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Pico immersion
ludic explorations in personal projection

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Wien, 24.11.2011

Stephan Lohwasser | Geraldine Fitzpatrick

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MASTER'S THESIS

in

Medieninformatik

by

Stephan Lohwasser
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to the Faculty of Informatics
at the Vienna University of Technology

Advisor: Univ.Prof. Geraldine Fitzpatrick, Phd.

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Abstract

Mobile phones with integrated pico-projectors are predicted to take the market by the storm within the next couple of years. Such projector-phones hold the potential to significantly change the ways we use and experience mobile computation. And while current devices are marketed for business and media presentations, researchers and designers have begun to explore the design-space that has been opened by personal projection, searching for new forms of interaction and a broader array of possible uses.

This research seeks to assist in the investigation of this design-space by focusing on the potentials of personal projection for playful engagement and immersion within the constraints of technological possibilities. Combining a pico-projector with motion-sensing input controllers, a mobile augmented-reality system was proposed, that aimed to create immersive experiences by allowing users to navigate, explore and interact with virtual spaces. Based on the principles of ludic design and artistic practice, a series of technical and conceptual prototypes were evaluated. The prototypes were set up in little exhibitions and participants were invited to engage with them. The aim of these exhibitions was on gathering people's experience through observations, conversations, pictures and videos. The results were used to assess the quality of the interactions, the aesthetics and the level of engagement personal projection affords, and to draw lessons for further application of the technological principles.

Kurzfassung

Mobiltelephone mit integrierten, kleinen Picoprojektoren (sogenannte ‚Projector-phones'), versprechen die Art und Weise, mit welcher wir mobile Technologien benutzen und erleben, grundlegend zu verändern. Und während die aktuell erhältlichen Geräte ausschließlich für die mobile Präsentation von Bildern und Videos beworben werden, haben DesignerInnen und WissenschafterInnen begonnen ein breites Spektrum neuer Interaktionsformen, Inhalte und Anwednungen für dieses Medium zu erkunden.

Diese Masterarbeit erforscht mobile Projektionstechnologien in Bezug auf ihr Potential für spielerische Interaktion und Immersion. Durch die Kombination eines Picorpojektors mit bewegungserfassenden Sensoren wurde ein mobiles Augmented Reality (AR) System entwickelt, welches immersive Erlebnisse erzeugt, indem es UserInnen ermöglicht virtuelle Räume zu erforschen und mit virtuellen Objekten zu interagieren. Mittels Methoden der digitalen Kunst und den Prinzipien des Ludic Designs, wurden verschiedenste Technologien, Interaktionen und ästhetische Konzepte prototypisch implementiert. Die Evaluierung dieser Prototypen geschah in Feldtests, in denen UserInnen eingeladen wurden mit den entstandenen Artefakten zu interagieren. Ziel war es war die Reaktionen und Erlebnisse der UserInnen auf die Technologie durch Beobachtungen, Interviews, Bilder und Videos zu verstehen. Eine Analyse der gesammelten Daten wurde verwendet die Qualität der Technologien, der Interaktionen, der Ästhetik des System zu beurteilen, um daraus Prinzipien für zukünftige Anwendungen abzuleiten

Contents

1. Introduction

We have all been to the movies. So we all know what it's like to sit in a darkened room perfectly still, for an hour or two, gazing at a screen. This passive way of consuming projected images - gathering around a screen and staring at it for a while - has become the common notion of what projection is all about, no matter whether we watch movies, slide-shows, *Power Point* [1] presentations or the football world cup.

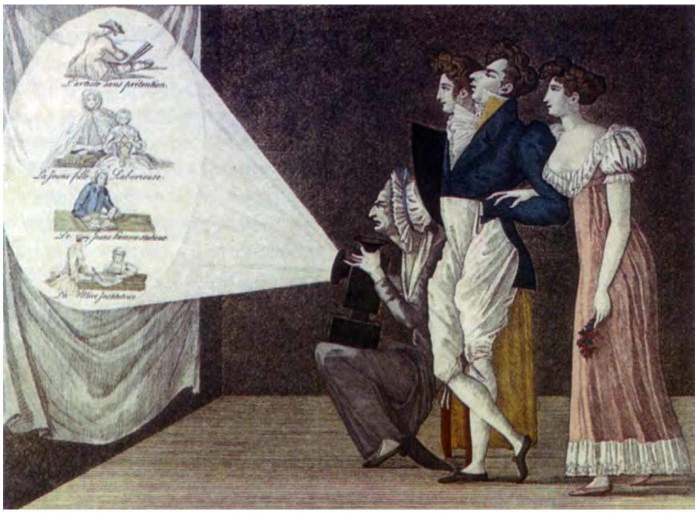


Figure 1. Illustration depicting the use of an magic lantern. Le Vieux Style, 1811 (Jack Judson Collection). [3]

1.1 History of mobile projection technologies

Yet, projection has a remarkable property that affords much more than the uninvolved ways we now generally use it: The size-ratio of the small projection device to the potentially huge image coming out of it. This unique quality of projection has been recognized a long time ago and the idea of interacting with projected images dates back way beyond the cinema days and was first introduced with the Magic Lantern in 1646 [2] (see figure 1). In a Magic Lantern, the light of a candle would pass through a painted sheet of glass, magnify the image and project it onto a surface. In later iterations of the same principle became popular attractions in 19th century Europe [4] and Japan [5]. The main problem of Magic Lanterns however was, that although they were small in comparison to the images they created, they still were pretty big and heavy when compared to the person operating them. Consequently the Magic Lanterns and their offsprings eked out a marginal existence, while static projectors evolved and shaped the way we use projections today.

Within the last decade however [6], a new class of projection devices has revived the interest in the technology: Personal projectors are *"small and inexpensive video projection devices intended for use in battery-powered handheld or wearable products"* [7]. The smallest of those devices, so called *pico-projectors*, measure just a few inch and even afford to be embedded into other gadgets (such as mobile phones) (see figure 2). Now for the first time, projectors have become small and robust enough (they now use lasers instead of oil-candles) to be considered truly mobile, promising a revolution in the ways we engage with projected images and mobile computation. Yet, in order to take advantage of the technology's potential, we need to re-evaluate our established notions about the ways projection can be used and the (lack of) interactions it affords. The design of interaction techniques for handheld projectors and the investigation of a broader array of possible applications has been a growing area of interest in the field of Human–Computer Interaction (HCI) and in particular for researchers in Ubiquitous Computing. [9] [10].

Figure 2. Advertisement for "the first projection mobile in the world." [8]

1.2 Problem statement

This thesis seeks to assist in the exploration of these as of yet untapped potentials. More specifically, it is interested in the potentials for immersive engagement and ludic interaction. In the 17th century, people, enjoyed the sheer sight the Magic Lantern's colourful images appearing in the darkness. Today we are well used to bright lights and MTV [11]. But with the aid of computation and the sensor technologies we now have the means to make projected images not only fun to look at but also fun to play with.

1.2 Methodological approach

The idea that play and fun are valuable concepts in human-computer-interaction has evolved from more traditional approaches like the cognitive sciences, as the computer has evolved from a tool which's sole purpose was the increase of productivity, to a device that can stir our emotions. One such design-philosophy is Ludic design, which does not try to help solve a specific task, but it invites to engage with and reflect on and find meaning in an object through the experience of playing with it [12]. It recognizes that people are playful creatures [13] and that play can be a *'mechanism for developing new values and goals, for learning new things and for achieving new understandings'* [14]. In honour of the Magic Lantern's playful heritage and following the principles of Ludic Design, the goal was to explore the ludic potentials of personal projection by inviting users to play with it and by engaging them in immersive experiences.

As a framework for my research, I propose a mobile mixed-reality system, consisting of a pico-projector and motion-sensing input controllers to track user movements. The projector acts as a *'Magic Torchlight'* (akin to a *Magic Lens* [15]) which allow participants of engage with virtual environments. The experience thus created resembles those of large-scale *Virtual Reality (VR)* applications (see figure 3).

In a series of prototypes various ideas for aesthetic interactions were implemented. The results of the user-studies in which the prototypes were evaluated were then used to create a set of guidelines to serve as a reference for future projects.

1.3 Overview

The remainder of this thesis will document my efforts. Chapter 2 discusses the connections and similarities that exist between modern HCI and digital Art, concluding that they are sometimes impossible to distinguish from one another. Based on those observations, chapter 3 presents an overview of related projects both science and the arts. In chapter 4 the main research questions are framed and the methods to answer these questions are presented. In chapters 5 and 6 the applied methods and the collected data are surveyed in greater detail, and chapter 7 evaluates their findings. The final chapter 8 sums up the key issues and speculates on possible future projects.

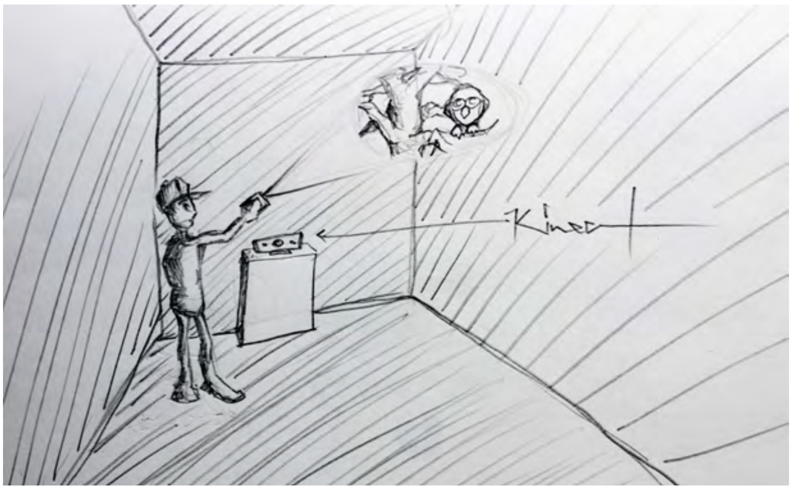


Figure 3. Early design sketch illustrating the core principle of the proposed system

2. HCI and arts

The following section will give a short overview of the origins of HCI and how it evolved from the cognitive sciences to include various other disciplines like design [16], anthropology [17] and phenomenology [18], and how it is now converging towards artistic practices by encompassing concepts like aesthetics [19], emotions [20] and ambiguity [21]. On the other hand, I will also show how the digital arts are beginning to take a more scientific stance, and argue that is sometimes all but impossible to distinguish HCI and art from one another.

2.1 HCI

Computers used to be little more than *'glorified calculators'* [22], and their only goal was to increase productivity. That was more than 20 years ago.

Within these last two decades however, computation has changed dramatically. Computers aren't beige boxes under office-desks anymore. They are portable, they are wearable and they pervade all aspects of our daily lives. *"We now live with technology and not just use it."*[23] As the ways we engage and interact with computation are becoming richer and more intricate, HCI has developed approaches to human cognition, that are less concerned with information-processing than they are with human values [24] such as aesthetics [19], emotions [20], reflection [25], play [26] and fun [27]. Embracing the inherent ambiguity [28] of human nature their methods try to *"capture how the use of technologies may unfold over time and in different situations"* [23].

2.2 Ludic Design

Among these approaches to human-computer-interaction is *Ludic Design* [26]. Based on the notion that man is a playful creature [29], it promotes engagement in the exploration and production of meaning, rather than helping to perform a specific task. It recognizes that *play* is not merely a matter of entertainment, or a waste of time, but can be a *"mechanism for developing new values and goals, for learning new things and for achieving new understandings"* [30].

Ludic design is based on the following principles: *"First, scientific approaches to design need to be complemented by more subjective, idiosyn-*

cratic ones." This point is concerned with how we design rather, than what we design. It is difficult *"to conceive of a task analysis for goofing around"*, and we must find alternative approaches to design that allow interpretation and uncertainty. *"Second, designing for Homo Ludens means allowing room for people to appropriate technologies."* And *"thirdly, and most importantly, pleasure comes before performance, and engagement before clarity."* *"[P]eople are characterized by play as much as by anything like thinking or tool use or what have you"* and *"offers a nice alternative to assumptions that design should be about problem solving or about functionality or about trying to [..] pursue tasks in particular ways"* [30].

To design systems and interactions that meet these demands, methods are employed that bear more resemblance to the practices of art, than to those of research and design. William Gaver for example created a cultural commentary by hiring a filmmaker to produce a documentary of his work. Analogies may be drawn artists like Banksy [31] and Monsieur Chat [32], who both used documentaries to present their art and to communicate their cultural critiques (Banksy's *"Exit through the gift shop"* [33] and *"Chats Perchés"* by Chris Marker). Another aspect usually associated with the arts is the central role of the designer. Where user-centred design strategies are based on ethnographic studies, logging of interactions, and surveys, Ludic Design puts emphasis on the experiences and intuitions of the designer.

The connections between art and design are intricate and manifold. But they are not the same. Where design attempts *"to transform the world from the current state to a preferred state"* [34] by solving given problems, art aims to transform the world from within by reflecting and re-appropriating the current state. Design artefacts are tools –*"things that are used for something"* [35]. Artistic artefacts on the other hand, are manifestations of ideas. They challenge the ways we see the world and make room to develop own understandings.

HCI as a discipline is made up of many different areas and schools of thoughts and it is often difficult to decide where the one area begins and the another one ends. In case of Ludic Design it is open to interpretation whether Ludic Design indeed is design, or whether one places it closer to the domain of arts (see figure 4).

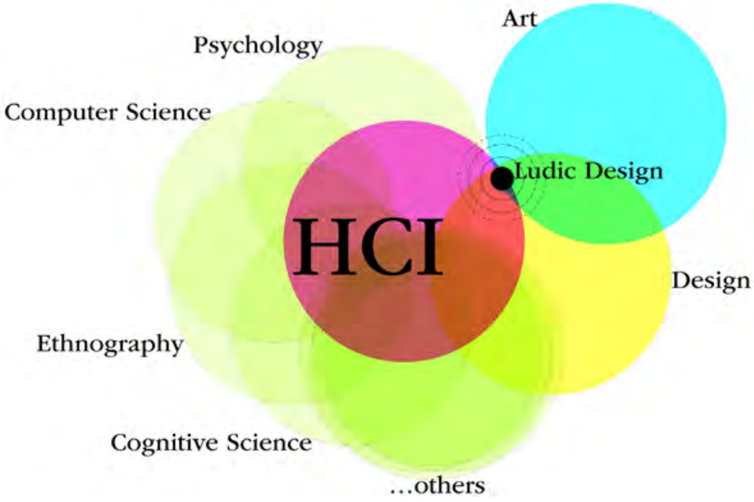


Figure 4: An attempt to place Ludic Design within the space of disciplines that form HCI.

The History Tablecloth [36] for example, is a design artefact but it does not solve a problem. Instead, it creates a glowing halo when an object is placed on it and it slowly fades back to white after the object has been removed (see figure 5). *"The piece is intended to create an ambiguity of relationship"* [36], as the interpretation of the halos is left to the people who encounter the tablecloth. *"Some might feel that it is a prompt to tidy up more often; others might become reluctant to move objects on the table lest they disrupt a particularly pretty pattern of lights."* [36]

Figure 5: The History Tablecloth [36]

2.3 Digital arts

And while HCI draws nearer towards the arts, there are artistic tendencies that converge towards a more scientific self-image. Inspired by the use and culture of Open-Source-Software [37] [38], which – like science – is about sharing knowledge and about expanding, criticizing and revising existing work, the artist self-conception has changed. The lonely genius who is misunderstood by the world has made way for a social being that shares its findings, readily helps its peers [39] and is open for peer-review and criticism [40] [41]. Zachary Lieberman, who is an artist as well as a scientist (e.g. [42]) explicitly called artistic practice a kind of research and stated that art it is *"an RnD department for humanities"* [43]. And like in HCI, as the agendas of art change, so do the methods. Instead of working alone and presenting an artwork only after completion, the artist now believes in *"making deeply engaging, entertaining and meaningful interactions"* [43] (Liberman calls them *"open-mouth-moments"* — when a person's jaw drops wide open in awe. See figure 6) and considers the process of creation and the audience's interactions equally important as the actual object.

Figure 6: Open-mouth-moments during one of Zach Lieberman's installlations [42]

Analysing the potential of this convergence between artistic practices and HCI evaluation methods from a scientific standpoint, Höök et al. argue that in a way an *"interactive artwork is [..] like a research paper: the artist uses it to communicate his or her ideas directly"* [44]. And although they acknowledge the similarities and consider their studies a part of an art piece themselves, they conclude that *"art and HCI are not easily combined"* [44]. I disagree, as I believe that at times, science and art are in fact one and the same thing.

To illustrate this point, I will now present two projects from the respective areas in more detail and show their likeness with respect to their methods, aims and outcomes: The academical effort is the *"Presence Project"* [45] by William Gaver, which investigates the *"ways that technology can be used to increase the presence of older people in their local communities"*. And the artistic project is the *"Eye Writer"*, *"an ongoing collaborative research effort to empower people who are suffering from [Amyotrophic lateral sclerosis] with creative technologies"* [46].

2.4 The Presence Project

The Presence Project [45] is a textbook example of the ludic design approach, in that it did not have a clearly outlined problem that needs solution, but used technology in finding ways to empower people – and especially older people – to interact with computers and communication technologies. From the mission statement: *"The big problem with information technology is that it tries so hard to be rational. By contrast, humans are happy to be rational only part of the time. Most other times (apart from the fact that they sleep so much) people operate in very different modes: of daydreaming and pondering; of joy and melancholy; of hope and of despair – apart from all the other subliminal states of which, most of the time, we are not even aware. Now, all of these I would call the non-rational [...] Because all information technology systems have started out in life with a big ration of the rational, the logical conclusion seems to be that, indeed, we should work towards a new and perfect world – a technocracy directed by the empty ethos of machines. [..] Presence rejected this purely positivistic absurdity, that along with the development of the computer, has been furiously promulgated over the last 50 years. However, rather than taking a 'neo-Luddite' stance, i3 [Intelligent Information Interfaces research initiative] aspired to start from human-centred notions to see how new technology could be invented and interwoven in that context. It asked for ways of supporting (and not replacing) everyday people doing everyday things: of supporting creativity and imagination, of friendship and community, having a chat, of …" — Jakub Wejchert, Future and Emerging Technologies Unit, European Commission.*

During its development the researches used methods that ranged from design-led user studies, to conceptual proposals for innovative services and systems, to design experiments and tests of working prototypes in the communities themselves [47]. The desired qualities interfaces which were developed during the project shod have were: *"be pleasureable devices"* and *"considering the aesthetics of the interaction as a major element to be developed in tandem with functionality"* [47]. A notion which is remarkably similar to Zach Liebermans conception of art (see [43]).

2.5 Eye Writer

The Eye Writer on the other hand, though being called a research effort, was initiated and carried out by artists rather than by scientists. *"Members of Free Art and Technology (FAT), OpenFrameworks, the Graffiti Research Lab, and The Ebeling Group communities have teamed-up with a legendary LA graffiti writer, publisher and activist, named TEMPTONE. TEMPTONE was diagnosed with [Amyotrophic lateral sclerosis] in 2003, a disease which has left him almost completely physically paralyzed… except for his eyes. This international team is working together to create a low-cost, open source eye-tracking system that will allow ALS patients to draw using just their eyes. The long-term goal is to create a professional/social network of software developers, hardware hackers, urban projection artists and ALS patients from around the world who are using local materials and open source research to creatively connect and make eye art."* [46] The project enables TEMPTONE to continue his love for graffiti despite his disabilities and even allows him to interact and engage with the outside world by projecting his artworks onto buildings he might have otherwise covered with paint (see figure 7).

