of high quality to ensure immersion.
- **Vibration feedback**: Nudges of approx. 300ms seem to be comfortable for the user. Long vibrations over 500ms should be avoided since it cannot be adequately located due to sensory saturation. Vibration feedback can give a feeling of spatiality to audio, even if the audio only functions on an x-axis level and works well with audio to enhance immersion.

- **Thermal Feedback**: Thermal feedback has not been much utilized in gaming applications, therefore benefits from a surprise factor. Numbers of Peltier elements and strength should be adjustable to body sensitivity.

- **Navigation**: 8 vibration motors without a compromise in direction have proven to be the most intuitive choice for haptic navigation in 8 directions on the neck in form of a collar.

While the two prototypes still do not cover the whole design range of the game concept and still lack a clean product design to hide the technology inside, it can be summarized that the two iterations were successful in providing insights in how to non-visually navigate users through an urban environment and how to multimodally, but non-visually, generate an immersive user experience, whereby they met all the set objectives for this project.

5.2. Limitations

There are certain limitations that are applying to the proposed concept and the prototypes used in this project. Some of them were encountered during user tests and some were encountered as a result of the design decisions made. It is important to mention these so they can be improved for further iterations.

While the first prototype was functional, the design was far from polished. The cables connecting the control unit with the buttons to the Arduino were long enough for the test inside the room, however, when used in the real-world setting, the wires proved to be quite short. Therefore, the experimenter had to walk quite close to the test subject, which might have led to a certain influence in the walking direction of the test subject. Also, since the device is collar-based and had many wires around it, wearing it in public for the navigated walk might have had an influence on the test subject if they noticed passers-by looking at them. Manually triggering the vibrations without a connection to a computer during the walk had the disadvantage that the input could not be verified in the serial console. This did not pose a problem for the straight axis navigation, however, since two buttons had to be pressed at almost the same time for a diagonal vibration to be triggered, it cannot be 100% guaranteed that the experimenter always triggered the intended direction of vibration. Testing 8 directions with 8 motors was successful, but it needs to be tested whether even more than 8 directions can be reliably triggered with 8 actuators or if the number of modules needs to increase together with the umber of desired directions to trigger.

The second prototype also comes with certain limitations. The provided slightly scary sequence of events worked well in the user test, but it seems that a large portion of this was due to the surprise factor of the experience itself and the use of the cold thermal sensation, which some mentioned as being a new sensation. The element of surprise, however, might only work so many times and the novelty of the thermal feedback might diminish over time. Future work therefore has to focus on whether the immersion can be kept for a longer period of time. Another limitation are the currently hard-coded vibration feedback sequences for the audio. Since every little vibration has to be hard-coded into the system, it is little flexible and even small deviations of milliseconds can ruin the synchronized sensation of audio and vibration that made this feedback combination the most successful one. A possible solution could be to create an algorithm to automatically create vibration patterns based on the audio input. Furthermore, users with a limited capability to voluntarily visualize images (aphantasia) might not be able to enjoy the experience to the same extent as other people who do not have this condition.

Chapter 6
Conclusion and Future Work

The work presented in this research proposes a new way to enjoy mobile AR gaming applications without becoming distracted by the visual component that most of the existing AR applications focus on. The author was inspired to conduct this project by observations and discussions about mobile phone addiction and the potential concerns regarding traffic safety that continuous phone usage while walking – not only by texting or browsing the web, but also by playing mobile games games focusing on visuals. This work introduced haptic feedback for the purpose of non-visual navigation as well as in combination with audio to generate a multimodal immersive user experience for gaming purposes. The two fields of the haptic feedback design – navigation and immersion – have been tested individually and both gained positive feedback from the study participants. The emotional impact reported by the test subjects triggered by the crossmodal elements in the second user test can be seen as one of the most important factors for immersion. Based on the user feedback, guidelines for designing haptic AR games could be derived. Users were eager to engage more in this experience despite not including any visuals. Substituting the visual sense with other modalities can therefore be seen as a way to provide an enjoyable gaming experience without visual distractions.

