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Faculty of Media
Degree Program Computer Science and Media

Can't Touch This - A Prototype for Public Pointing Interaction

Master Thesis

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Abstract

Museums can be perceived as old fashioned. Potential audiences therefore often do not consider visiting one for themselves. Nevertheless, there are many modern and open minded ones, which are willing to experiment with new possibilities, to get rid of their dusted reputation and to evolve.
In order to increase interactive potential of exhibits behind glass, I implemented a novel information interaction system for a museum of pre- and protohistoric history. The challenge was not only to develop a working, intuitive prototype, but also consider low maintenance and robustness for everyday use. The system I developed employs the natural behavior of visitors by detecting potential users and enabling them to interact with the system via pointing gestures. Additionally, the museum personnel can easily set up and maintain the system themselves.
Interaction of the system is initiated automatically with a visitor walking up to the installation. No additional devices on the users side are required, they only need to point at one of the interactive exhibits inside the showcase. The system then determines which exhibit is addressed and displays corresponding information in the form of explanatory texts and detailed images on a screen.

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Affidavit

Affidavit

I hereby declare that this master thesis has been written only by the undersigned and without any assistance from third parties. Furthermore, I confirm that no sources have been used in the preparation of this thesis other than those indicated in the thesis itself, as well as that the thesis has not yet been handled in neither in this nor in equal form at any other official commission.

Michael Pannier

Abbrevations

IMI	Interactive Museum Installation
MS	Microsoft
RFID	Radio-Frequency Identification
FSD	Functional Specification Document
MIT	Massachusetts Institute of Technology
SDMS	Spacial Data-Management System
WYSIWYG	”What you see is what you get”
GUI	Graphical User Interface
SUI	Single-User Interface
MUI	Multi-User Interface
HCI	Human Computer-Interaction
TUI	Tangible User Interface
VR	Virtual Reality
3D	three-dimensional
HMD	head-mounted display
DOF	degrees of freedom
AR	Augmented Reality
SDK	Software Development Kit
CAVE	Cave Automatic Virtual Environment

2D	two-dimensional
BCI	Brain-Computer Interface
MVT	Museumsverband Thüringen
HDD	Hard Disk Drive
PDLC	Polymer Dispersed Liquid Crystal
IR	infra-red
FUBI	Full Body Interaction
UI	User Interface
wpm	words per minute
cpm	characters per minute
IV	Independent Variable
SD	Standard Deviation
ID	Identificator
AOA	Area of Affinity
LOS	Length of Stay
n/s	not specified
SUS	Standard Usability Scale

1 Introduction

In this work, I describe the development of an interactive museum installation (IMI). The system presents a novel way to augment public displays with a system that is intuitive to use, easy to maintain, and inexpensive. Natural interaction without additionally required devices on the users end lowers inhibition and frustration. Simultaneously, awareness for the displayed contents is raised.

Figure 1.1: Interactive Museum Installation inside the Haßleben-showcase at the Museum für Ur- und Frühgeschichte Thüringens.

Before the system depicted in Figure 1.1 could be developed, a collaboration with a local museum had to be established. Because the installation would be based on in- and output modalities that actually make sense in a museum, visitors and staff had to be observed and interviewed. After looking at several suitable museum candidates in Weimar. I chose the one with the most promise in fitting properties as well as institutional openness for my purposes. Together, we conceived some ideas for possible installations. Not all of them were applicable an some were too far off my expertise. Nevertheless, there were two concepts for augmenting the *gravesite of Haßleben-showcase*, that we were very interested in and excited about.