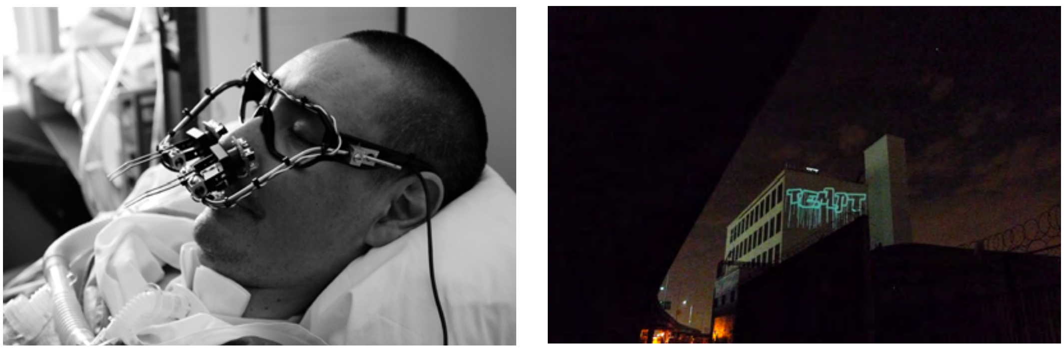


Figure 7: Left: Artist TEMPTONE, who was diagnosed with ALS. Right: Virtual graffiti by TEMPTONE. [46]

2.6 Observations

When viewing both projects side by side, I find it difficult to discern their backgrounds by just looking at the used methodologies and outcomes: Both show a great sensitivity towards their audience and respectfully consider what can and cannot be done. Both try to help those people by means of technology. And in both cases, the technology is just a tool. What's important is that the individual can relate to and interact with its surroundings. I'm convinced that an installation of the Presence Project in a major arts exhibition could gain a lot of attention. As would the Eye Writer on a conference on human computer interaction.

Having explained the connections that exist between arts, design and HCI, I will now turn towards the technological background and related work in the field of projection and interactivity, drawing freely form scientific as well as artistic research.

3. Related work

The previous chapter laid out the conceptual background on which this research was based, by explaining the similarities and differences between design and art, and by explaining how concepts like play and fun have become important aspects in human-computer-interaction. This chapter will relate its technological foundations. The main focus will be on projection technologies, mixed reality applications and personal projection. The capabilities and shortcomings of those technologies will be explained and related projects will be presented. A second part will consider technologies that facilitate interactions, i.e. input controllers and sensors, especially focusing on the latest developments in gaming controllers, like the Nintendo WII [48] and the Microsoft Kinect [49].

3.1 Mixed Reality

Mixed Reality is the concept of combining reality and virtual worlds in order to create immersive environments. The spectrum of Mixed Reality applications reaches from attempts to completely replace the physical world with a virtual counterpart (*Virtual Reality* [50]), to the augmentation of physical objects with digital information (Augmented Reality [51]).

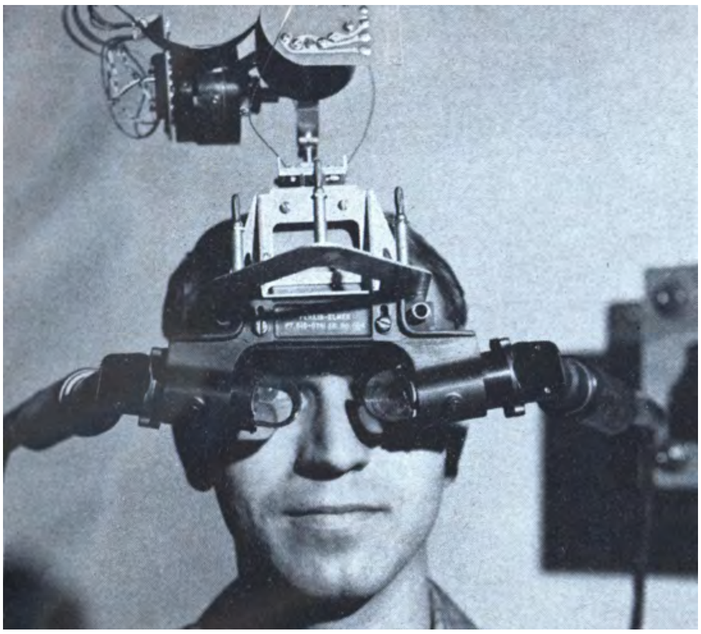


Figure 8: Ivan Sutherland's Ultimate Display [53]

3.1.1 Virtual Reality

Virtual Reality (VR) was pioneered by Ivan Sutherland's *Ultimate Display* [52], which used a Head Mounted Display to hide reality and substitute it with computer graphics by projecting directly into the users eyes (see figure 8 [53]):

> *"Slip this display device on your head and you see a computer-generated 3-D image of a room before your eyes. Move your head and your perspective changes, just as though you were actually inside the room. Architects could use the device to draw buildings in three dimensions; realtors could use it to show buyers the interiors of homes without even leaving the office."* [53]

But wearing the complicated apparatus proved to severely restrict the users ability to move. So systems were constructed that, instead of projecting directly into the eyes, projected onto surfaces that completely surround the user, allowing him to move freely inside the volume. The most well known implementation of such a system is the *CAVE*: A *"Surround-Screen Projection-Based Virtual Reality"* [54] (see figure 9 [55]). Using large projection screens, it creates an all-virtual environment and is able to create highly interactive experiences that range from scientific visualizations [56], to telepresence [57] to artistic installations [58]. The problems with such systems however, are their enormous size, their complexity to setup and maintain and their huge price tag [54].

Figure 9: Inside the CAVE [55]

3.1.2 Augmented Reality

On the other side of the spectrum of mixed-realities lies *Augmented Reality* (AR), which does not try to replace, but instead overlays reality with digital information. Auzma [51] defines AR as systems that have the following characteristics:

- Combines real and virtual
- Interactive in real time
- Registered in 3D

To to gain those properties many applications use a variety of the Magic Lens metaphor[15], where the appearance of an object is changed when seen through such a lens (see figure 10 [59]). With modern smartphones growing ever more powerful and featuring all kinds of sensors (e.g. cameras, accelerometers, gyroscopes, magnetometers…) that can be used for 3D registration, the concept of the magic lens is also applied in what's called *mobile-AR* or *outdoor-AR* [60], and the number of commercially available *point-of-interest* (POI) (e.g. [61]) applications and AR games [62] as well as the number of academical projects with the domain has increased significantly (e.g. [60] [63]). And although such applications do provide a high level of immersion and presence [64], their possibilities are severely limited by the small screens they use as a window into cyberspace.

Figure 10: Example of a Magic Lens [59]

3.3 Projection Mapping

A different approach to blur the border of reality and cyberspace is what has come to be known as *Projection Mapping* [65]. Using large scale projections that embody the geometry of its environment, Projection Mapping is not as interactive as mobile-AR and magic lenses, but it is much bigger. Virtual entities that are precisely mapped onto physical objects can utterly change the appearance of the underlying geometry and create illusions of deformation and dynamics (see figure 11). When combined with interactive technologies that allow participants to influence those changes, such installations are able to create highly immersive experiences. Night Lights is such a project. In 2009 the Auckland Ferry Building was turned into an interactive playground by taking the viewers body movements and amplifying them 5 stories tall [67] (see figure 13). Another example is InterPlay, a platform from MIT Media Lab, which *"transforms public spaces into immersive environments to create shared experiences that encourage active play and social interactions"* [68] (see figure 12). But as it is the case with VR applications, the major limitation of such Projection Mapping systems are the their static and immensely complex setup.

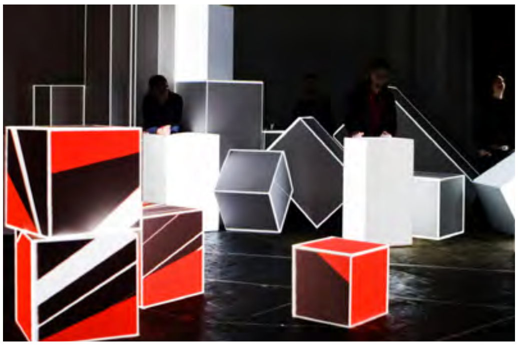


Figure 11(left): Projection Mapping [66]
Figure 12 (top): InterPlay, by Seth Hunter [68]

Figure 13 (top and left): Night Lights by Zach Lieberman. [67]

3.4 Personal Projection

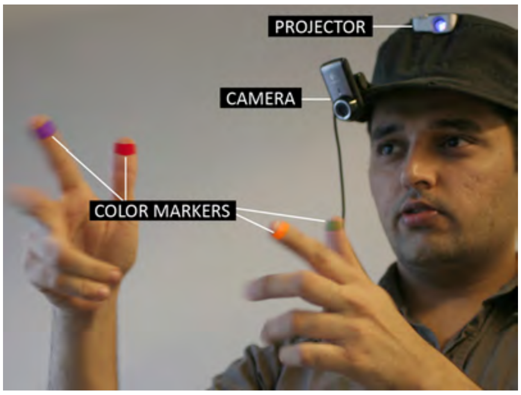
But what if one were to combine the flexibility of mobile-AR with the sheer size of Projection-Mapping? A most promisingly looking technology to do just that is *Personal Projection*. In principle, personal projectors are just ordinary projectors which happen to be very small. And in fact, the current generation of such devices is advertised to be used exactly as their bigger siblings, with the one difference, that now the staging and sharing of content can be performed in an elevator, instead of a conference room (see figure 14). But the mobility of pico-projectors and their diminutive size, which allows them to be embedded into other devices such as mobile phones [70] – resulting in what's called a projector-phone [10]– holds promise to create an entirely new class of applications that go way beyond slide shows, business presentations and watching movies [71] [9] [10].

Figure 14: Advertising for pico-projectors [69]

If market analysts are correct, mobile phones with embedded projectors will *"take the market by the storm"* [72] within the next couple of years. And with mobile phones being among the top three items we usually carry with us (the other two being keys and cash) [73], personal projection may soon become an integral part of our daily interactions with computation. Even so, despite the rapid technical developments and the promises made, the number of personal projection devices in the general consumer markets up until now remains insignificant [72]. One explanation for this phenomenon might be the fact that the real killer applications, i.e. applications that would justify owning such a device, have not yet been discovered. To change that, researchers have created a plethora of projects which ask basic questions like *"How do people want to use personal projection?"* [74], *"How do they actually use it?"* [9] or *"What kinds of information do they want to see?"* They consider aspects like spatial navigation [75], collaboration [76] [77] [78], and other new ways of interaction [79] [80] [81] the technology affords.

But not all is well: As research progresses, many issues and challenges emerge. Apart from the teething troubles of current devices (like low light-output, low resolution and long start-up times), more profound matters are concerned with usage patterns in terms of privacy, acceptability and social consequences. While it might seem that the end of privacy is inevitable [82] [83], questions about the nature of projected information and the way it is presented remain valid. When browsing a picture library for example, it might be that there is a number of images that are not intended for public consumption, but when projected they can effectively are and can be seen by any passerby. What are the best ways of handling the tensions that arise between personal data and a potential large audience? And on the other hand, how do bystanders react if confronted with such personal information? [74]. Thinking one step further, the intentional presentation of content might become *'cool'* (or annoying to others), just as squawking cellphones on the bus are today. And surely capitalism will seize the opportunity to projectively spam us with advertising wherever we go. As of yet, no answers to those issues have been found. But it is likely that social practice will be established and that these questions will resolve themselves in time [10].

Other questions are about the interactions personal projection affords. By equipping pico-projector with input sensors, researchers have developed systems that are able to make sense of their environment. *Map Torchlight* [84] for example, uses the metaphor of a torchlight and road-sign-like arrows for GPS-based pedestrian navigation. *iLight* [85] uses a camera-projector-unit for indoor navigation and object recognition in a museum. Other projects like *Twinkle* [86], or *Motion Beam* [87] allow the user to interact with physical objects and *SideBySide* [88] allows users to interact with each other. *WUW (Wear Ur world)* [89] is probably the most holistic and impressive approach so far. It is a wearable device that can perform a number of tasks and which attempts to be always *ready-at-hand* [90] by naturally interacting with the user and his environment (e.g. augmenting a newspaper with video, projecting the time when the user draws a circle on his wrist or taking a photograph when a 'frame-gesture' is performed. See figure 15).



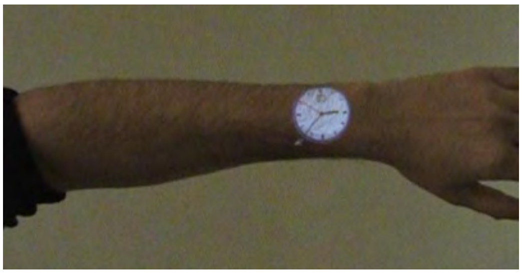


Figure 15: Wear Ur World, by Pranav Mistry [89]

The majority of the applications, which try to put the device in context to their surroundings rely on optical cameras and computer vision and are thus able to determine what object they are looking at (e.g. [91]). But they cannot tell where they are in relation to that object and from which direction they see it. Put differently, this means that the content of the projection can be dynamically adjusted to correspond to objects it recognizes, but that it makes no difference whether the objects are recognized from far off, form up close or from a birds perspective. As long as the object is in the field of view, the content will be the same. To to exploit this additional information and to allow for much richer interactions, one would need precise measurements of the projectors position and orientation in physical space, something which is very hard to determine with the sensor technologies currently used.

3.5 Gaming Controllers

"You gotta use your hands? That's like a baby's toy!"

—Kid in Cafe 80s, Back to the Future II.

Games are nothing but interaction and video-games are all about players interacting with computers. To do so efficiently, specialized gaming-controllers have evolved (see figure 16). And while the joypads from back in the days were exclusively used for gaming, the latest generation of motion-based controllers like the *Nintendo WiiMote* or the *Microsoft Kinect* have not only changed our notions of what video-games are (we can now play virtual instruments [93], play with virtual pets [94] and even do not-so-virtual workouts [95] [96]) and opened up the market for a previously non-gaming demographic (such as senior citizens [97]). But they have also changed the way we approach human-computer-interaction in general.

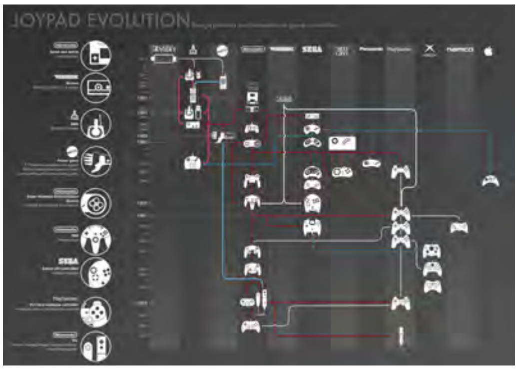


Figure 16: Joypad evolution.[92]

In 2008 Johnny Chung Lee at Carnegie Mellon University started reappropriating WiiMotes to build inexpensive head-tracking-systems and digital-white boards. Today, just a few years later, the Kinect is (ab-)used by artists [98] [99] [100] (see figure 17), musicians [102], hackers [103], researchers [104] [105] [106] and – of course – the porn-industry [107] . In Jordan, for example, a hacked Kinect is used to reconstruct an archeological dig site [108] and at the university of Washington, Kinects are being used in robotic-surgery [109].

Equipped with a depth sensing camera, the Kinect is able track objects and users in physical space and in real-time. The WiiMote on the other hand has a built in accelerometer and a gyroscope, and is thus able to determine its orientation in the three dimensions. When combining these two devices one is able to construct an accurate and robust 6Dof (Degrees of freedom) tracking device for under 200 dollars. Using such a system to measure the projector's movements in physical space, one might be able to create immersive experiences by means of a personal projector.

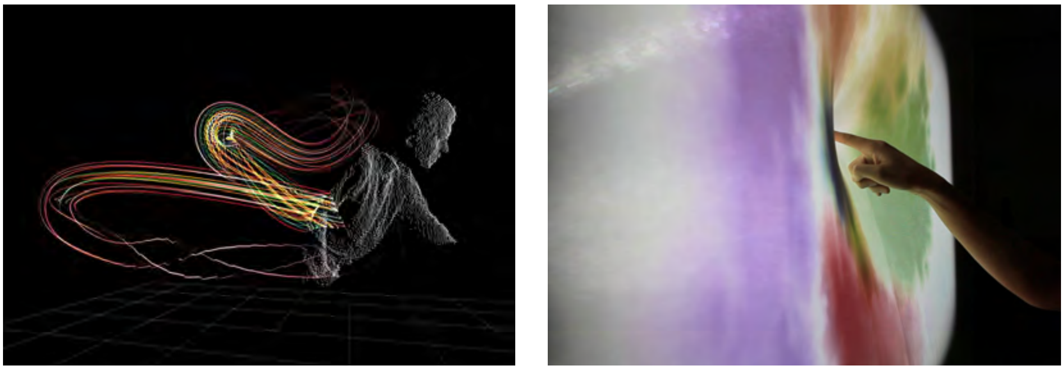


Figure 17: Kinect Artworks [101]

3.6 Summary

The previous chapter gave a survey of research projects and artistic contributions in the areas of Mixed Reality, personal-projection and motion based input controllers. Discussing the technology's promises and shortcomings I concluded that personal projection has the potential to become ubiquitous and deeply embedded into our daily lives. But for this to happen, many questions have yet to be answered: Questions about the relationship between content (personal versus public), audience (an individual versus a large group) and the circumstances (at home versus on-the-go), as well as questions about the ways we will use and interact with the technology. The next chapter will motivate and formulate my own questions and introduce the methods that were employed in trying to answer them.

4. Methods and research question

The review of existing work in the area of personal projection produced the following insight: Despite all kinds of sensory gizmos, all but few of the projects (one noticeable exception being *LittleProjectedPlanet* [110]) still treat pico-projectors are as if they were *normal* projectors that happen to be portable. A conventional projector, once it has been set up, always projects at the exact same spot. So whenever the projector is moved, the image moves accordingly. And while this behaviour is certainly desirable in a static setup, applying it in a mobile context can create serious problems (e.g. motion jitter [111].

What if the content of the projection would be regarded not as static with respect to the projector, but in relation to the surfaces it is projection upon? Using the technologies described in chapter 3 to determine the location and orientation of the projector in physical space, a metaphor akin to that of the magic lens could be applied to build a *'mini virtual reality cave'* [10]: The projection would be a *Magic Torchlight* that can be moved over the surface to reveal (parts of) the underlying content. (Figure 18 illustrates the concept: The top image shows a static projection. The image in the middle demonstrates the normal behaviour: If the projection is being moved, the content moves along with it. The bottom image exemplifies the projected magic lens metaphor: When the projection is being moved the content remains static but a different aperture is unveiled) By doing so, one would be able to combine the immersive experience of a large scale VR application with the flexibly and mobility of personal projection.

4.1 Research Question

So the question to answer was: *Is it possible to create a mobile, yet immersive cave-like mixed-reality system using a pico-projector and off-the-shelf sensor technologies? If so, what are the interactions, aesthetics and levels of engagement it would afford?* The goal of this feasibility study was to explore and assess technologies, aesthetics and interactions which constitute the foundations of mobile immersive projection.