There are several future directions for this game concept. The prototypes introduced in this project only cover two of the parts that make the game concept – navigation and immersion. However, future iterations need to focus on the interaction between the player and the yōkai to find out which kind of interactions are possible with the haptic collar and which implications those interactions could have for the flow of the story, e.g. different storylines triggered by different interactions. Also, the navigation and the immersion parts have to be merged to test the game concept of finding the yōkai by vibration feedback and then interacting with it in an engaging and immersive way. Although the main part of the game concept – the quests – do not rely on visuals, the visual design of the game as well as the UI in-between quests has to be considered and prototyped. In addition to vibration and thermal feedback, other senses could be explored and implemented to give a more immersive and multimodal augmented reality experience.

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Appendices

A. Questionnaire Used in the First User Test

A.1 Pre Test

1. Age .....
2. Gender
   O Female O Male O Prefer not to say O Other.....
3. Nationality
   .....
4. Do you use mapping apps like Google Maps?
   O Yes O No O Others .....
5. If yes, which?
   .....
6. On a scale from 1 to 10, how often do you look at your phone when you navigate?
   not at all 1 O O O O O O O O O O 10 very often
7. Please give a reason for your choice (e.g. situation):
   .....
8. Have you played location-based gaming apps like Pokémon GO before?
   O Yes O No O Others .....
9. If yes, which?
   .....
10. If you have played Pokémon GO, have you used the Pokémon GO Plus before?
    O Yes O No
11. Do you know what haptic feedback is?
    O Yes O No O Kind of O Others ....

A.2 Questionnaire Used for the Vibration Pattern Study

1. Sustained short: On a scale from 1 to 10, how did the vibrations feel on your neck? (8 motors)
   very uncomfortable 1 O O O O O O O O O O 10 very comfortable
2. Sustained short: On a scale from 1 to 10, how clear did the direction of the vibrations feel? (8 motors)
   very unclear 1 O O O O O O O O O O 10 very clear
3. Multiple long: On a scale from 1 to 10, how did the vibrations feel on your neck? (8 motors)
   very uncomfortable 1 O O O O O O O O O O 10 very comfortable
4. Multiple long: On a scale from 1 to 10 , how clear did the direction of the vibrations feel? (8 motors)
   very unclear 1 O O O O O O O O O O 10 very clear
5. Multiple short: On a scale from 1 to 10, how did the vibrations feel on your neck? (8 motors)
   very uncomfortable 1 O O O O O O O O O O 10 very comfortable
6. Multiple short: On a scale from 1 to 10, how clear did the direction of the vibrations feel? (8 motors)
   very unclear 1 O O O O O O O O O O 10 very clear
7. Sustained long: On a scale from 1 to 10, how did the vibrations feel on your neck? (8 motors)
   very uncomfortable 1 O O O O O O O O O O 10 very comfortable
8. Sustained long: On a scale from 1 to 10, how clear did the direction of the vibrations feel? (8 motors)
   very unclear 1 O O O O O O O O O O 10 very clear
9. Was there any pattern you felt was the most comfortable? If yes, why?
   .....
10. Was there any pattern you felt was the least comfortable? If yes, why?
    .....
11. Was there any pattern that made you feel like you could accurately guess the directions?
    .....

12. Was there any pattern that made you feel the directions where blurry or unclear?
    .....

A.3 Questionnaire Used for the Number of Actuators Study

1. On a scale from 1 to 10, how did the vibrations feel on your neck? (4 motors)
   very uncomfortable 1 O O O O O O O O O O 10 very comfortable
2. On a scale from 1 to 10, how clear did the direction of the vibrations feel? (4 motors)
   very unclear 1 O O O O O O O O O O 10 very clear
3. How well do you feel you did on this test? (4 motors)
   .....
4. Do you feel like you had to guess a lot or were the directions clear for you? (4 motors)
   .....
5. Do you feel the directions were easy to understand or was it hard? (4 motors)
   .....
6. On a scale from 1 to 10, how did the vibrations feel on your neck? (6 motors)
   very uncomfortable 1 O O O O O O O O O O 10 very comfortable
7. On a scale from 1 to 10, how clear did the direction of the vibrations feel? (6 motors)
   very unclear 1 O O O O O O O O O O 10 very clear
8. How well do you feel you did on this test? (6 motors)
   .....
9. Do you feel like you had to guess a lot or were the directions clear for you? (6 motors)
   .....
10. Do you feel the directions were easy to understand or was it hard? (6 motors)
    .....
11. On a scale from 1 to 10, how did the vibrations feel on your neck? (8 motors)
    very uncomfortable 1 O O O O O O O O O O 10 very comfortable
12. On a scale from 1 to 10, how clear did the direction of the vibrations feel? (8 motors)
    very unclear 1 O O O O O O O O O O 10 very clear