The first concept, *"Interaction with Tangibles"*, directly addressed visitors' haptic perception. Therefore, it was planned to use Microsoft (MS) Gadgeteer-hardware[1] as embedded components of tangible devices. A number of reproductions could be placed outside the showcase. Each interactive tangible could then be manipulated or placed on a pedestal to gain information about its corresponding exhibit. Here, certain exhibits could have been photogrammetically scanned in three dimensions. After that, the digital model could be scaled to a handy size and otherwisely modified. Ultimately, the tangible could be printed or casted. Such an object could then be enhanced by using RFID-technology[2]. In order to make it interactive, it would be fitted with such a RFID-tag. There is a RFID-module for Gadgeteer, which would have allowed identification of each tangible. The corresponding information could then be provided by any medium compatible with Gadgeteer.
A different approach was based on an assumption of natural behavior of visitors. After a meeting at the museum, a second concept of *"Interaction by Pointing"* emerged. Later the underlying assumption was confirmed by the observation of visitors' behavior around showcases. Visitors do not only talk about exhibits, but they also point at certain exhibits during interaction with each other. Therefore, a device should be build or utilized for users to point with, enabling them to select a certain exhibit inside the showcase. Additional information about the point of interest would then be displayed in an appropriate manner.
While all involved understood these concepts were fairly comprehensible, their technical realizations were unclear at first. Throughout further investigations, the work turned from testing various modes of input to a more technical approach. Both ways of input revealed different challenges along the way.

Throughout the following chapters I document my proceedings during the development

1 MS Gadgeteer is a modular system of various hardware-components distrubuted by GHI Electronics. It resembles Arduino- and other microcontrollers.

2 RFID-transponders or -tags do not require any batteries, are cheap and robust. In addition, their range is very limited, which allows several tags on one tangible.

of the aforementioned system. Chapter 2 gives background information about the fields of study which are included in my work. Thus, there is a brief outline about the progression of technologies employed by museums, behavior of users around public interfaces and with tangibles. In addition, a brief overview of virtual reality-techniques is given.
Afterwards, I present my goals for the development of this system. Before I come to explain the technical principles and evaluation of my implementations, I give a short review of my partnering process. Thus, Chapter 3 deals with finding a suitable museum for a collaboration.
Chapter 4 explains the whole development-process of the system's functionality. It begins with possible system designs and explains their possibilities and constraints. In the end of Chapter 4, the final concept is shown along with necessary obligations such as an Functional Specification Document (FSD) and the contract between me, the university and the museum.
Chapter 6 addresses the implementation of the system's functionality. Therefore, all libraries and softwares are explained in more detail.
Experimental lab-installations and the final museum-installation are described in Chapter 5. Therefore, measurements, hardware specifications, and other influential criteria are presented in detail.
The final installation is evaluated in Chapter 7, where visitors were observed and interviewed before and after alterations by the system. Chapter 8 then deals with the discussion of the evaluation's findings.
In the end, I discuss potential future work, which could improve, extend, and follow my system. In Chapter 9, I would also like to mention reactions and suggestions I encountered along my work.

2 Background and Motivation

Over time, public places became more and more enriched with all kinds of technology. Nowadays, on nearly every corner something is beeping or blinking and buttons, leavers and knobs make us - their potential users - interact with our environment. This trend does not spare anyone or anything. Even traditionally calm and sophisticated places open up to the possibilities of contemporary technologies.

2.1 Museums

Museums, much like libraries, are foremost seen as a place of knowledge and its preservation. Hence, visitors behave in a very reserved manner. Whilst applying for libraries, museums are willing to involve people instead of merely providing information. Many museums therefore employ guides, who give tours and tell visitors about the exhibits. In addition to their factual knowledge, they also provide interesting anecdotes and other exciting information needed to bond with a certain topic. Apart of instructive and teaching staff, museums have tried many other ways to involve their visitors. One of those is utilizing technology. With time technology evolved, and so did technological augmentations in museums.
The name ”museum” comes from the ancient greek’s ”Museion”. It refers to a sanctified place in honor of a muse [43]. Basically, museums are collections of arts and science or at least parts of them on display. In modern history, those collections were of an artistic nature and mostly private. Later, scientific and otherwise cultural museums were established for the general public [ibid.].
One of the first high-tech installation of the modern age was the *Diorama*. In 1821,

Louis Jacque Mandé Daguerre[3] and the painter Charles Marie Bouton partnered up to develop this spectacle. It is an elaborate combination of painting and lighting [55]. Through ingenious lighting, the paintings became vivid. This way, a diorama could simulate the moods of a whole day within minutes. Thus, it is seen as an early predecessor of the cinema. Even today, although in much smaller size, dioramas are still of certain interest [49].
The first interactive displays appeared at the *Urania* in Berlin around 1889, when they introduces visitor-activated models and a scientific theater. In 1907 the *Deutsches Museum* in Munich also began experimenting with film and mechanical models, which were operated by visitors [37]. Later, other museums all over the world followed. Since then the

> *"[...] wider museological community's understanding of nature and purpose of interactiveness"* [53]

has taken shape.