Figure 18: Illustration of the idea to consider the content of a projection static with respect to the projection surface.

4.2 Methods

The process used to facilitate this exploration was highly iterative. Adhering to one principle of agile software development, *"Release early, release often"* [112], short and frequent prototype cycles were used, which provided the possibility to single out individual ideas to and concepts for closer examination. The results were continuously tested, evaluated and reworked into new prototypes. To evaluate their qualities, small exhibitions were set up and the participants were invited to interact with the artefacts. The qualities of an interaction or and aesthetic expression are a very subjective and personal matter. This means, that the traditional methods for the evaluation of interactive systems are cannot be applied, as *"[i]t is difficult to conceive of a task analysis for goofing around, or to think of exploration as a problem to be solved, or to determine usability requirements for systems meant to spark new perceptions"* [26]. Instead, practices of Ludic Design and digital art were used to implement and evaluate this contribution. In each iteration of the design process, small exhibitions (user-studies) were set up and participants were invited to engage with the various prototypes. Using Video, photography and notes, the interactions with the artefacts and the reactions they provoked were documented.

The reason for choosing an exhibition as the setting for presentation and evaluation had conceptual, as well as practical reasons: Using a setting that we usually associate with leisure time rather than with work, I laid emphasis on the fact that my design is not about getting things done but about engagement and fun. The practical reasons were, that in those surroundings I had control over the lighting conditions (current mobile projectors still have a very low light output and need darkness in order to work properly) and that concerns about privacy and acceptability could be now neglected for now. Each time a new prototype was demonstrated, a small exhibition space was created in a room that was big enough for my participants to move around and in which offered good control over the lighting conditions. Most of the times, the living room of my apartment was utilized and the participants were invited to visit. Offering tea and biscuits an atmosphere was created that felt less like a lab study and more like a social call. Other times I visited the participants and set up the system in their home. Six such exhibitions were made, and in each of which one or more prototypes were demonstrated. In each case there were between one and five people present and each session took about two hours, whereas more time was spent drinking tea than testing the device. Also, a long term study with two of the participants and a larger public exhibition with about 60 users were performed.

4.3 Participants

Based on the premise that all humans (old, young, girls, boys, smart, dull…) like to play, my criteria for finding participants which could help me with my work were imagination, curiosity, a sense for aesthetics and patience, rather than aspects like gender, age, education or technical knowledge. I tried to find participants from various backgrounds, since they would each see something different in my work, and give me different kinds of feedback. Five such people were found. I am a aware that five users is a very small group and that they aren't representative (in a quantitative sense) by any standards. But the plan was not to measure and analyse, but to observe and intuit, in which case, the number of participants was of far less importance than their personalities. In this upcoming part a short introduction of each of my participants will be presented.

Figure 19: Amber

Amber is 28 years old and comes from northern Germany. She currently majors in philosophy and media studies and she loves computer games. But not only does she know a lot about the history and philosophy of videogames, but she is also very good in them. Among other achievements, she has for example reached level 52 in Tetris [113] on the Nintendo Gameboy [114], wave 52 in Plats vs. Zombies Vase Breaker [115] and she is a Peggle Extreme Grand Master [116].

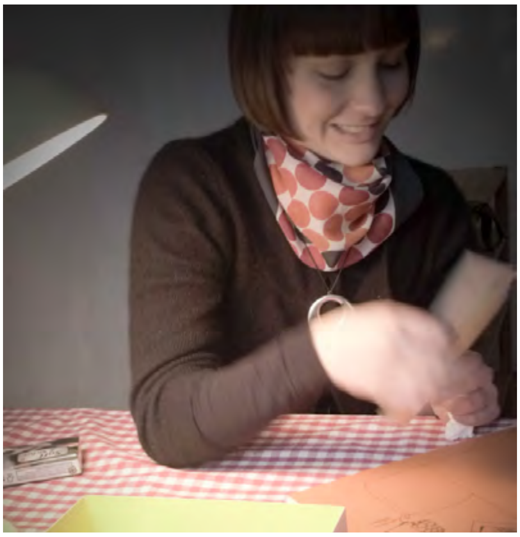


Figure 20: Fiona

Fiona is a 26 year old woman from southern Germany. She works as an occupational therapist and has no academical background. She has not artistic background, but real good taste and an great sense for aesthetics.

Figure 21: Eliza

Eliza is 29 years old and living and working in Vienna. Her background is computer science and interaction-design, and she is currently working on her Ph.D. What made her a most valuable participant in my studies are her years of experience in designing interactions and her refreshing frankness. She had many ideas how to improve things and she was not afraid to tell me about them.

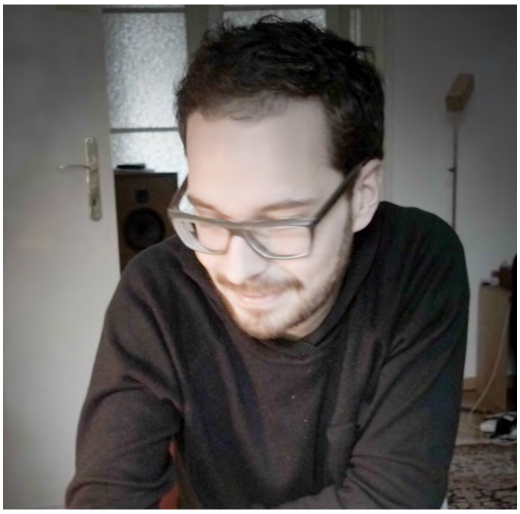


Figure 22: Seth

Seth is a 31 year old designer from Tyrol. Having studied the design and production of interactive media, he is now the user-interface-design lead of a major online company. What makes him great is his attention to details, his love for technology and the ability to think outside the box. Especially productive were our conversations, in which he made me reconsider many of my old ideas and led me to new ones.

Figure 23: Malcolm

Malcolm is from Vienna and of undisclosed age. A man of many talents he can sing (being a former member of the Vienna Boys' Choir), he can climb, he can do martial arts (being a former instructor at the Austrian army), he is a successful artist and he is a professor for fashion design. And although he surely has seen a lot, he continues to be fascinated in the face of new things and experiences.

In chapter 4 the questions posed by the review of existing projects in the area of personal projection were formulated and the methods employed to answer them were introduced. In the upcoming chapter, one of these methods, a provocative design strategy called *Cultural Probes*, will be examined more closely.

5. Cultural Probes

…the Probes embodied an approach to design that recognizes and embraces the notion that knowledge has limits. It's an approach that values uncertainty, play, exploration, and subjective interpretation as ways of dealing with those limits" [117]

5.1 Motivation

The first step in the development process was to get to know the participant and to get a feeling about their interest and dreams. To do so, I used Cultural Probes, a provocative design technique that intends to provoke inspirational responses [16]. A cultural probe is a package of maps, postcards and other material which is left with the user. Each item inside the probe contained questions or asked to perform a little task (e.g. taking pictures or marking places on a map). The probes were left behind so that the user could then work in their own time and in comfortable surroundings.

I tried not to constrain the future design by asking about needs and wishes that have already been understood. The questions had little to do with computers and projectors, but instead were about dreams and feelings. But since I did not want to be too open and unspecific, the tasks and questions circled around two main themes: Light and space.

The upcoming section will give account of the contents of the cultural probes. Following that will be a discussion of the responses I received.

5.2 Contents

Each cultural probe consisted of a handmade cardboard box which contained the following items (see figure 24):

- A personal letter explaining my intentions.
- A world-map to mark significant places
- A list of things to photograph
- A number of cards with catchwords for free association
- A sheet of cardboard with the outline of a little house
- Presents/bribery.

Figure 24: The cultural probes prior to delivery.

A personal letter explained what cultural probes are and why I used them. It also stressed that there were no rules and that every question/task could be answered by any means (e.g. sketches, text, photographs), and that they did not have to answer any question at all if they did feel comfortable.

Figure 25: Eliza's world map.

The world map aimed to probe the notion of space (and cyberspace) by asking about places one likes, and places one does not like and places one wants to visit some time. Figure 25, for example shows Eliza's map after completion. Pink and orange markers indicate places she likes. Yellow markers stand for places she would like to see.

The list of things to photograph regarded the physical surroundings and objects. I asked for pictures about places and objects that were important, either because they are dear or because they are not dear at all. The reason I specifically asked for photographs in this context was, that I wanted to get information about the surroundings and how my participants felt about them, rather than speculation about how those surroundings might be.

The probe also contained the cardboard house, which asked to be decorated to resembled the dream home.

A great source of inspiration proved to be cards with catchphrases written on them. Each of them contained either a single word (e.g. *spooky* - written in a spooky hand) or statements (e.g. *'my favorite recurring dream'*) that invited for free association see figure 26).

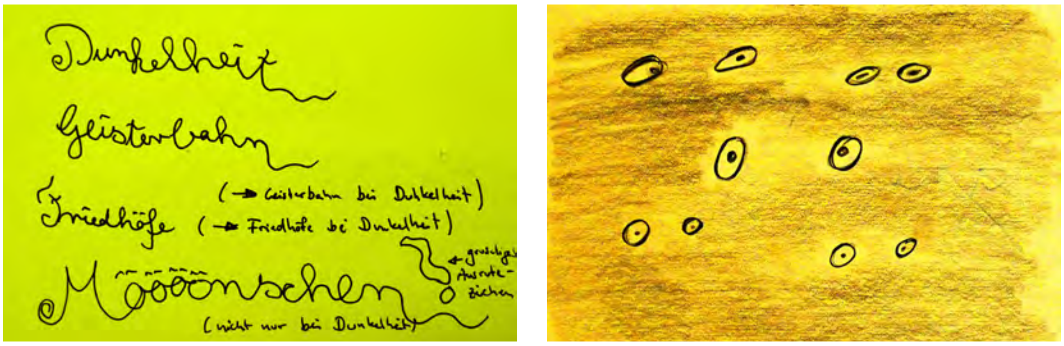


Figure 26: Associations to the word 'spooky'

Finally the box contained little presents in form of a small notebook, some high quality pencils and inspirational candy (which was very much appreciated). For a more detailed account see Appendix A.

The probes stayed with the participants for an average of about four weeks, since I did not want to pressure them but hoped they would solve them on their own accord. And that's what they eventually did. Upon completion I picked the probes up and had a conversation with each participant, talking about their thoughts, about the tasks and about their results. After the study of the answers, my findings of this first design stage can be divided into two categories: Things I've learned about cultural probes and things that inspired my project.

5.3 Findings

The main lesson learned about cultural probes was, that people notice when things are made with love. Gaver believes *"aesthetics to be an integral part of functionality"* [16]. A notion I took to heart when designing my own versions of the probes. I tried to convey a type of aesthetic that is both professional and intimate. Professional in a sense that the tasks and questions are neither childish nor condescending. And intimate by using handcrafted and hand written materials, as not to appear like official forms of commercial marketing. My impression was that all participants felt how much effort was put into designing the probes and they treated them with care (In fact, all of them wanted to keep the box when I came to pick up the results). What also helped to convey a informal and personal tone were the little presents included in the probe: There were fine pencils which were to encourage drawings and sketches. There was a notebook which had no purpose but to be a present they could take with them. And there was candy which was intended to be consumed while answering the questions but which were eaten up by the time I finished my explanations.

Figure 27: Cryptic artefacts in response to the cultural probes.

One thing I misjudged was the amount of work I expected from my participants. My goal was for them to be able to complete them in about an hour or two, but in fact it took some of them several hours, while others just skipped some of the tasks. The sad thing is, that some of the things that were left out would have been helpful, while other questions didn't yield any results. It would have been better to have a much simpler preliminary stage, in which the scope could be defined, thus lessening the about of work for the participants while at the same time lowering the risk of asking irrelevant questions.

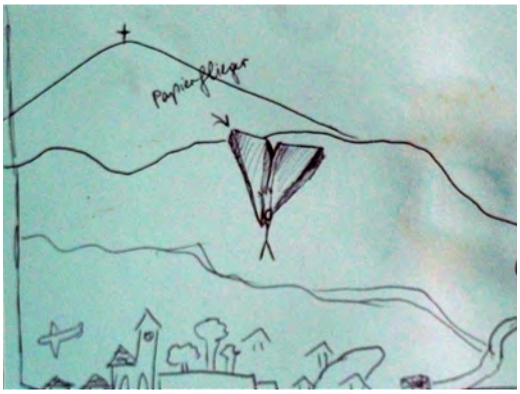
More important than the things learned about cultural probes however, are the artefacts received in response and the ways in which they inspired the design process. Many of them were useful, some of them were cryptic (see figure 27). In order to assess and analyse the items they were annotated, divided into groups, and placed on a wall (see figure 28).

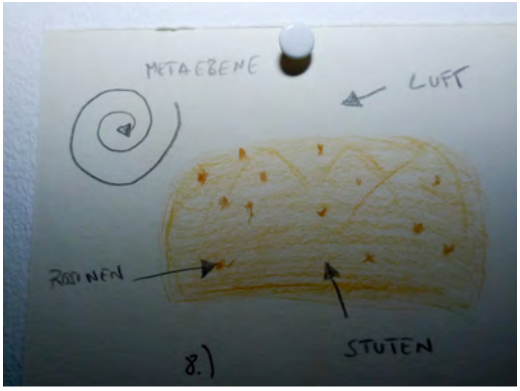
Figure 28: Responses to the cultural probes.

The questions and tasks invited to reflect upon real and imaginary places and the things one might discover there. The answers and items I received in response showed a special interest in the fringes of reality. Malcolm for example, would like to be a drop of water in a mountain creek, which looks at the world from beneath the surface. Amber speculates about the Meta-Layer and Eliza dreams about riding a paper plane (see figure 29).

Other questions tried to capture feelings and impressions connected with darkness. The responses had an eerie tone and spoke of hell, perils and dismal music. Amber wrote that *"in the darkest night, nothing on the sea is more dangerous to other ships than sending out a light".* Seth is concerned about the things that might hide inside the darkness. And Eliza retorted by stressing the importance of light and openness But The most important thing is the world in which we live in and interact with. Malcolm would rather be at home, Eliza is *"rather happy"* in Vienna, and Amber complains about the lack of love and surprises she would expect on the moon (see figure 30).

The previous chapter discussed the use of cultural probes to provoke inspirational responses from my participants. By designing and crafting packages that invited to reflect on the world, on darkness and on the things in-between. The inspirations and intuitions gained form the resulting artefacts form the basis for the next stage of the development process, which will be presented in the now following section.





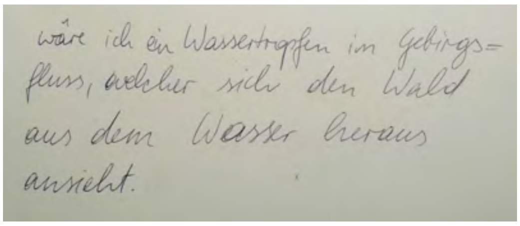
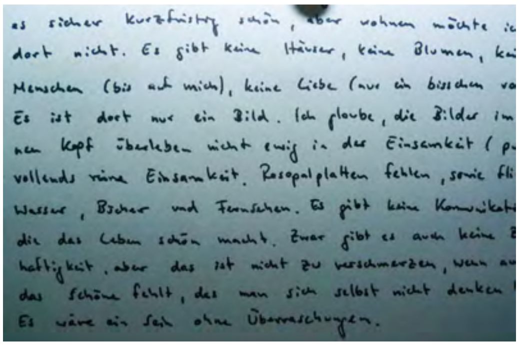


Figure 29 Cultural probes. Margins of reality



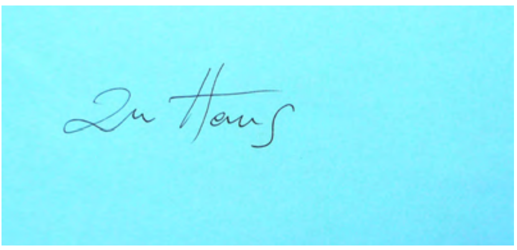


Figure 30: Cultural probes. Reflections on the earth.

6. Technical probes

In parallel to the user-centred design methods physical prototypes were developed. It was decided to implement many small physical and software prototypes, in order to get a feel for the technology, the applications and the aesthetics. The goal was to develop usable applications that work with todays technologies (albeit in a rough and limited way), not something that only speculates about what might be possible at a later stage. I also deliberately excluded topics that would have been great to work on, but which were out of scope for this project (e.g. incorporating the real geometry of the surrounding space, the way projection mapping does).

In early iterations I focused on the technological issues, testing the capabilities of the projector, evaluating various types of input controllers and different software environments. From the outcomes of these preliminary studies, I started developing more involved software prototypes that were based on the themes found of the cultural probes. The following section will give detailed account of the development process. First will be a summary of the technologies that were employed, followed by a description of each prototype in chronological order. For every iteration there will be given the motivation behind it, a description of the system architecture, the aesthetics it employed, and a description of the study setup and the results gathered.

6.1 Technologies

The architecture of the system consists of three main modules: Input controllers that track the users' movements, output devices (a pico-projector and a audio synthesizer), and a laptop running the software that ties everything together. Message coupling (OSC, MIDI) made it easy to experiment with different configurations of hardware and software. The software framework consists of several helper applications for user tracking and message routing and a main application that generated the data that was sent to the output devices (see figures 31 and 32). For a more detailed reference of the software I used and a link to the source code, see Appendix B.

Figure 31: Hardware and software used in building the prototypes

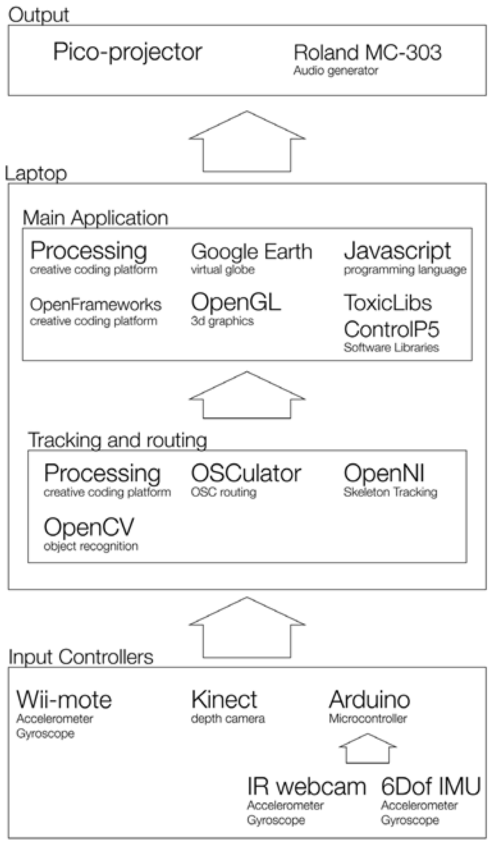


Figure 32: System architecture used for the development of prototypes

6.1.1 Projector

The pico-projector was a *Microvision ShowWX* [118] (see figure 33). It measures 2 x 9 x 7 inches and weights about 1 pound, which makes it a comfortable size to carry around. The projectors main advantage over competing products is the use of focus-free lasers, i.e. it is possible to project on any surface from any angle and the image is always in focus. It's disadvantages are the low light output (10 lumen), the short battery life, the long boot time, and the heat it develops when used for a prolonged amount of time (after about 30 minutes of use it gets quite hot).

Figure 33: Pico projector and custom housing with IR camera.