13. How well do you feel you did on this test? (6 motors)
 .....
14. Do you feel like you had to guess a lot or were the directions clear for you? (8 motors)
 .....
15. Do you feel the directions were easy to understand or was it hard? (8 motors)
 .....

A.4 Questionnaire Used after the Haptic Walk as a Use Case

1. On a scale from 1 to 10, how easy or hard were the directions to understand?
 very hard 1 O O O O O O O O O O 10 very easy
2. On a scale from 1 to 10, how sure were you about being on the right track?
 very unsure 1 O O O O O O O O O O 10 very sure
3. On a scale from 1 to 10, how much do you feel you trust haptic feedback as a means of navigation?
 not at all 1 O O O O O O O O O O 10 very much
4. On a scale from 1 to 10, how likely would you be to wear such a device for navigation / games?
 not at all 1 O O O O O O O O O O 10 very much
5. Comments or Suggestions
 .....

B. Error Data of the Number of Actuators Study

Compiled amount of errors for each direction in each motor setup as result of the number of actuators study

4 Motor Setup F=front, FR = front-right, R = right, BR = back-right, B = back, BL = back-left, L = left, FL = front-left

	F	FR	R	BR	B	BL	L	FL	
User/Direction	1	2	3	4	5	6	7	8	
A	0	1	1	2	0	0	0	1	5
B	0	0	1	2	0	2	0	0	5
C	0	2	0	1	0	0	0	2	5
D	0	1	1	0	0	0	0	0	2
E	0	1	0	2	0	0	0	0	3
F	1	1	0	0	0	2	0	0	4
G	0	1	1	1	0	1	0	0	4
H	0	2	0	1	0	2	0	1	6
I	0	0	1	2	0	2	1	0	6
J	0	2	1	0	1	1	1	0	6
K	0	2	0	1	0	0	1	0	4
	1	13	6	12	1	10	3	4	