> *"This understanding almost invariably involves:*
>
> 1. *The presence of some technological medium.*
> 2. *A physical exhibit which is added to the main display.*
> 3. *A device which the visitor can operate, involving physical activity."* [53]

As electronics and microchips evolved, computers became popular and affordable. The technological equipment of museums grew with what was available and new kinds of devices and installations appeared. Today, nearly every museum has a certain guide system such as an audio guide. It either leads visitors through the museum on a predefined course or a visitor can choose the track according to a given code for each included exhibit. In 2004, Chou et al. compared different museum guide systems in various categories, which were considered necessary to provide a user-friendly and informative experience. Expositors, tape machines, CD-players and a PDA were judged. The PDA was most versatile and easy to use system [9] (see Figure 2.1). The described system had the portability of an audio guide, but due to position recognition the PDA would always

3 Daguerre is a scene painter and stage designer by trade. He also is the inventor of the first photographic process called daguerreotypy

present the current exhibit. The system could replace common audio guides and immobile information terminals all together. In addition, it still was able to give predefined tours depending on the user's interests.

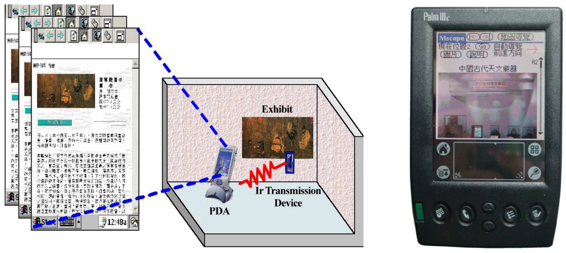

Figure 2.1: A conceptual sketch of the guide system (left) and the GUI of its application on a PDA [9].

Yet another chapter was opened, when the internet and wireless communication were introduced. Museums began to also maintain websites. Burgard et al. went a step further, included robotics and build an autonomous tour-guide robot called *RHINO* [8] depicted in Figure 2.2. It was able to navigate through the museum freely and without bumping into visitors. On demand, RHINO worked as an information terminal for present visitors and it could be used as a tour-guide as well, because it had a simple build-in web interface. Thus, the museum's contents where simultaneously used by the website and the robotic tour-guide. RHINO was deployed at the *Deutsches Museum Bonn* in 1998 [ibid.].

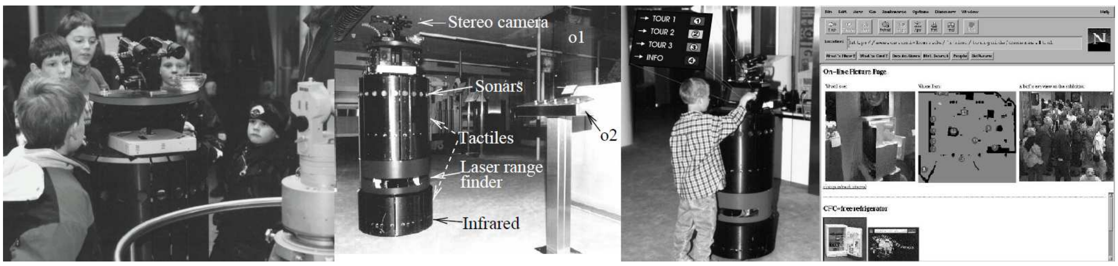

Figure 2.2: An overview of the RHINO tour guide robot [8].