6.1.2 Synthesizer

To generate audio, a *Roland MC 303* groove box was employed (see figure 34). The software created notes that were sent via midi and synthesized by the 303. Using a hardware synthesizer made it easy to create all kinds of sound and thus allowed to experiment with the impact audio would have on the experience.

Figure 34: Roland MC-303 groovebox.

6.2 Tracking

Choosing sensors for measuring the position of the user and the device was more difficult. Several criteria needed to be traded off against one another to find the solution that best suited my needs:

- The ability to measure the position and the orientation of the projector in physical space
- Accurate and robust
- Low cost
- Easy to set up

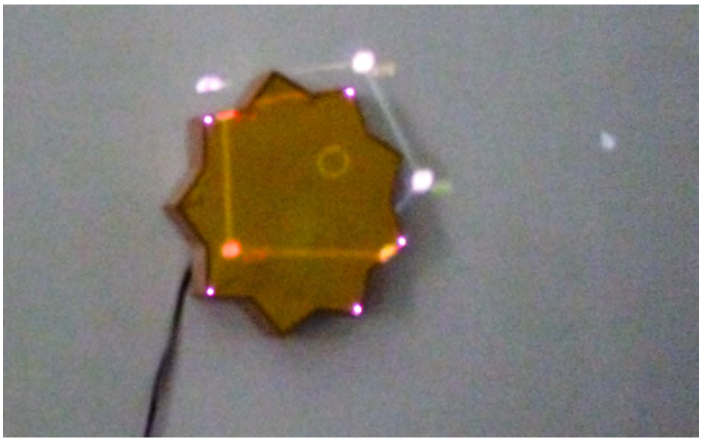


Figure 34: Marker based optical tracking.

6.2.1 Optical tracking

The first technology to be examined was marker-based optical tracking based on a modified webcam and infra-red (IR) LEDs (see figure 34). The advantage of this technology is the huge number of reference projects using this technology, the low price point and the ease of deployment. By replacing the IR filter of a webcam with blackened strips of negative film I was able to see a preconfigured group of LEDs without interfering with the light of the projection. OpenCV tracked the LEDs and their positions in the image were sent to a POSIT algorithm with calculated the camera's position and orientation relative to the marker. The downsides of this approach were the inaccuracy of the tracking and the need for markers to be distributed around the environment.

6.2.2 Inertial Measurement Unit

The second iteration employed an inertial measurement unit (IMU) [119], consisting of a three-axis accelerometer and a three-axis gyroscope, providing six degrees of freedom (Dof). The data was read by an Arduino microcontroller [120] and sent wirelessly to a Processing sketch that used a *Kalman filter* [121] to calculate the orientation and velocity of the device and its position in relation to a reference point. Unfortunately only six Dof were not sufficient and lacked an essential piece of information, since the yaw (rotation around the y-axis) could not be captured.

6.2.3 WiiMote

The Nintendo WiiMote combines the principles of optical tracking and IMU tracking. Equipped with an IR camera, a gyroscope and an accelerometer it provides robust, accurate and easily accessible tracking information. The raw signal sensors were sent via Bluetooth to OSCulator, processed, and the rotation and position values were routed to Processing via OSC. Unfortunately the WiiMote lacks depth information (only the x and y position of the viewport are being captured, the position of the user is unknown), which was discovered to be essential to create the feeling of standing inside a virtual volume, rather than interacting with a two-dimensional plane.

6.2.4 Kinect

The next iteration used the Microsoft Kinect to track the movement and position of the users skeleton, and to calculate the orientation of the device based on positions of the limbs. Having in only come out in November 2010 the technology is brand new and open-source drivers and libraries are still in beta and prone to frequent updates. Equipped with a depth-sensing IR camera and a RGB-camera, the Kinect is able to record a three dimension of the scene in front of it. By means of OpenNI [122] it can recognize persons in the scene and calculate the positions of their limbs. The excellent user tracking enabled to infer the projectors orientation by interpolating the positions of the elbow and the wrist (see figure 35). The negative aspects of the technology were the increased setup complexity and the inaccuracy of the orientation measurements.

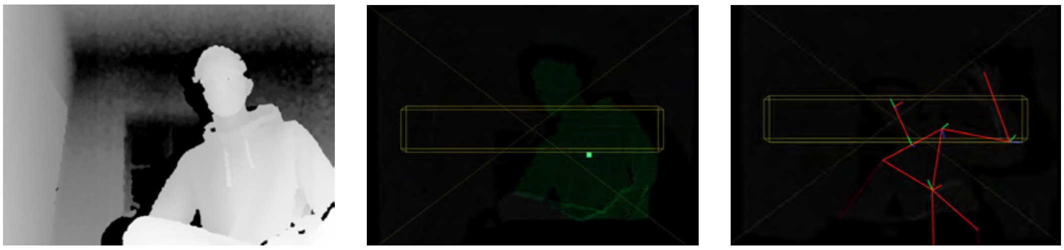


Figure 35: Kinect user tracking. Depth image (left), user recognition (middle) and skeleton tracking (right)

6.2.5 Kinect & Wii

When combining the position measurements of the Kinect with the orientation values provided by the Wiimote, one gets a very robust and easy to interface tracking system. The Wiimote information was routed via OSC from OSCulator to a processing sketch where they were combined with the skeleton information from OpenNI. Via an OSC interface position and angular vectors were then routed to the main application (see figure 36). The price one has to pay for this setup is the increased setup complexity introduced by the use of multiple sensors.

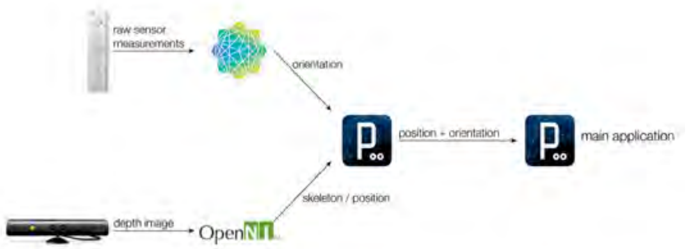


Figure 36: Messaging architecture for combined Kinect and WiiMote routing.

Table 1 sums up the properties of all the tracking technologies. Note that the combination of Kinect and WiiMote priced to be the most feasible solution, despite being the most expensive and most complex to install.

Technology	Accuracy	Costs	Complexity
Optical / IR markers	inaccurate and laggy	lowest	
IMU	inaccurate, lacks yaw measurements		
WiiMote	accurate and robust, lacks depth information		lowest
Kinect	very good position tracking, lacks orientation vector		
Kinect & WiiMote	very good tracking of position and orientation	highest	highest

Table 1: Overview of tracking technologies. Intense green represents the best performance in a respective area and red represents the worst performance. Colours in-between a ranked by hue.

6.3 Prototypes

Having described the system architecture and the technologies employed, this upcoming section will describe the individual prototypes I developed in greater detail.

A quick remark before I begin presenting the prototypes: When speaking about content (like a video or a rendering) that is shown, this always implies that the user can only see parts of the whole content and that he can move around to explore the hidden parts. The same goes for screenshots: If an image depicts a screenshot of a scene I used, it always implies that the user was only able to see parts of that scene. This is due to the principle of the magic torchlight, which encourages the exploration of the environment.

6.3.1 Weather forecast

The first iteration was an experiment aimed to evaluate vision based tracking and possible useful applications. Inspired by projects like Kawsar et al. [91], as well as by Ambient Information Systems (AIS) [123] and applications like the Apple dashboard [124], the system could recognize a sun shaped objects and augment it with the weather forecast: When it rained there would be clouds and the lamp-light barely visible, and when the sun was shining the lamp would shine and there would be a blue sky. The aesthetics were simplistic and functional, consisting only of a blue background, two stylized suns (the lamp and its virtual companion) and basic cloud shapes (see figure 37).

Figure 37: Weater forecast prototype.

To test the prototype, an impromptu exhibition space was set up in the kitchen of my apartment and Eliza was asked to play with it. She engaged with it for about 10 minutes and judging from her laughter, she enjoyed it. The tracking algorithm introduced a huge lab between her movements and the reactions of the system, causing the virtual sun move very slowly around the projection surface. *"Like a cute little animal that crawls towards the sun."* I considered the lag to be a critical bug and the demonstration a failure. Eliza on the other hand wasn't discouraged by the lag but encouraged me to pursue this behaviour: *"You could have many little things crawling all over the place."* I also noticed that she was utterly ignorant to the intended usefulness of the application, because she was too busy giggling and playing with her new found pet (see figure 38). During the study, pictures and videos were collected and notes from the conversation with Eliza were taken. In evaluating the records, I made three findings: Firstly, that the use of optical tracking was not feasible in the context of my research. Because a marker needs to be visible to the camera at all times, one would need many such markers to create an immersive virtual environment. Secondly, that the light output of the projector is too small to allow interactions with bright objects. And thirdly, that very simple interactions (e.g. a glowing objects crawling over the projection surface) are sufficient to make the system engaging and fun.

Figure 38: Image sequence from Eliza's interactions wit the first prototype

6.3.2 Virtual Sculpture

Continuing with the assessment of tracking technologies, the next cycle made use of a six Dof IMU. To test its accuracy in determining the user position, a kinetic virtual sculpture (based on the works of Marius Watz [125].) was displayed and participants could walk around to observe it from different vantage points No other interactions were possible. The aesthetic appeal of the piece was characterized by high contrasts, bright neon colours and bold shapes (see figure 39).

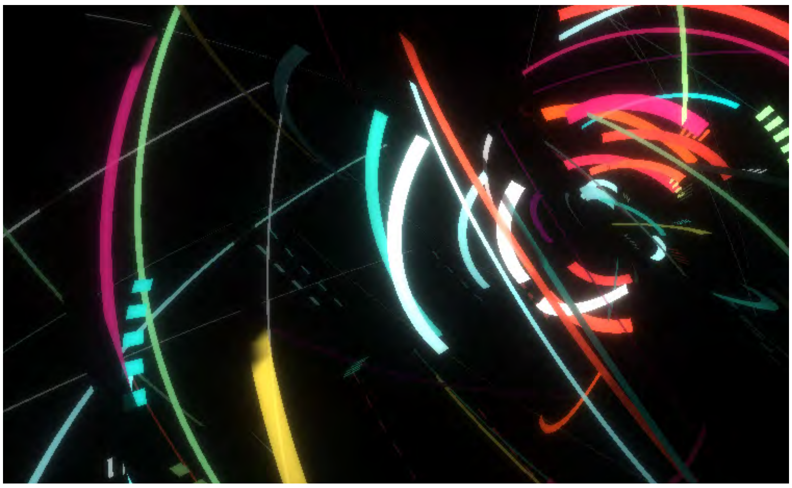


Figure 39: The second prototype: virtual sculpture

The prototype was presented together with the LaserTag prototype (see next section) in a session with Fiona and Seth. The exhibition space was set up in Seth's living room. Compared to the LaserTag, the virtual sculpture gained little attention, due to it's lack of interactions. I noticed that both users were anxious to even hold the device. Asked about the reasons, Fiona held the delicate hardware next to the sturdy WiiMote and remarked: *"I'm afraid to break it"*. Also, the tracking accuracy was unacceptably low, making it very difficult for the participants to establish the connection between the own movements and the reactions they cause in virtual space. *"I'm moving, he's not moving… Now he's moving. No! Way too far. This makes no sense!"*, Seth complained. Asked whether they felt as if the sculpture was inside the room, both participants vehemently answered in the negative The aesthetics on the other hand very much appreciated. *"Ohhhh neon. I like neon!"* Fiona exclaimed. And Seth remarked on how pretty the sculpture rotated if it happened to stay in one place for some time. The tone with which he said this, however suggested that he did not mean to be taken seriously. Analysing the conversations we had and the notes I took during the user study (see figure 40), I arrived at three results:

- The technology must not be in the centre of attention, but it must fade into the background. The user needs to be free to concentrate on the content.
- The aesthetics of high contrast and bold colours work very well with the given technology (low light output, low resolution).
- IMU tracking (and scratch-built solutions in general) are unsuited for my purposes, due to their inaccuracy and fragility.

Figure 40: Notes taken during a user study

6.3.3 Laser Tag

Resorting to off-the-shelf-technology, instead of scratch building tracking technologies, the next prototype was an adaption of the GRL Laser Tag [126] project using a Nintendo WiiMote. In the original project whole buildings can be tagged by means of a laser-pointer and a powerful projector. In my version the WiiMote was used instead of a laser and camera and the user could tag a wall instead of whole building (see figure 41). In cloning an existing piece, I would be able to evaluate my own efforts by comparing them to the original artwork. Another motivation behind the prototype was to evaluate the capabilities of a single WiiMote as tracking technology. The aesthetics were of the Laser Tag remained unchanged and consisted of a big green brush which was used for tagging on black (transparent) background. What made this special and interesting were the drips of colour that ran down like real thick paint.

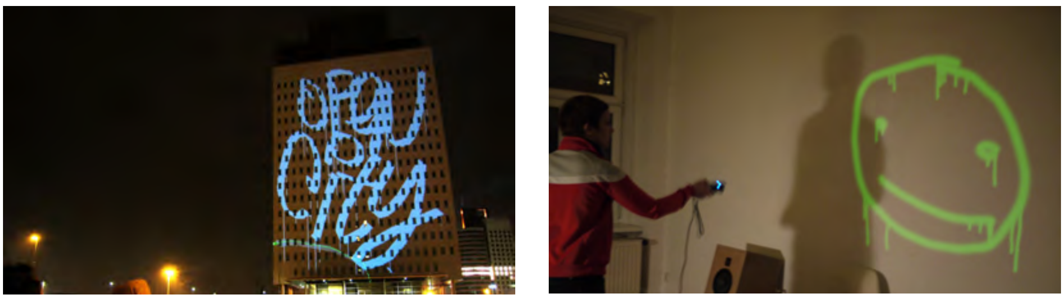


Figure 41: The original laser tag (left) and my version (right)

The Laser Tag prototype was shown to Fiona and Seth along with the virtual sculpture. It was much better received. The tracking worked accurately and the interactions seemed to be fun. Both took terms in drawing similes, houses and other simple works of art. When asked for their impressions, Fiona mentioned that she liked the drips and that it felt a bit like real paint. Both agreed that it was fun, but that they did not feel like standing in a virtual space, but rather like standing in front of a virtual wall. Upon reflection why this was the case, I found two main reasons: For one thing, the WiiMote limits the movements of the user by affording only a limited projection surface. It relies on optical tracking and needs to see a marker at all times. And for another thing it cannot measure depth information, which seems to be curtail in creating a feeling of space. In comparison to the original Laser Tag, it becomes obvious how different my system is to the original setup: While the original installation was designed for huge two-dimensional surfaces, my system is to be used in much smaller three-dimensional volumes. It thus creates a whole different experience and requires other kinds of interactions.

6.3.4 Reference room

Considering of the importance of space and volume, the next iteration aimed to explore the systems capabilities in creating the illusion of depth. The users were confronted with a simple tiled room and the only interaction they could perform was to move inside the volume. The room was very reduced and rendered in very stylized thin lines, and there were no objects inside the room (see figure 42). For user tracking a single Kinect was used.

Figure 42: Screen shot of the reference room (left) and Amber interacting with it (right)

The prototype was shown to Eliza, Amber and Malcolm in a short study performed in my living room and they engaged with it for only about five minutes. Using only a Kinect to perform the tracking introduced a severe constraint for the participants: They were required to hold their wrists aligned to their forearm, or else the orientation would be calculated incorrectly. The reactions of the participants to this restriction differed. While Amber got used to it quickly, both Eliza and Malcolm complained about how unnatural it felt, and exhibited sign of fatigue. But apart from technical issues, the illusion of space the application created appeared to be convincing. All three participants acknowledged the feeling when asked for their opinion. While Amber was using the system, she focused especially on the edges of the virtual room and pointed out mismatches between the virtual geometry and the edges of the real room. The lessons learned from my observations were the following: A lack of opportunities for engagement makes technical deficiencies more apparent. And the Kinect provides excellent position tracking, but the attempts of calculating the orientation vector need further revision.

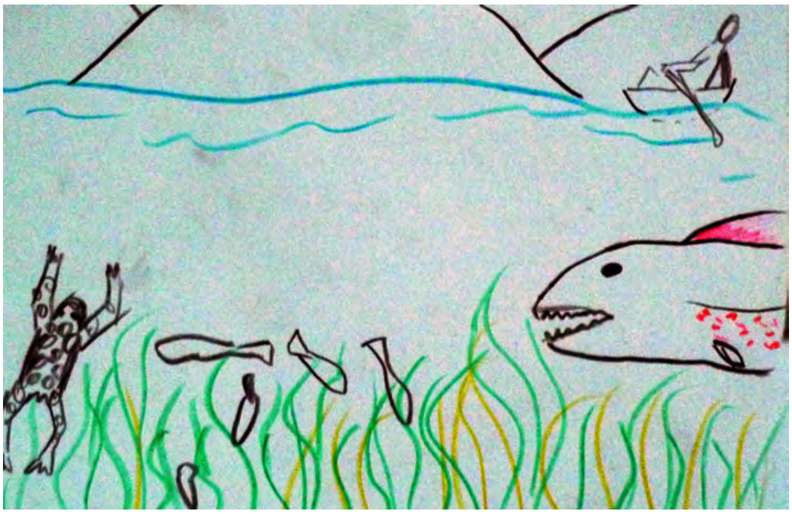


Figure 43: Inspiration from the 'underwater' prototype.

6.3.5 Underwater

One of the reoccurring themes in the cultural probes was about being under water. So in the next iteration the participants were presented with a video depicting of fish, corals and waves. While the video was shown, sounds of gurgling water were played in order to enhance the experience. Returning to a two dimensional surface instead of depicting a 3D scene made it possible to compare the effects of audio on the experience. Apart form audio, the prototype also experimented with the use of video and noninteractive animations and a combination of WiiMote and Kinect as tracking technology. The aesthetics of the piece were characterized by the ways the camera rocked back and forth and by the sounds of water. The combination of these created an impression of dynamic and movement (see figure 44).

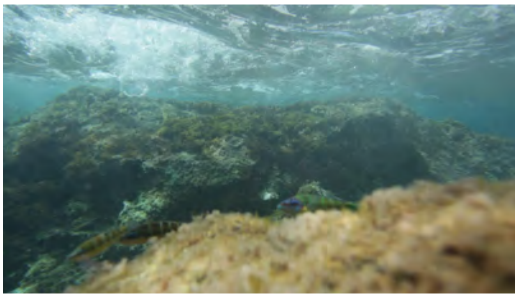
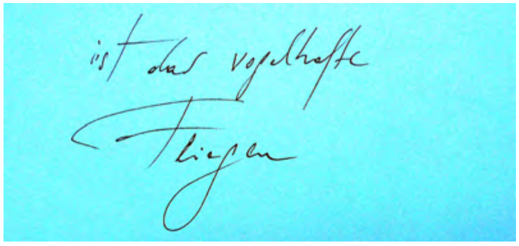



Figure 44: Underwater prototype. Left: screenshot. Right: during a user study

The prototype was exhibited in my apartment and the participants together with the earth prototype (see below). The participants were Fiona, Eliza and Seth. During the study it became apparent how big the influence of sound on the feeling of immersion really was. In the beginning, no sounds were audible and I observed that all three users became irritated by the erratic movements of the video camera. *"This is starting to make me dizzy",* Fiona remarked. When audio was played on high volumes, the irritation subsided and the users started to enjoy the presentation: Eliza for example, walked close to the walls as to better observe a small school of fish that kept appearing in the video. Combining a WiiMote and a Kinect to perform the user tracking proved fruitful. None of the participants remarked on it, which indicates that the technology works well enough as not to be noticeable.