6 Motor Setup

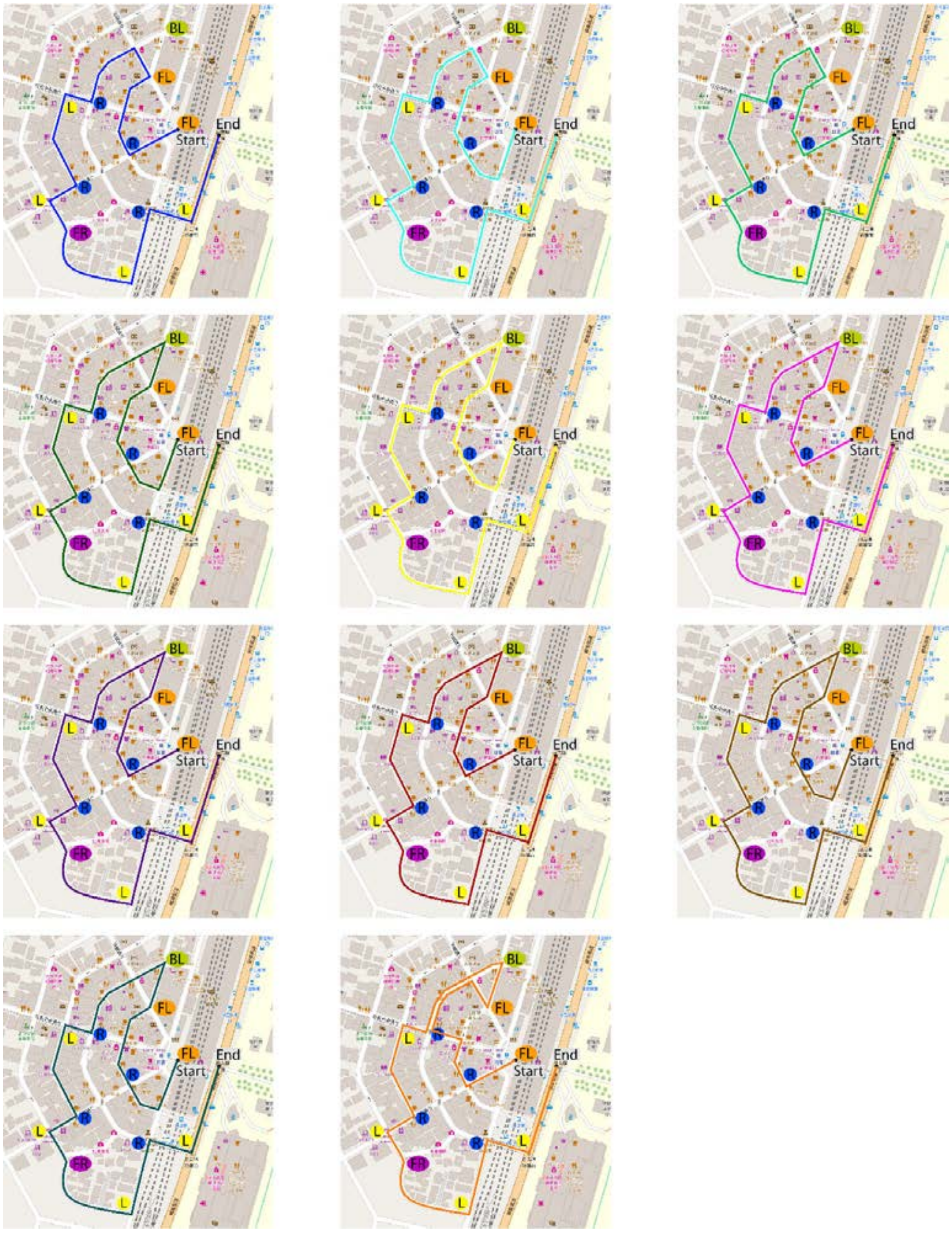
	F	FR	R	BR	B	BL	L	FL	
User/Direction	1	2	3	4	5	6	7	8	
A	1	0	1	1	0	0	0	0	3
B	0	1	1	1	1	2	2	0	8
C	1	1	1	0	0	0	1	1	5
D	0	0	1	0	2	1	0	0	4
E	1	0	0	0	0	0	0	0	1
F	1	0	0	0	0	0	0	0	1
G	0	1	0	0	0	0	0	2	3
H	2	0	0	0	0	1	0	1	4
I	1	0	0	1	0	0	0	1	3
J	2	0	0	0	0	0	0	0	2
K	1	0	0	0	0	0	0	0	1
	10	3	4	3	3	4	3	5	

8 Motor Setup

	F	FR	R	BR	B	BL	L	FL	
User/Direction	1	2	3	4	5	6	7	8	
A	0	0	0	1	0	0	0	0	1
B	0	0	0	2	0	2	0	2	6
C	0	0	0	0	0	0	1	0	1
D	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0
G	0	0	0	0	1	0	0	0	1
H	0	0	0	0	0	0	0	0	0
I	0	0	0	1	0	0	1	0	2
J	0	0	0	0	0	0	0	0	0
K	0	0	0	0	1	0	0	0	1
	0	0	0	4	2	2	2	2	

C. Recorded Test Subject Route of the Haptic Walk

Actual route of each test subject during the haptic walk based on recorded GPS data of the participants