In 2002, a group from the *University of Limmerick* made a survey in *Hunt Museum*. The museum is owned and run by the Hunt-family. Its tradition is to involve the visitors since its early days. Therefor, they had so-called *cabinets of curiosity* [10], special compartments within the exhibition, where additional exhibits were hidden. For example, a curious visitor had to open drawers in order to find a collection of plates (see Figure 2.3). Via this exploration, the visitors became involved. Inspired by their observations, Ciolfi et al. implemented a completely new and interactive part of the exhibition in 2003 [15]. Two new rooms were introduced. First, there was the *study room* with three interactive devices for getting further information about certain exhibits. They were disguised as a chest, a painting and the interactive desk depicted in Figure 2.3. The second room, the *room of opinion*, was plain white with plinths, on which visitors could record their interpretations of the intended function of certain exhibits. In order to manage all the data, a third and hidden room was used to host all the data-servers.

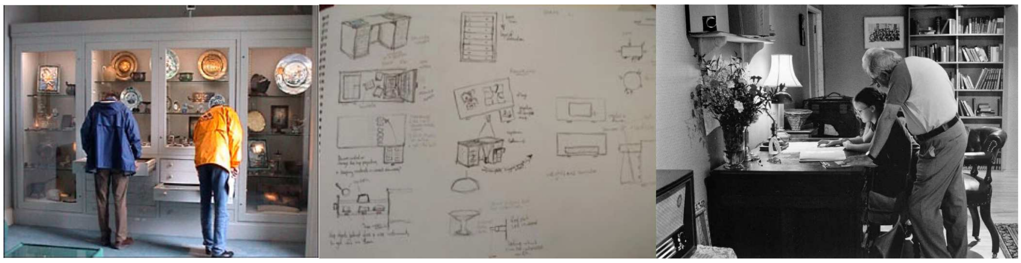

Figure 2.3: Cabinets of curiosity at the Hunt Museum (left) [10] and a conceptual drawing (middle) [ibid.] of the later interactive desk (right) [15].

The *medien.welten*-exhibition at *Technisches Museum Wien* was not only showcasing technical devices from all eras and genres of modern media, it also invited visitors to make use of some. As Hornecker et al. described in [28], throughout the exhibition users were given opportunities to produce their own medial content. The interfaces ranged from an abacus over a telegraph to a whole rebuild of a news-studio from an Austrian TV-channel. Figure 2.4 shows those and other installations.

Figure 2.4: Abacus, news-studio, and telegraph installation at the medien.welten [28].

Visitors of medien.welten could not only use the devices, but also store some of their produced contents in a *digital backpack* [ibid.]. This way, visitors did not only have an exciting experience, but also something to remember it by later.

2.2 Interfaces and Interaction

People visiting a museum come from different backgrounds and in various numbers. There can be large groups like a school class on a field trip or a single person strolling around. Their technical and physical abilities might also vary. Hence, an installation's ease of use, especially in a museological context, is of great importance. Because the interface is the only connection between users and the system, it has to be as intuitive and easy to use as possible. It dictates the way of interaction and, therefore, whether the whole systems works or not. A ground breaking system is worth nothing without proper interaction between its operator and it. This presents the need for suitable kinds of input and feedback. Thus, Ben Shneiderman once introduced his *eight golden rules of interface design*:

1. *"Strive for consistency.*
2. *Enable frequent users to use shortcuts.*
3. *Offer informative feedback.*
4. *Design dialogs to yield closure.*
5. *Offer error prevention and simple error handling.*
6. *Permit easy reversal of actions.*

7. *Support internal locus of control.*

8. *Reduce short-term memory load."* [50]

Following this guideline should yield a well operable interface. However, there still might be particular difficulties for specialized or novel systems. Especially public user-interfaces bring new factors, which are not explicitly included in Shneiderman's rules. How should an interface behave,

- in order to invite users?
- on a user's first encounter?
- if there are multiple users?

The ideal interface should be as intuitive and naturally to use as possible. This requirement was already addressed in 1980 by Richard A. Bolt. He described the *Media Room* at Massachusetts Institute of Technology (MIT) shown in Figure 2.5 as an office with a chair, a wall-sized screen and other analogue or electronic installations. The room's equipment allowed the user to navigate through the *Spacial Data-Management System (SDMS)* called *Dataland*. The user would sit down and had several input-devices at its disposal. One of them was a small device that could measure its position and orientation in space. The device was used to calculate where on the big screen the user was pointing. In combination with simple voice-commands the user was able to create and manipulate geometrical primitives [6].