6.3.6 Google earth and Space

Two other themes in the cultural probes circled around were the earth and outer space. Seth for example marked Vienna on the world map with the caption: *"I'm rather happy here."*. And Eliza summed it up in an image that shows the moon, the distant earth, a spaceship and an astronaut (see figure 45). The next iterations attended to these topics. The Goggle earth prototype examined the use of external 3D scenes to be integrated in my system, which would make it easy to broaden the range of possible applications. A web-application interfaced with Google earth [127], and the tracking data received form WiiMote and Kinect were routed to Javascript, allowing the user to fly over a virtual Vienna. The piece was designed with reference to William Gaver's Drift Table [14]. Its aesthetics were the same as the Google earth interface, with the exception that a dark vignette was created around the image, in order to create a smooth transition to the surrounding darkness.



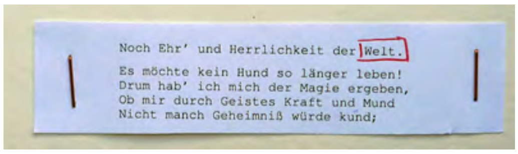


Figure 45: Inspiration from for the earth- and space-prototypes

The space prototype, which was developed in parallel to Google earth, was set in outer space and consisted of a system of exploding particles, set to an soundtrack by the band Archive (a band mentioned in one of the probes) (see figure 46). While the music builds up, more and more start exploding and the darkness gets filled with light. The aesthetics were intricate with many small particles and subtle movements. The motivation behind the prototype was to further investigate the effects of sound and music on the creation of atmosphere and to experiment with finer and more detailed kinds of visual representation.

Both prototypes were exhibited together in a study with Amber and Malcolm and notes and pictures were taken for documentation. The use of web based 3D content proved to be unsuccessful, as it was slow and the discrepancies between the users movements and the display of content ruined the experience. The use of music to match the visual content on the other hand was very successful. Both participants enjoyed the eerie atmosphere and the connections of music and visual representation. Unfortunately the visual aesthetics were too intricate and subtle. "*This would look beautiful, but I can hardly recognize a thing*", Amber commented. This results supports previous findings, that simple and bold graphics work much better with the given technologies.

Figure 46: The Google Earth and the Space prototypes. Top: Screenshots. Left: Eliza using the Space prototype.

6.3.7 Voronoi-Audio

In the final prototype, all lessons learned from previous prototype were combined. There were:

- Interaction need not be complex to provoke engagement, but they need to be designed carefully.
- Trying to be too realistic is counter-productive. The more real a scene is, the more obvious are its shortcomings.
- Audio is essential for an immersive experience.
- Bold graphics, high contrasts.

Based on above principles, a large Voronoi-tessellation [128] was used to generate procedural music. With simple game mechanics a feeling similar that of playing an unpredictable musical instrument was conveyed. Each of the structures cells would light up and produce sounds, if the user moved the projection above it. By moving the centre towards other cells, the individual sounds became a melody. The visual appeal was deliberately bold and simplistic, consisting only of few white lines and bright areas of colour (see figure 47). The sounds were generated by a vintage Roland MC303 groove box [129] that allowed me to manipulate the sound in hardware (e.g. adjusting the tone/balance, applying low frequency oscillation or the use of an arpeggiator).

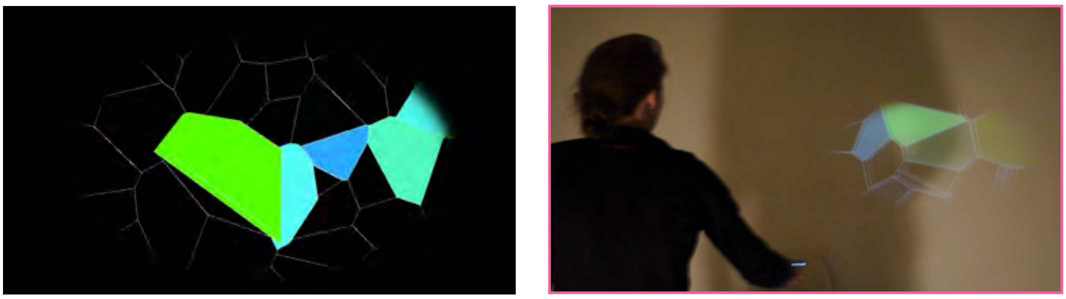


Figure 47: Voronoi-Audio prototype. Screenshot (left) and user study (right)

This final prototype was exhibited in Seth's apartment to all five participants in a prolonged study. Pictures, videos and notes were taken. All five participants took pleasure in playing with the device. Especially the modification of the audio output to produce all sorts of different sounds was very much liked. *"Dumm. Dumm. Dubbedy. Piep"* Amber joined in and Malcolm was consumed by turning nobs and pushing buttons on the sequencer. None of the participants remarked on the technology, which indicates that the tracking as well as the visual aesthetics did not distract form the interactions.

Table 2 shows a compact overview of all prototypes I developed and figure 48 illustrates the themes and connections between them.

Title	Motivation	Aesthetics	Partici-pants	Data Col-lected	Findings
Weather report	Assessment of optical Tracking, 'useful applica-tions'	Simplistic	Eliza	Photos, Video	Optical tracking inapt, Simple interactions suffice
Virtual sculp-ture	Assessment of IMU Tracking	Bold, neon	Fiona, Seth	Notes, Pho-tos	Technology must aim to be invisible, high contrasts, bold graphics, IMU tracking inapt
Laser tag	Assessment of Wii Tracking, Comparison with existing artwork	Bold, or-ganic	Fiona, Seth	Notes, Pho-tos	Wii Tracking inapt, Focus on space and depth, high contrasts, bold graphics
Reference Room	Assessment of Kinect Tracking, Creating an illu-sion of space	Minimalistic, geometric	Eliza, Amber, Malcolm	Notes, Video	Too much realism lays focus on short-comings, Kinect tracking inapt
Underwater	Assessment of Wii + Kinect tracking, immersion with sounds, theme of being under water	Dynamic, water	Fiona, Amber, Malcolm, Seth	Photos, Video	Kinect + Wii track-ing very good, sound have great impact on experi-ence
Google earth	Use of external 3D scenes, flying theme	Google earth inter-face	Amber, Malcolm	Notes, Pho-tos	Web based 3D-content unfeasible

Space	Use of music to create atmosphere, outer-space theme, fine and subtle graphics	Particle system, intricate, bright explosions	Amber, Malcolm	Notes, Photos	High contrasts, bold graphics, Music essential in creating atmosphere
Voronoi-Audio	Essence of earlier findings, procedural music	Voronoi tesselation, high contrast, bright colours, procedural music	Fiona, Amber, Eliza, Malcolm, Seth	Video, Notes, Photos	Highly engaging, technology not in the centre of attention

Table 2: Synopsis of all prototypes..

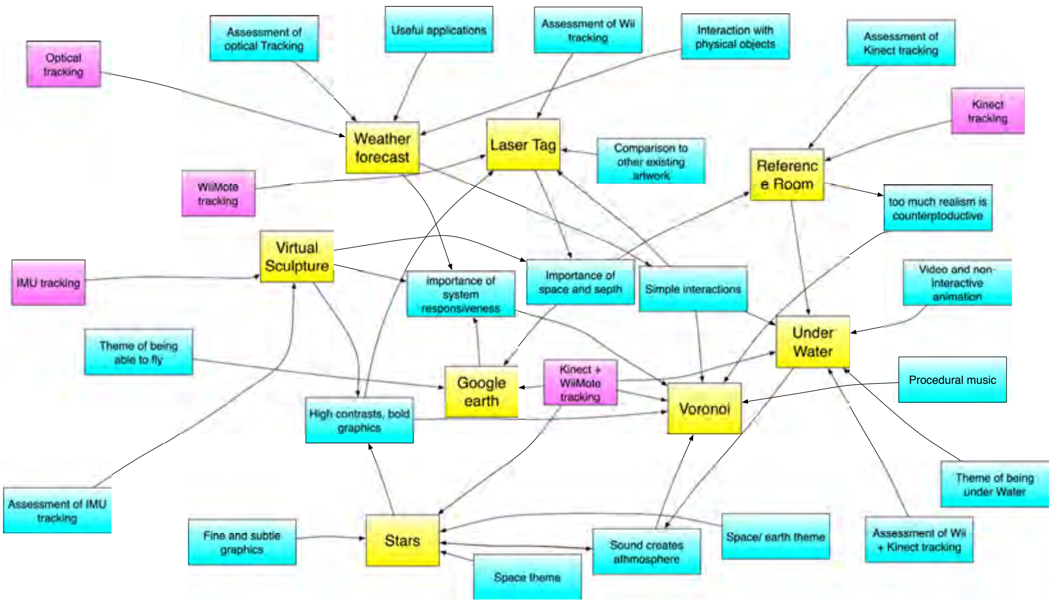


Figure 48: Relationships between the prototypes. The prototypes are yellow, tracking technologies are magenta and ideas/inspirations are cyan.

6.4 Long term study

After the prototyping cycles, I considered the question of how the system would work outside an exhibition context. All prior studies were conducted in a dedicated space, set up for the occasion. Yet one ideas was to use the system in a home environment, complementing devices like TVs and gaming consoles. To assess its capabilities, the system was set up in Amber's and Malcolm's flat for a long term test. It did not work. Despite my efforts to make the setup accessible and easy to use, they only played with it exactly once. It seems like the system was to complex to go through the troubles of turning it on.

6.5 Public exhibition

For a public exhibition held at the Institute for Design and Assessment of Technology at TU Wien, most of the prototypes were reworked to be compatible with WiiMote & Kinect tracking technology. The space was open for about five hours and had approximately 60 visitors, of which about 10 actively used the system. The aim was to draw a broader audience and to re-evaluate the findings made during the smaller studies. To document the event, multiple photo- and video-cameras were installed. The results largely agree with previous observations: Applications involving sound and affording more involving kinds of interactions than mere navigation, were much appreciated, whereas simpler instances were being ignored (see figure 49).

In the last chapter I gave detailed account of the technological development process. In a series of prototypes I implemented and analysed various kinds of interactions, aesthetics and concepts that aimed to create immersive experiences by means of personal projection. First an overview of the software, the hardware and the system architecture was given. Then each iteration of the development process was explained in greater detail. The ideas and intentions behind each prototype were specified. The system architecture and aesthetics were related. The user studies were described. And the basic results were explained as motivation for future iterations. The following section will analyse and evaluate the observations and findings more closely.

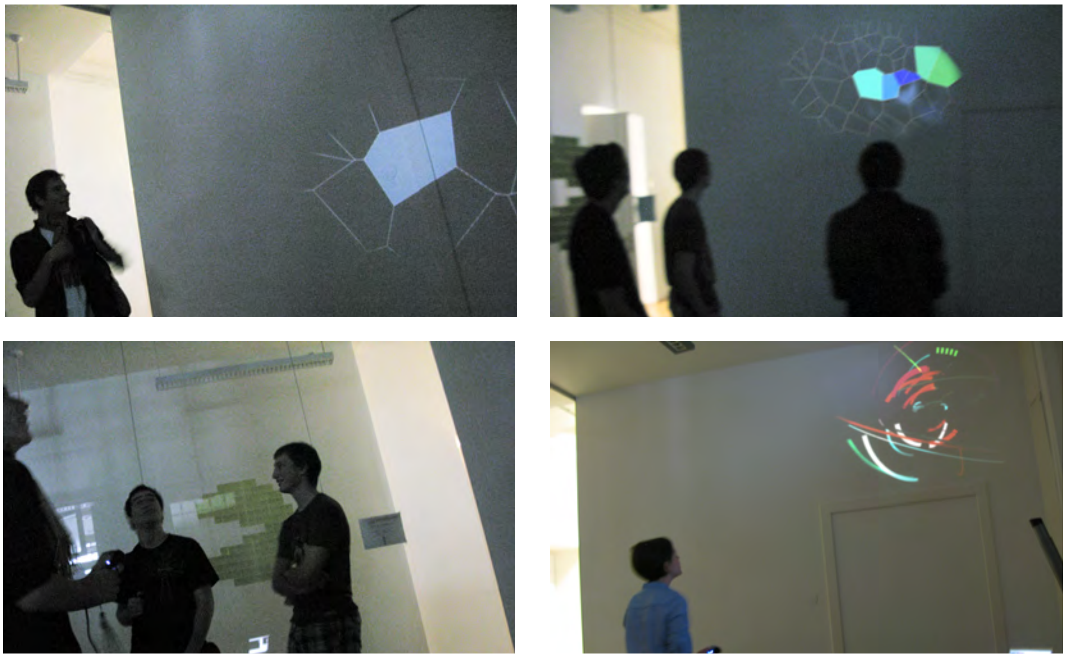


Figure 49: Impressions from the public exhibition

7. Evaluation

Chapters 5 and 6 described design and evaluation of my proposed immersive mobile mixed-reality system. For each stage of the design process the motivations, the studies and their influence on later iterations were presented. This upcoming section will sum up the most important findings and consider the outcomes of my efforts with respect to various other aspects: First, there will be a survey of the design process and the artefacts it yielded in the context of research, design and digital arts. Using a set of criteria for *"evaluating the quality of an interaction design research contribution"* [34], the similarities and contrasts between my own efforts and those of other artists / designers will be explained. Thereafter will be a discussion of my experiences and observations regarding the technologies, aesthetics and interactions of my system. Based on the potentials and caveats encountered during the design process, I will formulate guidelines and principles that might form the basis for future endeavours in mobile immersive projection.

7.1 Art and design - the four lenses

The beginning of this thesis explained how our interactions with computation are growing ever more complex and described some of the strategies HCI has developed to address these changes. Modern HCI no longer *"treats interaction [..] as a form of information processing but as a form of meaning making in which the artefact and its context at all levels are mutually defining and subject to multiple interpretations"* [130]. To reflect these paradigm shift, new methods to design and evaluate interactive systems, that allow room for the appropriation of technologies and the creation of meaning have been developed. I explained how Ludic Design employes design strategies that are traditionally considered artistic practice, and showed how digital art on the other hand, is beginning to take a more scientific stance. Concluding these observations, I argued that it is sometimes possible to interpret a research/design project as a work of art, and vice versa. My own research allows such interpretations, as its artefacts are no tools aimed at *"efficiency and performance"* [35], but experiments in immersion and engagement. The following section will present an evaluation that is *"in a way similar to the* *methods developed in art critique"* [35], and the process and outcomes of my research will be assessed with respect to the four lenses: Process, invention, relevance and extensibility [34].

The four lenses are *"a set of criteria for evaluating the quality of an interaction design research contribution"*. Their central claim is that a design process differs from traditional engineering approaches by engaging *"massively under-constrained problems" and by "integrating ideas from art, design, science, and engineering, in an attempt to make aesthetically functional interfaces"* [34]. It is recognized that the repetition of a design process will never yield the same results, and consequently they focus more on the artefacts and outcomes than on the documentation of the process. The four lenses are intended to be a design-critique and it was explained earlier, how design and art are two separate things. The principles of the critique however, are formulated in ways that allow them to be applied to artistic efforts as well. After all, both art and design engage with under-constrained problems, stress the importance of aesthetics and embrace the ambiguity of human nature. In those respects where art and design diverge, the criteria were adopted to reflect the differences.

7.1.1 Process

The first lens examines the process employed in the creation of the artefacts. But as there are no expectations that its repetition will yield the same results, *"the judgement of the work examines the rigor applied to the methods and the rationale for the selection of specific methods."* [34]

This aim of this research was to design artefacts that are immersive, engaging and playful, but which ultimately have no use. To reflect these goals, the process aimed to appear deliberately informal and laid-back towards the participants: The provocative probes for example, were meticulously crafted, the user studies always involved tea and cookies, and while a participant interacted with the system I remained in the background trying not to interfere -as not to disrupt the experience [131]. The results of these methods are ambivalent. The upsides are that the participants felt very comfortable at all times and showed reactions and emotions they might have restrained form in a more serious atmosphere (see figure 50 - excerpts form the series *"Am-*

ber. Dancing"). The downside was that I sometimes had the impression of not being taken seriously: Items in the cultural probes for example were being neglected, and study appointments got cancelled for no obvious reasons.

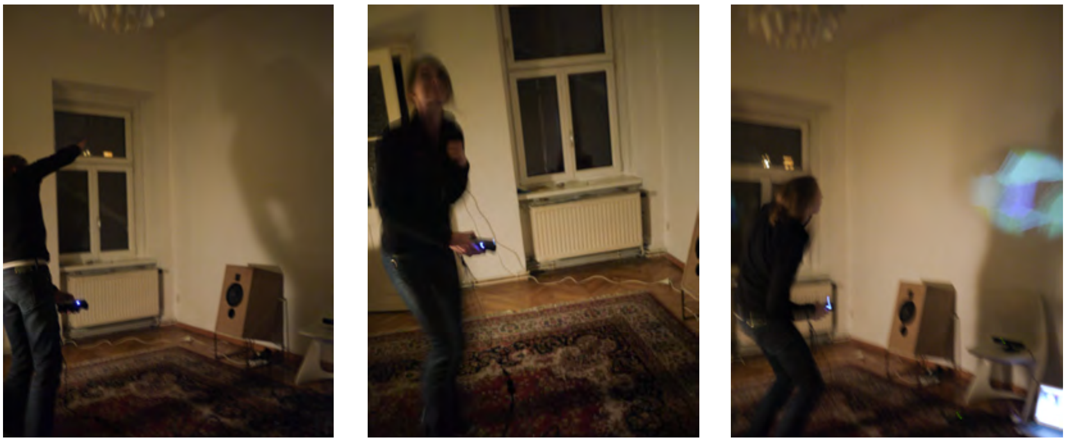


Figure 50: Excerpts form the series "Amber. Dancing"

7.1.2 Invention

Researchers who practice research by design *"must demonstrate that they have produced a novel integration of various subject matters to address a specific situation. In doing so, an extensive literature review must be performed that situates the work and details the aspects that demonstrate how their contribution advances the current state of the art in the research community."* While this is true for design practices, which try to answer a specify question and by doing so *"transform the world from its current state to a preferred state"*, I believe that this is not the case in artistic practice. Instead of talking about progress and invention, their questions are about presence and reflection and engagement. However, the resulting artefacts, which are often created by repurposing existing technologies (eg. the Eyewriter [46]) into a new system that is able to create certain experiences might as well be called an invention. As an extreme example consider the *Readymades* by Marcel Duchamp (see figure 51): One might argue that a bicycle wheel mounted upside-down on a wooden stool is just that: A wheel and a stool. But with his works Duchamp has arguably created some of the most important works of modern art. The artworks called into question our whole perception of what art really is and by doing so have changed the world from its former state to a preferred state by changing the way we see the world. This research does not try to be put in one line with Marcel Duchamp. This would be very impudent. But it thought along the same principles: Based on a extensive review of the body of existing work (see chapter 3), an assembly of readily available technologies was used to construct a novel system that investigates the ways we use and interact with projection.

Figure 51: Readymade, by Marcel Duchamp.