D. Sequence of Events

The sequence of events and their timeline (in milliseconds) of audio and haptic events for the second prototype

```
delayedExecute(ct, 0, { self.thermalOn() } )
// turns on peltier for a cold sensation
delayedExecute(ct, 5000, { self.stepsLeftQuiet() } )
// quiet steps without vibration on the left
delayedExecute(ct, 11000, { self.stepsRightQuiet() } )
// quiet steps without vibration on the right
delayedExecute(ct, 17000, { self.stepsLeftBecomeLouder() } )
// steps on the left becoming louder with increasing vibration
intensity
delayedExecute(ct, 25000, { self.stepsRightBecomeLouder() } )
// steps on the right becoming louder with increasing vibration
intensity
delayedExecute(ct, 33000, { self.runLeft() } )
// running sound on the left side with vibrations from back to front
via the left side with vibrations
delayedExecute(ct, 37500, { self.runRight() } )
// running sound on the right side with vibrations from back to front
via the right side with vibrations
delayedExecute(ct, 42000, { self.doYouHearUs1() } )
// narration "Do you hear us?" on the left without vibration
delayedExecute(ct, 45500, { self.doYouHearUs2() } )
// narration "Do you hear us?" in lower voice on the right side
without vibration
delayedExecute(ct, 50000, { self.exhale() } )
// exhaling sound with strong vibration on the BL, B and BR motors
plus cold thermal sensation
delayedExecute(ct, 54500, { self.canYouSenseUs() } )
// narration "Can you sense us?" on the right side
delayedExecute(ct, 59300, { self.properHuman() } )
// narration "It's been such a long time since we had a proper human
here *chuckles* We've been waiting so long." on the right side
delayedExecute(ct, 73300, { self.stepsLeftToRight() } )
```

```
// step sounds from the left to the right via the front with vibrations
delayedExecute(ct, 79800, { self.weAreYokai() } )
// narration "We are y^^c5^^8dkai." on the right side
delayedExecute(ct, 82300, { self.runBackToLeft() } )
// running sound from right to left via the back with vibrations
delayedExecute(ct, 85300, { self.bakezori() } )
// narration "Bakez^^c5^^8dri." from the left side
delayedExecute(ct, 87300, { self.stepsLeftToRightBack() } )
// step sounds from left to right via the back with vibrations
delayedExecute(ct, 93300, { self.builders() } )
// narration "Builders, worthless builders, always building things,
they build this place, they build this place and they LEFT US. HERE."
from the right with vibration on the right for louder parts (in
capital letters)
delayedExecute(ct, 104300, { self.stepsRighttoLeft() } )
// step sounds from right to left via the front with vibrations
delayedExecute(ct, 112800, { self.discardedShoes() } )
// narration "Do you know what it's like to be left? Just a shoe.
Just a SHOE." from the left
delayedExecute(ct, 123800, { self.stepsToFollow() } )
// narration "But it's okay. We found new feet, new steps to follow.
How about yours?" from the left
delayedExecute(ct, 140800, { self.laughter() } )
delayedExecute(ct, 140800, { self.runAround() } )
// sound of loud laughter going from left to right and back to left
together with vibration of the step sounds that are triggered at the
same time and cold sensation
delayedExecute(ct, 145300, { self.stepsFade() } )
// step sounds on the left including vibration fading and disappearing
```

E. Questionnaire Used in the Second User Test

1. Age
   .....
2. Nationality
   .....
3. Did you feel scared?
   O A lot O A little O Not at all
4. Did you feel startled?
   O Yes O A little O No
5. Did you feel calm?
   O Yes O Somewhat O No
6. Did you feel surprised?
   O Yes O A little O No
7. Did you have fun?
   O Yes O A little O No
8. Did you feel like something was in the room?
   O Yes O Somewhat O No
9. Did you feel like the cold sensation helped you believe something was there?
   O Yes O A little O Not at all
10. Did you feel like the vibration sensations helped you believe something was there? O Yes O A little O Not at all
11. Did you feel like the audio helped you believe something was there?
    O Yes O A little O Not at all
12. Was there a combination of sensations that was most effective in making you believe something was there?
    .....
13. Was there a combination of sensations that was the least effective in making you believe something was there?
    .....
14. Did you expect this to happen?
    O Yes O No
15. Did you enjoy the experience?
    O Yes O No
16. Would you like to engage more in this experience? O Yes O Maybe O No

17. Do you think adding visuals would help your immersion into this experience?
    O Yes O I don't know O No
18. What do you think would help you feel more like something in this room?
    .....
19. Was there anything you disliked about this experience?
    .....
20. Was there anything you liked about this experience?
    .....
21. On a scale of 1 to 5 how much did you like this experience?
    1 Disliked a lot O O O O O 5 Really liked it
22. On a scale of 1 to 5 how much did you believe there was something in the room?
    1 Not at all O O O O O Very much
23. On a scale of 1 to 5 how much did you feel immersed into this experience?
    1 Not at all O O O O O Very much