7.1.3 Relevance

For scientific research to be relevant, it needs to be valid. Traditionally in HCI validity means, that the process must be documented in a ways that can be reproduced by others with the same results. But as mentioned before, art and design have no expectations that a repetition of the process will yield the same results. Instead of validity, the benchmark to be applied should be relevance and *"a shift from what is true [..], to what is real"* [34], Zimmerman argues that in design-based research relevance is achieved by articulating the preferred state the design attempts to achieve and by providing support for why the community should consider this state to be preferred. But art has no conception of a preferred state the world needs to be turned into. Instead there is just the current state and changes occur from with, by means of reflection, re-appropriation and re-interpretation of existing concepts. So relevance for artistic research might be defined by the questions and statements it poses, and by the ways it allows observers to create meaning.

In most projects involving personal projection, the focus is on the device itself and environment in which they are used is nothing but projection surfaces. But what if one would consider the device in relation to the physical space it inhabits? Is it possible to create a feeling of immersion with mobile projection? How to engage with such technology? My system ponders those questions, suggests answers and creates artefacts to demonstrate their feasibility.

7.1.4 Extensibility

Extensibility is defined *"as the ability to build on the resulting outcomes"* of a research project, *"either employing the process in a future design problem, or understanding and leveraging the knowledge created by the resulting artifacts"* [34]. This contribution fits the later category. The resulting artefacts are implementations of ideas that probed the potentials of immersive personal projection. The artefacts and the reactions they provoked demonstrate the promises and perils of the technology. Also, experiments with different kinds of sensor technologies and an analysis of aesthetic capabilities were performed (see below). For my own speculations on the what such future work might be, see chapter 8.

The previous paragraphs examined the qualities of this thesis as an art-based research contribution with respect to the four lenses: Process, Invention, Relevance and Extensibility. For each of them, arguments in support of my work were presented. But since the quality of art is always a very personal matter, the final judgement is left to the respected reader.

The remainder of this chapter will relate the conclusions drawn from the evaluation of the technical probes. The key findings will be analysed with regard to technologies, aesthetics and interactions, and I will propose a set of guidelines that might serve as a reference point for future projects with a similar theme.

7.2 Technologies

From a technological perspective, this thesis assessed the combination of pico-projectors and motion based input controllers for their ability to create immersive experiences. The system should also be cheap, easy to set up and easy to maintain. In general, my proposed system meets all the requirements. A combination of Microsoft Kinect and Nintendo WiiMote is capable of fast and accurate tracking of both the users position and orientation. The projector, being small and focus-free, is comfortable to hold, and able to cope with movements, odd angles and all kinds of surfaces. The software tying both them together was thus able to create a convincing illusion of volume and depth. Instead of using a WiiMote, it might be advisable to instead use a projector phone. Most of these devices sport identical sensors and the number of gadgets in the system would be reduced by one.

There is however much room for improvements. The major issue with the technologies was that they ware first-generation-products (meaning that they have some serious flaws which are to be expected to be fixed by coming generations): The projector had a very low light output that is and all but unusable, except for strictly controlled lighting conditions. Its battery life is short and the device gets hot very quickly. The Kinect, having come out only a year ago, is a very good product. But the open-source drivers are not on par yet: Once the user detection is performed, all works well, but starting the system and calibrating the user is still not good. And while those issues cannot be helped at the moment, two other main shortcomings of my system were the rudimentary calibration and the setup complexity that resulted form the need for a dedicated host computer.

Calibration of virtual environments is an important aspect in presenting a convincing image of cyberspace [132] [133]. But most mixed reality installations are static and need only be calibrated once. In my case, the setup was very flexible and a little different each time. Devising a robust calibration strategy for such a setup would have been very complex, so a very crude from of calibration based of few input parameters was implemented. While working reasonably well during general use, getting very close to the projection surface or prolonged fast movements caused very noticeable and unwelcome errors.

Another serious issue is the need for a dedicated host computer. Instead of using an integrated system consisting of a pico-projector and a handheld computer, a *real* computer was necessary to interface with the Kinect and to process the rather large amount of information (user recognition, 3D rendering…). While the former would have been desirable to create an easy-to-set-up and easy-to-use system, the latter could not be avoided. Installing the system involved many components and cables, which made it unsuitable for spontaneous presentation and the intended long term study. On the other hand, this architecture provided great flexibility and proved to be ideally suited for experiments with different configurations of hard- and software.

7.3 Interactions

While the systems technological capabilities could be assessed along well defined parameters (such as accessibility and accuracy), the evaluation of the interactions it affords, and the aesthetics it conveys is a highly subjective matter. There exist no objective measures to rate the quality these parameters, as every individual experiences them differently. The question to ask is not *"Was the design successful?",* but rather *"What happened?"* [36]. And the only distinctive signals for failure and success would be a complete lack of engagement with a piece [36], or an open-mouth-moment respectively. So to judge the visual aesthetic and interactive qualities of my designs, the following paragraphs are based on observations of the intensity and expressiveness with which the participant engaged with the system.

The basic interaction all prototypes affords is the exploration of virtual realities using a Magic Torchlight. The projector was regarded as a torch that allowed users to shed light onto virtual objects. This metaphor proved to be very intuitive and once the user-calibration (the skeleton tracking of the Kinect requires a calibration upon entering a scene - a process that is tedious and unpredictable) was done all but one participant started walking around almost instantly. Further investigation however showed, that while this basic interaction is able to create an illusion of immersion, it is not engaging on its own, but perceived as rather dull (Eliza while playing with the reference-room prototype: *"Is that it or is there something else gonna happen?"*). On its own, the interaction is not sufficient to create an engaging experience. Prototypes that afforded only navigation (such as reference room or the virtual sculpture) tended to be ignored (marking them a failure), while those with additional, albeit simple interactions (such as the final audio prototype) managed to create open-mouth-moments.

Another observation, is the fact that glitches and software bugs are not necessarily bad, but can actually increase the playfulness of the experience. In the weather report prototype all interactions were the result of a bug (a lag in data processing and the resulting unforeseeable behaviour of virtual objects). Unwilling at first to even present the artefact, I found that what I considered a failure was fun for the participant.

In summary, my findings indicate that the metaphor of a Magic-Torchlight is able to create an illusion of immersion, but to be engaging a system should provide additional interactions.

7.4 Aesthetics

The visual aesthetics of the artefacts is strongly influenced by the shortcomings of the pico-projector. The low light output and the low resolution made the display of complex structures very difficult. Experiments with different aesthetic showed that complex scenes were harder to relate to, as the shown objects were not easily recognizable (virtual sculpture, stars). Scenes featuring bold graphics and strong contrasts on the other hand were instantly related to.

Another aspect to be considered is the apparent realism of a scene. When objects are presented with too much detail, mismatches resulting from tracking errors are accentuated and might ruin the illusion. This problem was especially perceptible in the reference-room prototype, where incongruences between the real and the virtual geometry were the cause of some confusion (Malcolm: *"Why is that wall here and not there?"*). In prototypes that did not resemble anything real, such discrepancies did not exist and thus could not cause any distraction. These prototypes were much better received.

For future reference, I would suggest to design the visual aesthetics along the following principles:

- No realism
- Bold graphics

- Strong contrasts
- Sparse use of colour palettes
- Avoid visual clutter whenever possible

7.5 Summary

In the previous chapter this thesis was evaluated as an art-based research contribution with respect to the four lenses. For each of them, arguments in support of my work were presented, but the final judgement was left to the respected reader. Later conclusions were drawn from the evaluation of the user-studies. The key findings were analysed with regard to technologies, aesthetics and interactions, and a set of guidelines was proposed, that might serve as a reference point for future endeavours in mobile immersive projection (see table 3). The final chapter, will present a summary of my efforts and speculate on possible future projects.

Technologies	**Interactions**	**Aesthetics**
Combination of Kinect and WiiMote afford robust & precise user tracking	Magic Torchlight metaphor very intuitive	Bold graphics
Calibration very difficult	Immersive experiences and illusion of space	Strong contrasts
Problems of first-generation products	Additional interactions necessary to be engaging	Sparse uses of colour
	Simple interactions suffice	Not too much realism
	Importance of sound in the creation of atmospheres	No visual clutter

Table 3. Synopsis of the guidelines for developing immersive mobile mixed-reality applications.

8. Conclusions and future work

This thesis documents the results from the development of an inexpensive, mobile mixed reality system and the subsequent exploration of the playful interactions such a setup affords.

8.2 Conclusions

Using a pico-projector and motion-based gaming controllers, I implemented a system which uses the metaphor of a magic-torchlight (based on the ideas of magic-lanterns [4] and magic-lenses [15]) to create immersive experiences by allowing users to explore and interact with virtual spaces. By capturing the users movements in physical space and mapping them onto a virtual torchlight (represented by the pico-projector), the system was able to create experiences similar to those provided by large scale VR applications such as the CAVE.

In an initial stage different motion sensing technologies were evaluated and provocative design methods were employed to gather inspiration for possible applications that could be used with these prototypes. The findings and inspirations from these preliminary studies were then used to design and evaluate aesthetic and interactive concepts for the proposed system. The goal was not to create a useful *tool*, but to create artefacts that are fun to engage with and open for interpretation.

Since fun and engagement are very subjective experiences and thus difficult to measure, practices of Ludic Design and digital are were used to implement and evaluate my contributions. In each iteration of the design process, small exhibitions (user-studies) were set up and participants were invited to engage with the various prototypes. Using Video, photography and notes, the interactions with the artefacts and the reactions they provoked were documented.

This research aims to be a feasibility study and an exploration of the potentials of personal projection to create immersive and engaging experiences. The key findings discovered during this exploration were analysed with respect to technologies, aesthetics and interactions. From these results a set of guidelines was proposed, which might serve as a reference point for future endeavours in mobile immersive projection To finish off this report, I will now present some of my own ideas for future projects.

8.2 Future Work

Current interest in personal projection is enormous, and the number of projects published during the course of this research is staggering (eg. [134], [87], [75], [76]) Some of these projects are very similar to this research [135], hinting at its relevance.

A natural evolution of the existing system might consist of technical improvements. Using more sophisticated calibration routines and a proper registration between reality and cyberspace would significantly enhance the quality of the experience. By doing so, one could not only incorporate the geometry of the room (walls, ceiling, corners...) but also other (possibly dynamic) objects, similarly to the scenarios presented by WearUrWorld [89]. Advanced registration techniques could also be used to permit advanced collaborative use, in which several users (a potential huge audience, should projector phones indeed become ubiquitous) could interact with the environment and with each other (similar to [88])

Other projects might be concerned with further investigations of the interactions that are being used. Video games and game mechanics would be an obvious choice. As would be the creation of tools. Imagine for example a home in which motions sensor infrastructure exists and in which certain objects are registered as *'controllers'*. By using a projector phone with the controller, one might could pull certain types of information, or trigger specific actions. In other environments, the technology could be used as a navigational system, similar to *Pathlight* [75] or *Ghali* [136].

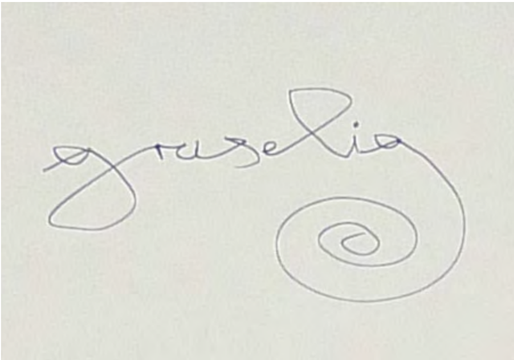
Generally speaking, I believe that the design-space of personal projection is enormous and that huge parts of it are still unmapped (despite the amount of research on this topic). And with Microsoft's efforts to promote its gaming hardware to scientists and enterprises [137] I think it is very likely that many more projects using similar technologies and concepts will emerge.

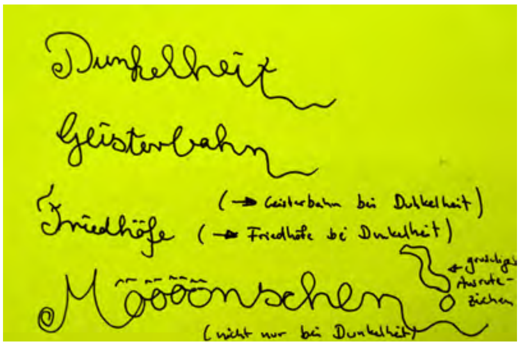
□

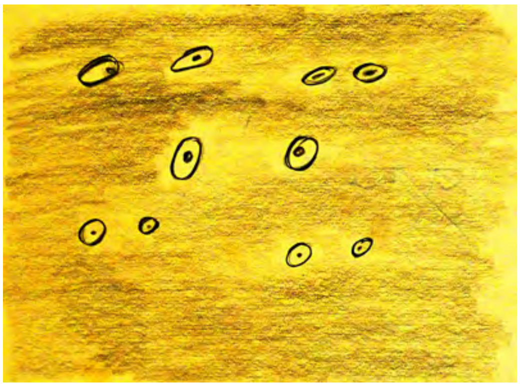
Appendix A: Cultural Probes

Contents of the cultural probes and selected responses.

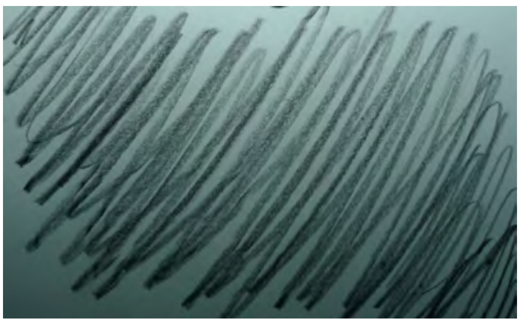
‘Spooky’

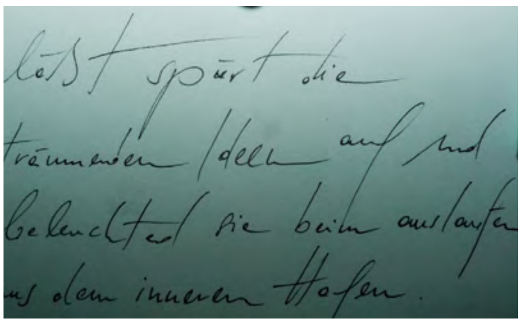


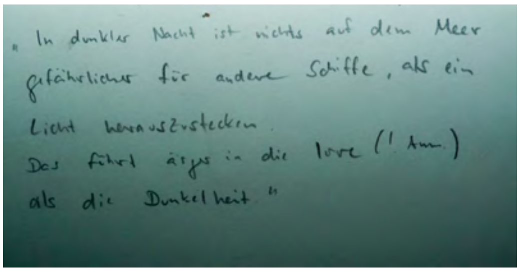


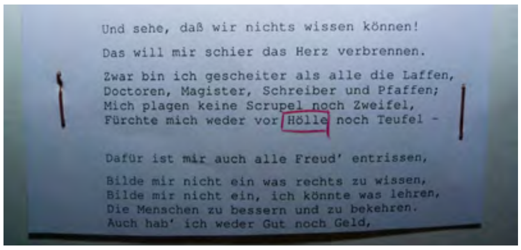


‘Darkness is…’



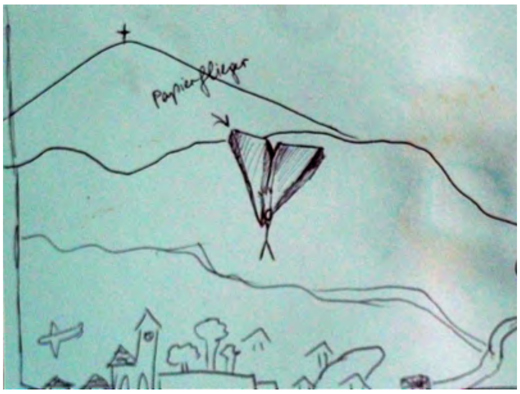


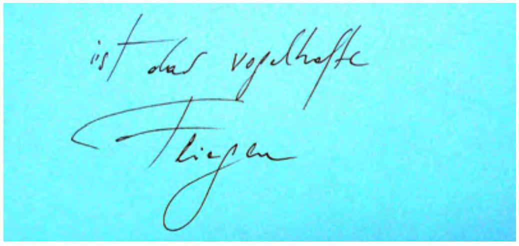




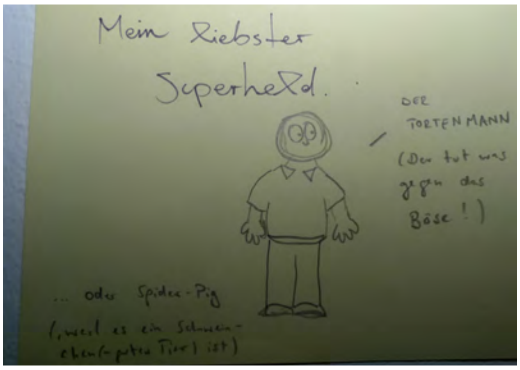
Und sehe, daß wir nichts wissen können!
Das will mir schier das Herz verbrennen.
Zwar bin ich gescheiter als alle die Laffen,
Doctoren, Magister, Schreiber und Pfaffen;
Mich plagen keine Scrupel noch Zweifel,
Fürchte mich weder vor Hölle noch Teufel –
Dafür ist mir auch alle Freud' entrissen,
Bilde mir nicht ein was rechts zu wissen,
Bilde mir nicht ein, ich könnte was lehren,
Die Menschen zu bessern und zu bekehren.
Auch hab' ich weder Gut noch Geld,

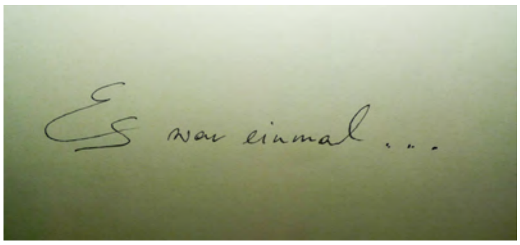
‘My favourite recurring dream’



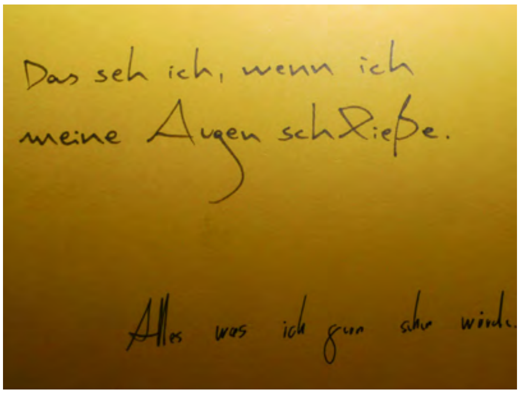


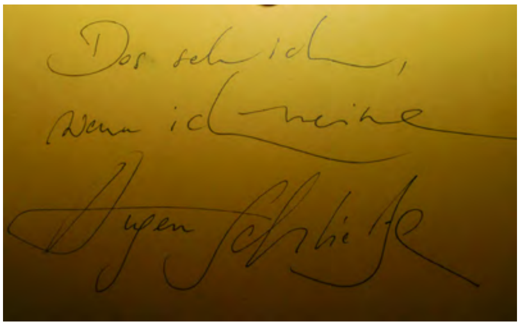
‘My favourite superhero’

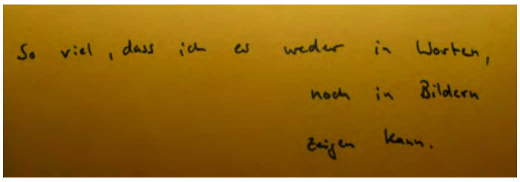


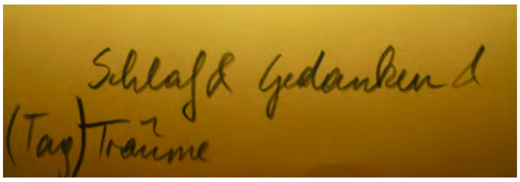


‘When I close my eyes I see…’

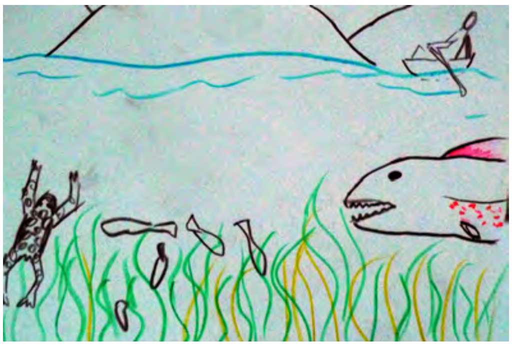


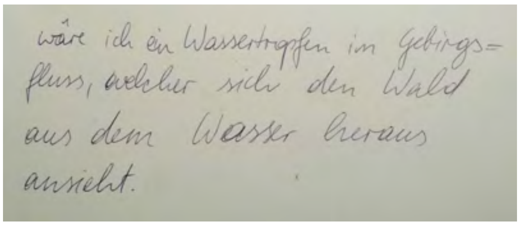


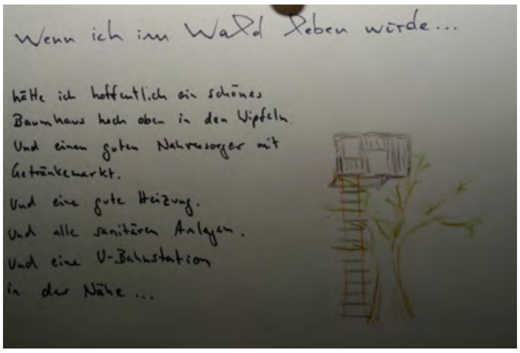




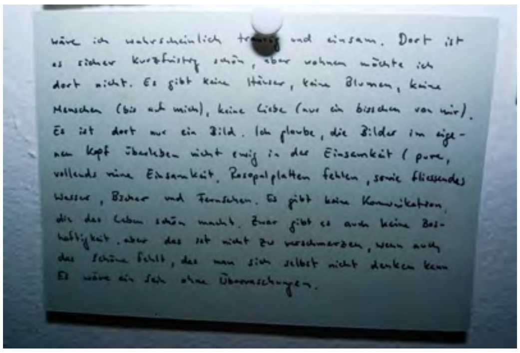
‘If I were living in the woods…’

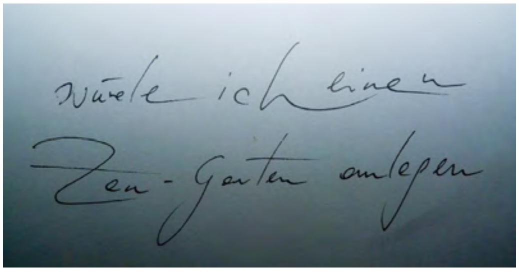




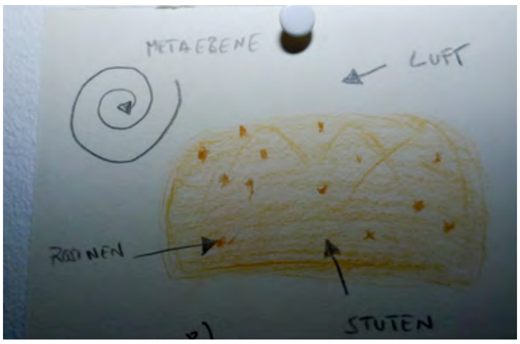


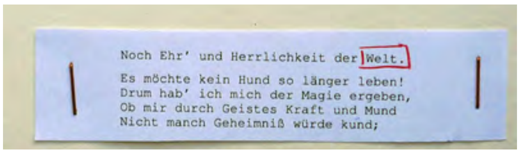
'If I were living in the on the moon…'

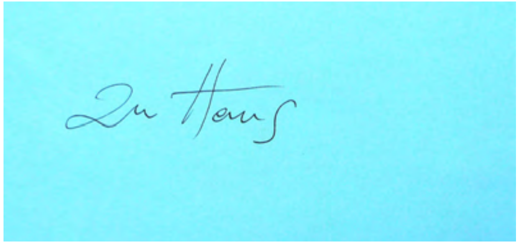




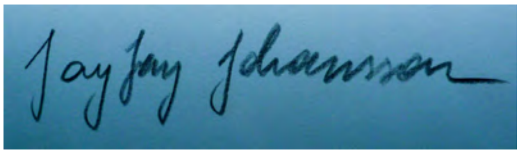
'I like it here'

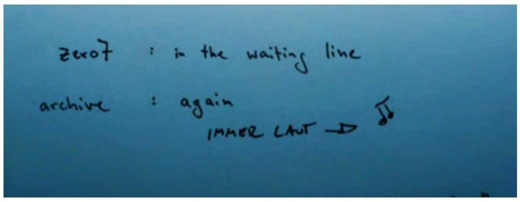




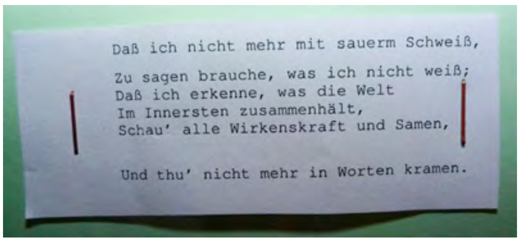


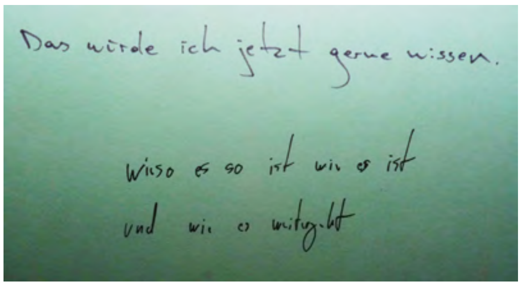
'Music for the darkness'



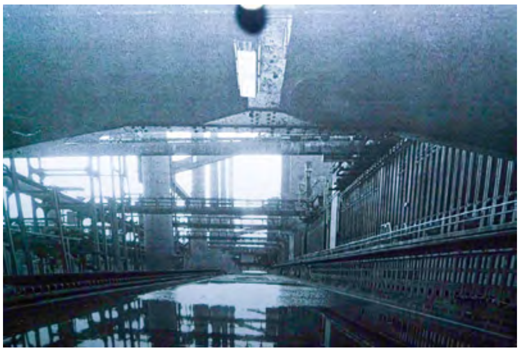


'I would like to know...'

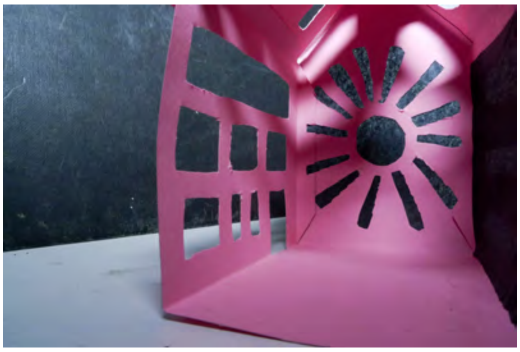


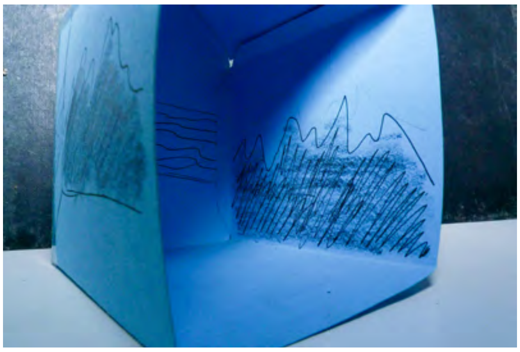


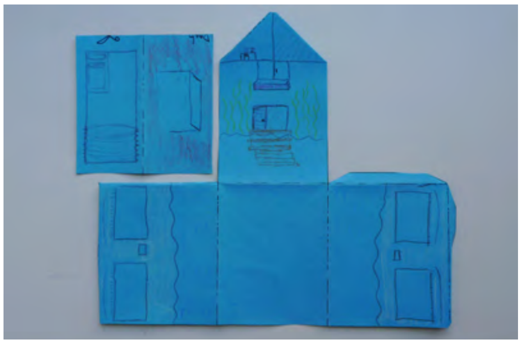
‘I would like to see…’

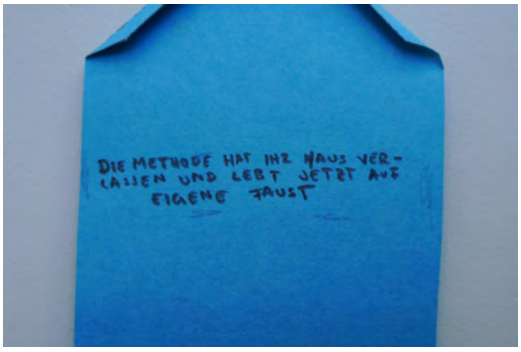


Your dream house








DIE METHODE HAT IHR HAUS VER-
LASSEN UND LEBT JETZT AUF
EIGENE FAUST

World Maps

Appendix B: Source Code

Selected code fragments from the software framework. A SVN repository containing the complete sources can be found at:

svn+ssh://lowi.org/var/svn/diplomV3

IMU accelerometer/gyroscope data processing

```
package org.lowi.input.imu.anoterIMU;

import org.lowi.input.imu.AbstractIMU;
import org.lowi.input.imu.util.IMU_Util;
import processing.core.PApplet;
import processing.core.PFont;
import processing.serial.Serial;

import java.util.Arrays;
import java.util.logging.Logger;

import static processing.core.PApplet.trim;

/**
* ported from http://code.google.com/applet/imumargalgorithm30042010sohm/
* *******************************************
* Description:
* - Uses orientation filter algorithm to orientate on-screen red, green and blue
axes.
* - Sensors calibration values must be specified within the source code and will vary
between apparently identical sensors.
* - Clicking the form will reset the 'zero position' of the on-screen image.
* - IMU must be stationary on start up in order to correctly sample gyroscope biases
* - Connections to Sparkfun IMU 6DOF Razor:
* - ACH0 = accelerometer x-axis
* - ACH1 = accelerometer y-axis
* - ACH2 = accelerometer z-axis
* - ACH3 gyroscope y-axis
* - ACH4 gyroscope x-axis
* - ACH5 gyroscope z-axis
* - Sensors should be uniquely calibrated.  Gains and Biases may vary between appar-
ently identical sensors and will vary with temperature.
* *******************************************
*/
public class AnotherIMU extends AbstractIMU {

     // FIELDS FORM http://code.google.com/applet/imumargalgorithm30042010sohm/
     // ----------------------------------------------------------------

     // quaternion orientation of earth frame relative to auxiliary frame
     private double AEq_1 = 1, AEq_2 = 0, AEq_3 = 0, AEq_4 = 0;
     // calibrated sensor measurements
     // accelerometer measurements
     double a_x, a_y, a_z;
     // gyroscope measurements
     double w_x, w_y, w_z;
```

```
     // sensor calibration variables and constants
      // accelerometer bias
     private double a_xBias = 32634.2779917682;
     private double a_yBias = 32300.1140276867;
     private double a_zBias = 32893.0853282136;

// accelerometer gains
     private final double a_xGain = -0.00150042985864975;
     private final double a_yGain = -0.00147414192905898;
     private final double a_zGain = 0.00152294825926844;

// gyroscope bias
     private double w_xBias = 25247;
     private double w_yBias = 25126;
     private double w_zBias = 24463;

// gyroscope gains
     private final double w_xGain = 0.00102058528925813;
     private final double w_yGain = -0.00110455853342484;
     private final double w_zGain = 0.00107794298635984;

// gyroscope gains
     private boolean initSample = true;

// 0.001Hz 1st order HP filter
     private IIRfilter HPfilterp = new IIRfilter(new double[]{0.999975456909767,
-0.999975456909767}, new double[]{1, -0.999950913819534});
     private IIRfilter HPfilterq = new IIRfilter(new double[]{0.999975456909767,
-0.999975456909767}, new double[]{1, -0.999950913819534});
     private IIRfilter HPfilterr = new IIRfilter(new double[]{0.999975456909767,
-0.999975456909767}, new double[]{1, -0.999950913819534});

     // filter variables and constants
     // estimated orientation quaternion elements with initial conditions
     private double SEq_1 = 1, SEq_2 = 0, SEq_3 = 0, SEq_4 = 0;
     // sampling period
     private final double deltat = 0.01;
     // gyroscope measurement error (in degrees per second)
     private final double gyroMeasError = 40;
     // compute beta
     private double beta = Math.sqrt(3.0 / 4.0) * (Math.PI * (gyroMeasError /
180.0));


     // FIELDS for reading the raw data of the arduino
     // -----------------------------------------------------------------

     // the the raw values read from serial (converted from above strings)
     int[] rawValues;

     // indices for the array position of the raw values
     final static int AX = 0;
     final static int AY = 1;
     final static int AZ = 2;
     final static int GX = 3;
     final static int GY = 4;
     final static int GZ = 5;

     boolean debug;
     boolean calibrating;
     boolean awaitingCalibration;
     int calibrationWaitCount;
     boolean isCalibrated;
```

```
private boolean intializing;
long timer;
long dTime;

double gyroXrate;
double gyroYrate;
double gyroZrate;

PFont font;

public AnotherIMU(PApplet applet, Serial serial, Logger logger) {
     super(applet, serial, logger);
     debug = true;
     timer = applet.millis();
     isCalibrated = false;
     font = applet.loadFont("Helvetica.vlw");

     // store orientation of auxiliary frame
     AEq_1 = SEq_1;
     AEq_2 = SEq_2;
     AEq_3 = SEq_3;
     AEq_4 = SEq_4;

     intializing = true;
}

//    sends a byte to arduino requesting calibration
private void requestCalibration() {

     System.out.println("requesting calibration");
     awaitingCalibration = true;
     calibrationWaitCoun
     // write any byte to indicate calibration requestt = 0;
     serial.write(65);
}

@Override
public void update() {
     checkCalibration();
     if (!isCalibrated) return;

     if ((applet.millis() - timer) >= deltat * 1000) {
          // update filter with sensor data
          filterUpdate(w_x, w_y, w_z, a_x, a_y, a_z);
          timer = applet.millis();
     }

}

@Override
public void draw() {
     {

          // calculate angles
          roll = (float) Math.atan2(2 * (SEq_1 * SEq_2 + SEq_3 * SEq_4),
               1 - 2 * (SEq_2 * SEq_2 + SEq_3 * SEq_3));
          pitch = (float) Math.asin(2 * (SEq_1 * SEq_2 - SEq_2 * SEq_4));
          yaw = (float) Math.atan2(2 * (SEq_1 * SEq_4 + SEq_2 * SEq_3),
               1 - 2 * (SEq_3 * SEq_3 + SEq_4 * SEq_4));

          // add sensor data text to graphics object
          applet.text("Accelerometer (m/s/s):", 0, 10);
          applet.text("x = " + IMU_Util.round(a_x, 2), 5, 25);
```

```
            applet.text("y = " + IMU_Util.round(a_y, 2), 5, 40);
            applet.text("z = " + IMU_Util.round(a_z, 2), 5, 55);
            applet.text("Gyroscope (rad/s):", 0, 75);
            applet.text("x = " + IMU_Util.round(w_x, 2), 5, 90);
            applet.text("y = " + IMU_Util.round(w_y, 2), 5, 105);
            applet.text("z = " + IMU_Util.round(w_z, 2), 5, 120);

            applet.pushMatrix();
            applet.translate(applet.width / 2, applet.height / 2, 100);
            applet.rotateX(0.3f);
            applet.rotateY(0.4f);
            applet.rotateZ(0.5f);

            applet.lights();
            applet.box(100);

            applet.noLights();
            applet.popMatrix();

        }
    }

    public void serialEvent(Serial serial) {

        if (intializing) {
            serial.clear();
            intializing = false;
            return;
        }

        // parse input
        // ------------------------------------------------------------------

        String inString = serial.readStringUntil('\n');
        inString = trim(inString);


        if (inString.matches("c\\s\\d{1,3}\\s\\d{1,3}\\s\\d{1,3}\\s\\d{1,3}\\s\\
d{1,3}\\s\\d{1,3}")) {
            calibrating = true;
            awaitingCalibration = false;
        }

        if (!inString.matches("n\\s\\d{1,3}\\s\\d{1,3}\\s\\d{1,3}\\s\\d{1,3}\\s\\
d{1,3}\\s\\d{1,3}")) return;

        String[] rawStrings = inString.split("\t");
        );

        if (rawStrings.length != 7) {
            System.out.println("wrong number of values in input string: " + Ar-
rays.toString(rawStrings));
            return;
        }

        rawValues = convert(rawStrings);
        if (rawValues == null) return;

        // assign values
        // ------------------------------------------------------------------

        if (calibrating) {
            a_xBias = (double) rawValues[0];
```

```
                a_yBias = (double) rawValues[1];
                a_zBias = (double) rawValues[2];

                w_xBias = (double) rawValues[3];
                w_yBias = (double) rawValues[4];
                w_zBias = (double) rawValues[5];

                isCalibrated = true;
                calibrating = false;

                System.out.println("CALIBRATED");
                System.out.println("a_xBias = " + a_xBias);
                System.out.println("a_yBias = " + a_yBias);
                System.out.println("a_zBias = " + a_zBias);

                System.out.println("w_xBias = " + w_xBias);
                System.out.println("w_yBias = " + w_yBias);
                System.out.println("w_zBias = " + w_zBias);

            } else if (isCalibrated) {
                updateReadings();
            }

            dTime = applet.millis() - timer;
            timer = applet.millis();

            // update filter with sensor data
            filterUpdate(w_x, w_y, w_z, a_x, a_y, a_z);

        }

        private void updateReadings() {
            //not sure at all whether this is correct - taken from http://arduino.cc/
forum/index.php/topic,58048.msg417140.html#msg417140
            a_x = (rawValues[0] - a_xBias) / 102.3;
            a_y = (rawValues[1] - a_yBias) / 102.3;
            a_z = (rawValues[2] - a_zBias) / 102.3;

            w_x = HPfilterp.step((rawValues[3] - w_xBias) / 1.0323);
            w_y = HPfilterp.step((rawValues[4] - w_yBias) / 1.0323);
            w_z = HPfilterp.step((rawValues[5] - w_zBias) / 1.0323);

        }

        private void filterUpdate(double w_x, double w_y, double w_z, double a_x, double
a_y, double a_z) {
            // local system variables
            // vector norm
            double norm;
            // quaternion rate from gyroscopes elements
            double SEqDot_omega_1, SEqDot_omega_2, SEqDot_omega_3, SEqDot_omega_4;
            // objective function elements
            double f_1, f_2, f_3;
            // objective function Jacobian elements
            double J_11or24, J_12or23, J_13or22, J_14or21, J_32, J_33;
            // objective function gradient elements
            double nablaf_1, nablaf_2, nablaf_3, nablaf_4;

            // axulirary variables to avoid reapeated calcualtions
            double halfSEq_1 = 0.5 * SEq_1;
            double halfSEq_2 = 0.5 * SEq_2;
            double halfSEq_3 = 0.5 * SEq_3;
            double halfSEq_4 = 0.5 * SEq_4;
```

```
        double twoSEq_1 = 2.0 * SEq_1;
        double twoSEq_2 = 2.0 * SEq_2;
        double twoSEq_3 = 2.0 * SEq_3;

        // compute the quaternion rate measured by gyroscopes
        SEqDot_omega_1 = -halfSEq_2 * w_x - halfSEq_3 * w_y - halfSEq_4 * w_z;
        SEqDot_omega_2 = halfSEq_1 * w_x + halfSEq_3 * w_z - halfSEq_4 * w_y;
        SEqDot_omega_3 = halfSEq_1 * w_y - halfSEq_2 * w_z + halfSEq_4 * w_x;
        SEqDot_omega_4 = halfSEq_1 * w_z + halfSEq_2 * w_y - halfSEq_3 * w_x;

        // normalise the accelerometer measurement
        norm = Math.sqrt(a_x * a_x + a_y * a_y + a_z * a_z);
        a_x /= norm;
        a_y /= norm;
        a_z /= norm;

        // compute the objective function and Jacobian
        f_1 = twoSEq_2 * SEq_4 - twoSEq_1 * SEq_3 - a_x;
        f_2 = twoSEq_1 * SEq_2 + twoSEq_3 * SEq_4 - a_y;
        f_3 = 1.0 - twoSEq_2 * SEq_2 - twoSEq_3 * SEq_3 - a_z;
        // J_11 negated in matrix multiplication
        J_11or24 = twoSEq_3;
        J_12or23 = 2 * SEq_4;
        // J_12 negated in matrix multiplication
        J_13or22 = twoSEq_1;
        J_14or21 = twoSEq_2;
        // negated in matrix multiplication
        J_32 = 2 * J_14or21;
        // negated in matrix multiplication
        J_33 = 2 * J_11or24;

        // compute the gradient (matrix multiplication)
        nablaf_1 = J_14or21 * f_2 - J_11or24 * f_1;
        nablaf_2 = J_12or23 * f_1 + J_13or22 * f_2 - J_32 * f_3;
        nablaf_3 = J_12or23 * f_2 - J_33 * f_3 - J_13or22 * f_1;
        nablaf_4 = J_14or21 * f_1 + J_11or24 * f_2;

        // normalise the gradient
        norm = Math.sqrt(nablaf_1 * nablaf_1 + nablaf_2 * nablaf_2 + nablaf_3 *
nablaf_3 + nablaf_4 * nablaf_4);
        nablaf_1 /= norm;
        nablaf_2 /= norm;
        nablaf_3 /= norm;
        nablaf_4 /= norm;

        // compute then integrate the estimated quaternion rate
        SEq_1 += (SEqDot_omega_1 - (beta * nablaf_1)) * deltat;
        SEq_2 += (SEqDot_omega_2 - (beta * nablaf_2)) * deltat;
        SEq_3 += (SEqDot_omega_3 - (beta * nablaf_3)) * deltat;
        SEq_4 += (SEqDot_omega_4 - (beta * nablaf_4)) * deltat;

        // normalise quaternion
        norm = Math.sqrt(SEq_1 * SEq_1 + SEq_2 * SEq_2 + SEq_3 * SEq_3 + SEq_4 *
SEq_4);
        SEq_1 /= norm;
        SEq_2 /= norm;
        SEq_3 /= norm;
        SEq_4 /= norm;
    }

    // convert the readings from serial to floats
    private int[] convert(String[] rawStrings) {
        int[] result = new int[6];
```

```
        for (int i = 0; i < 6; i++) {
            rawStrings[i + 1] = trim(rawStrings[i + 1]);
            try {
                result[i] = Integer.valueOf(rawStrings[i + 1]);
            } catch (NumberFormatException e) {
                System.out.println("value parse error: " + rawStrings[i + 1]);
                return null;
            }
        }
        return result;
    }

    private void checkCalibration() {
        if (!isCalibrated && !awaitingCalibration && !calibrating) {
            requestCalibration();
        }

        if (!isCalibrated && awaitingCalibration && calibrationWaitCount > 30) {
            requestCalibration();
        }

        if (awaitingCalibration) {
            calibrationWaitCount++;
        }
    }
}
```

Kinect / WiiMote OSC signal routing

```
package org.lowi.kinect;

public class KinectOscBakk extends PApplet{
/* --------------------------------------------------------------------------
* ADAPTED FROM:
* --------------------------------------------------------------------------
* SimpleOpenNI User Load + Save Calibration Test
* --------------------------------------------------------------------------
* Processing Wrapper for the OpenNI/Kinect library
* http://code.google.com/p/simple-openni
* --------------------------------------------------------------------------
* prog:  Max Rheiner / Interaction Design / zhdk / http://iad.zhdk.ch/
* date:  06/11/2011 (m/d/y)
* --------------------------------------------------------------------------
*/

SimpleOpenNI context;
OscP5 oscP5;
NetAddress myRemoteLocation;
PFont font;
ArrayList<String> messages;
PVector translation;
PVector translationMapped;
PVector minTranslation;
PVector maxTranslation;
ControlP5 controlP5;

// ids of the gui elements
final int MIN_TRANSLATION_X = 0;
final int MAX_TRANSLATION_X = 1;
final int MIN_TRANSLATION_Y = 2;
final int MAX_TRANSLATION_Y = 3;
final int MIN_TRANSLATION_Z = 4;
final int MAX_TRANSLATION_Z = 5;

final int SET_MIN_TRANSLATION_Z = 6;
final int SET_MAX_TRANSLATION_Z = 7;

final int SAVE_GUI = 8;

boolean isCalibrating;
boolean isCalibrated;
int calibrationFade;
int calibrationStart;
ArrayList<PVector> calibrationTranslations;
ArrayList<PVector> calibrationRotations;

PVector translationOffset;
PVector rotationOffset;

float wiiPitch;
float wiiYaw;
float wiiRoll;
boolean chatchEverySecondButtonEventHack = false;


public void setup() {

     //        ____________________________________
     //        INITIALIZE KINECT
```

```
//        ____________________________________
context = new SimpleOpenNI(this);
// enable depthMap generation
context.enableDepth();
// enable skeleton generation for all joints
context.enableUser(SimpleOpenNI.SKEL_PROFILE_ALL);

maxTranslation = new PVector();
minTranslation = new PVector();

//        _____________________________________________
//        INITIALIZE PROCESSING
//        _____________________________________________
background(200, 0, 0);
stroke(0, 0, 255);
strokeWeight(3);
smooth();
size(context.depthWidth(), context.depthHeight());

font = loadFont("Helvetica-Light-14.vlw");
textFont(font);

// list containing messages that are written on the screen
messages = new ArrayList<String>();

//        ____________________________________
//        INITIALIZE OSC
//        ____________________________________
/* start oscP5, listening for incoming messages at port 12000 */
oscP5 = new OscP5(this, 11999);
myRemoteLocation = new NetAddress("127.0.0.1", 12000);

int[] userMap = context.getUsersPixels(SimpleOpenNI.USERS_ALL);

//        _______________________________________
//        INITIALIZE GUi
//        _______________________________________
controlP5 = new ControlP5(this);

Slider slider;
slider = controlP5.addSlider(
     "min_translation_x", -1000, 1000, -800, 20, 20, 220, 10);
slider.setId(MIN_TRANSLATION_X);
slider.update();

slider = controlP5.addSlider(
     "max_translation_x", -1000, 1000, 800, 20, 50, 220, 10);
slider.setId(MAX_TRANSLATION_X);
slider.update();

slider = controlP5.addSlider(
     "min_translation_y", -1000, 1000, -800, 20, 90, 220, 10);
slider.setId(MIN_TRANSLATION_Y);
slider.update();

slider = controlP5.addSlider(
     "max_translation_y", -1000, 1000, 800, 20, 110, 220, 10);
slider.setId(MAX_TRANSLATION_Y);
slider.update();

slider = controlP5.addSlider(
     "min_translation_z", 400, 5000, 500, 20, 150, 220, 10);
slider.setId(MIN_TRANSLATION_Z);
```

```
    slider.update();

    slider = controlP5.addSlider(
        "max_translation_z", 400, 5000, 2000, 20, 170, 220, 10);
    slider.setId(MAX_TRANSLATION_Z);
    slider.update();


    Bang bang = controlP5.addBang("SAVE_GUI", 20, 200, 100, 100);
    bang.setId(SAVE_GUI);
}


public void draw() {
    // update the cam
    context.update();

    // draw depthImageMap
    image(context.depthImage(), 0, 0);

    printMessages();

    //        draw a tinted rect underneath the gui elements
    noStroke();
    fill(0, 100);
    rect(10, 10, 350, 200);

    // draw the skeleton if it's available
    int trackingId = getTrackingId();

    if (trackingId != -1) {
        translation = new PVector();
        context.getJointPositionSkeleton(trackingId, SimpleOpenNI.SKEL_LEFT_HAND,
translation);
        translation.x *= -1;

        if (isCalibrated && !isCalibrating) {
            translation.sub(translationOffset);
        }

        mapTranslation();

        drawSkeleton(trackingId);
        oscSend();
        printValues(trackingId);

        if (calibrationFade > 10) {
            pushStyle();
            fill(0, 255, 255, calibrationFade);
            noStroke();
            rect(0, 0, width, height);
            popStyle();

            calibrationFade *= 0.7;
        }

        if (isCalibrating) {

            translationOffset = new PVector(translation.x, translation.y, 0);
            isCalibrating = false;
            isCalibrated = true;
        }
    }
```

```
}

private void mapTranslation() {
     translationMapped = new PVector();

     translationMapped.x = map(translation.x, minTranslation.x, maxTranslation.x,
-1, 1);
     translationMapped.y = map(translation.y, minTranslation.y, maxTranslation.y,
-1, 1);
     translationMapped.z = map(translation.z, minTranslation.z, maxTranslation.z, 0,
1);

}

private void printMessages() {
     fill(0, 100);
     stroke(0, 255, 255);
     strokeWeight(1);
     rect(width / 2 + 10, height / 2 + 10, width / 2 - 20, height / 2 - 20);

     noStroke();
     fill(0, 255, 255);

     int i = 0;
     for (String m : messages) {
          text(m, width / 2 + 20, height / 2 + 30 + i * 18);
          i++;
     }

     if (frameCount % 20 == 0 && messages.size() > 0) {
          messages.remove(0);
     }
}

private String twoDecimals(float v) {
     DecimalFormat twoDForm = new DecimalFormat("#.##");
     return twoDForm.format(v);
}

void oscSend() {
     /* create an osc bundle */
     OscBundle myBundle = new OscBundle();

     /* createa new osc message object */
     OscMessage myMessage = new OscMessage("/translation");
     myMessage.add(translationMapped.x);
     myMessage.add(translationMapped.y);
     myMessage.add(translationMapped.z);

     /* add an osc message to the osc bundle */
     myBundle.add(myMessage);

     /* reset and clear the myMessage object for refill. */
     myMessage.clear();

     /* refill the osc message object again */
     myMessage.setAddrPattern("/rotation");
     myMessage.add(calculatePitch());
     myMessage.add(calculateYaw());
     myMessage.add(calculateRoll());

     myBundle.add(myMessage);
```

```
    myBundle.setTimetag(OscBundle.now());
    /* send the osc bundle, containing 2 osc messages, to a remote location. */
    oscP5.send(myBundle, myRemoteLocation);
}


// draw the skeleton with the selected joints
void drawSkeleton(int userId) {
    // to get the 3d joint data
    noFill();
    stroke(255, 0, 255);
    strokeWeight(3);

    context.drawLimb(userId, SimpleOpenNI.SKEL_HEAD, SimpleOpenNI.SKEL_NECK);

    context.drawLimb(userId, SimpleOpenNI.SKEL_NECK, SimpleOpenNI.SKEL_LEFT_SHOUL-
DER);
    context.drawLimb(userId, SimpleOpenNI.SKEL_LEFT_SHOULDER, SimpleOpenNI.SKEL_
LEFT_ELBOW);
    context.drawLimb(userId, SimpleOpenNI.SKEL_LEFT_ELBOW, SimpleOpenNI.SKEL_LEFT_
HAND);

    context.drawLimb(userId, SimpleOpenNI.SKEL_NECK, SimpleOpenNI.SKEL_RIGHT_SHOUL-
DER);
    context.drawLimb(userId, SimpleOpenNI.SKEL_RIGHT_SHOULDER, SimpleOpenNI.SKEL_
RIGHT_ELBOW);
    context.drawLimb(userId, SimpleOpenNI.SKEL_RIGHT_ELBOW, SimpleOpenNI.SKEL_
RIGHT_HAND);

    context.drawLimb(userId, SimpleOpenNI.SKEL_LEFT_SHOULDER, SimpleOpenNI.SKEL_
TORSO);
    context.drawLimb(userId, SimpleOpenNI.SKEL_RIGHT_SHOULDER, SimpleOpenNI.SKEL_
TORSO);

    context.drawLimb(userId, SimpleOpenNI.SKEL_TORSO, SimpleOpenNI.SKEL_LEFT_HIP);
    context.drawLimb(userId, SimpleOpenNI.SKEL_LEFT_HIP, SimpleOpenNI.SKEL_LEFT_
KNEE);
    context.drawLimb(userId, SimpleOpenNI.SKEL_LEFT_KNEE, SimpleOpenNI.SKEL_LEFT_
FOOT);

    context.drawLimb(userId, SimpleOpenNI.SKEL_TORSO, SimpleOpenNI.SKEL_RIGHT_HIP);
    context.drawLimb(userId, SimpleOpenNI.SKEL_RIGHT_HIP, SimpleOpenNI.SKEL_RIGHT_
KNEE);
    context.drawLimb(userId, SimpleOpenNI.SKEL_RIGHT_KNEE, SimpleOpenNI.SKEL_RIGHT_
FOOT);
}

// -----------------------------------------------------------------------------------
-----------------------
// OPEN_NI events
// -----------------------------------------------------------------------------------
-----------------------
public void onNewUser(int userId) {
    messages.add("onNewUser - userId: " + userId);
    messages.add("  start pose detection");

    context.startPoseDetection("Psi", userId);
}

public void onLostUser(int userId) {
    messages.add("onLostUser - userId: " + userId);
}
```

```
public void onStartCalibration(int userId) {
     messages.add("onStartCalibration - userId: " + userId);
}

public void onEndCalibration(int userId, boolean successfull) {
     messages.add("onEndCalibration - userId: " + userId + ", successfull: " + suc-
cessfull);

     if (successfull) {
          messages.add("  User calibrated !!!");
          context.startTrackingSkeleton(userId);
     } else {
          messages.add("  Failed to calibrate user !!!");
          messages.add("  Start pose detection");
          context.startPoseDetection("Psi", userId);
     }
}

public void onStartPose(String pose, int userId) {
     messages.add("onStartPose - userId: " + userId + ", pose: " + pose);
     messages.add(" stop pose detection");

     context.stopPoseDetection(userId);
     context.requestCalibrationSkeleton(userId, true);

}

public void onEndPose(String pose, int userId) {
     messages.add("onEndPose - userId: " + userId + ", pose: " + pose);
}


// ---------------------------------------------------------------------------------
------------------------
// pose calculations
// ---------------------------------------------------------------------------------
------------------------

// USING KINECT SKELETON

// calculated the pitch of the projector - in degrees
private float calculatePitch(int userId) {
     return (PApplet.acos(rotationVector(userId).y) - PI / 2) * -1;
}

// calculated the pitch of the projector - in degrees
protected float calculateYaw(int userId) {
     return PApplet.acos(rotationVector(userId).x) - PI / 2;
}

// USING WII MOTION PLUS

private float calculateYaw() {
     return wiiYaw;
}

private float calculatePitch() {
     return wiiPitch;
}

// calculated the pitch of the projector - in degrees
protected float calculateRoll() {
     return wiiRoll;
```

```
}

//returns the normalized orientational vector
private PVector rotationVector(int userId) {
     PVector hand = new PVector();
     PVector elbow = new PVector();

     context.getJointPositionSkeleton(userId, SimpleOpenNI.SKEL_LEFT_HAND, hand);
     context.getJointPositionSkeleton(userId, SimpleOpenNI.SKEL_LEFT_ELBOW, elbow);

     hand.sub(elbow);
     hand.div(hand.mag()); // normalize

     if (isCalibrated && !isCalibrating) {
          hand.sub(rotationOffset);
     }

     return hand;
}

// gui event handler
public void controlEvent(ControlEvent theEvent) {
     /* events triggered by controllers are automatically forwarded to
     the controlEvent method. by checking the id of a controller one can distinguish
     which of the controllers has been changed.
     */
     float value = theEvent.controller().value();
     switch (theEvent.controller().id()) {
          case (MIN_TRANSLATION_X):
          minTranslation.x = value;
          println("minX: " + value);
          break;
          case (MAX_TRANSLATION_X):
          maxTranslation.x = value;
          println("maxX: " + value);
          break;
          case (MIN_TRANSLATION_Y):
          minTranslation.y = value;
          println("minY: " + value);
          break;
          case (MAX_TRANSLATION_Y):
          maxTranslation.y = value;
          println("maxY: " + value);
          break;
          case (MIN_TRANSLATION_Z):
          minTranslation.z = value;
          println("minZ: " + value);
          break;
          case (MAX_TRANSLATION_Z):
          maxTranslation.z = value;
          println("maxZ: " + value);
          break;
          case (SAVE_GUI):
          println("SAVE");
          controlP5.setFilePath("/Users/lowi/projects/diplom/IDEA/diplomV3/out/pro-
duction/diplomV3/data/");
          System.out.println("controlP5 = " + controlP5.filePath());
          boolean allgood = controlP5.save();
          System.out.println("allgood = " + allgood);
          break;
     }
}
```

```
public int getTrackingId() {
     for (int i = 1; i < 10; i++) {
          if (context.isTrackingSkeleton(i)) return i;
     }
     return -1;
}

/* incoming osc message are forwarded to the oscEvent method. */
public void oscEvent(OscMessage theOscMessage) {
     if (theOscMessage.addrPattern().matches(".*/angles/0")) {
          wiiPitch = mapAndDegrees(theOscMessage.get(0).floatValue());
     } else if (theOscMessage.addrPattern().matches(".*/angles/1")) {
          wiiRoll = mapAndDegrees(theOscMessage.get(0).floatValue());
     } else if (theOscMessage.addrPattern().matches(".*/angles/2")) {
          wiiYaw = -mapAndDegrees(theOscMessage.get(0).floatValue());
     } else if (theOscMessage.addrPattern().matches(".*/button/B/0")) {
          if (!chatchEverySecondButtonEventHack)
               reset();
               chatchEverySecondButtonEventHack = !chatchEverySecondButtonEventHack;
          }
     }

     private void reset() {
          isCalibrating = true;
          calibrationFade = 255;
     }

     private float mapAndDegrees(float rawWiiValue) {
          return (map(rawWiiValue, 0, 1, 0, PI) - PI / 2);
     }
}
```

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