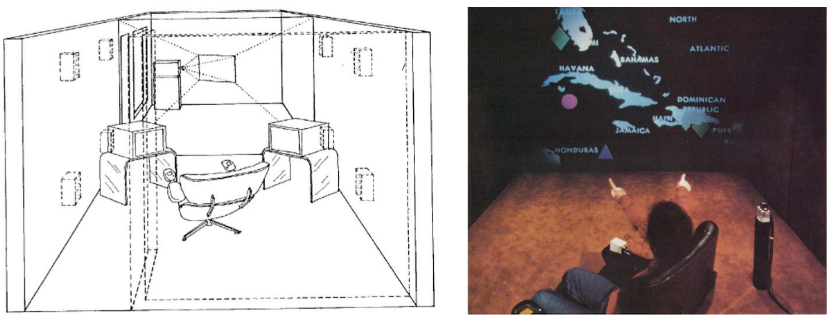

Figure 2.5: Sketch of the Media Room (left) and interaction inside it with free-hand pointing gestures and voice commands [6].

Since then, this seemingly futuristic furnishing could not be established as a common way of interaction. Keyboard and Mouse are still the most widely used input-devices. Meanwhile, touchscreens and voice-recognition are closing the gap though. The principle of "What you see is what you get" (WYSIWYG)[4] became of ever greater importance. Many interfaces are designed with Shneiderman's rules and usability in mind. Developments in Human Computer-Interaction (HCI) seem promising. More intuitive devices and interfaces are developed and tested thoroughly.

There are basically two types of interfaces. A Single-User Interface (SUI) is designed to be operated by only one user, whereas a Multi-User Interface (MUI) can be operated by a group of users at once. However, there is no strict distinction between the two. People might look over a SUI's user's shoulder and give instructions, or a lone person could operate a MUI on its own. Another factor that influences how people use an interface is the occasion. Public interfaces, such as a kiosk system at a cinema or for photo-developing provide a GUI on a touchscreen. Those systems are intended to be used by a single user, but might also be confronted with groups. Azad et al. investigated how groups behave around such kiosks. Most groups approached the interface asynchronously. Meaning, one member is interacting with the system, while the others watch. As time passes, the rest of the group might get more active due to *intra-group communication*. They further observed, that

> *"there is a semantic, profound difference between pointing and touching. Users who point are communicating ideas within a social group and may not want the technology to treat it as input."* [5]

Moreover, inter-group communication is also of great importance. Shyness or frustration may inhibit an individual or group from interacting with a system. Strangers can ease the use, when they act as an example or explain their actions to those shy or frustrated [27].

Interfaces can not only be categorized by their intended demographics. Input- and output-devices dictate the kind of interaction. As mentioned earlier, keyboard and mouse are being replaced with novel technologies. Touchscreens and voice recognition

4 WYSIWYG first came up in the 1970s, when the first office-programs appeared. Due to different resolution-densities of displays and printers, it was necessary to show correct relations of letters and page. Later on, the term was synonymously used for Graphical User Interface (GUI)-elements.

have become established means of input as well. Moreover, novel approaches towards interaction are made and influenced by novel possibilities in technology. Museums in particular strive for innovative interfaces to involve visitors and, therefore, tend to explore many fields of interactive possibilities.

> *"Interactive exhibitions are thriving, encouraged by a new approach to museology developed in response to current social demand and a much more participatory philosophy involving a redefinition of the concept of the museum in general and of the science museum in particular. [...] The classic concept of observation has been replaced by that of participation."* [14]

A Tangible User Interface (TUI) is a very natural approach. Here, a tangible object represents a digital entity. This could be a virtual object or something more abstract like an operation or property. Those tangibles can be used to interact with a system or even each other. In [52], Ullmer et al. described the principle of *token and contraint*, which played an influential role during the conception and is revisited in Chapter 4.2. Two name-giving types of tangibles are involved, tokens and constraints. They have two phases of interaction. At first, tangibles can be associated, which means that their physical shape dictates, whether tokens will or will not work with a particular constraint. After that, the constraint's properties dictate the further way of interaction as shown in Figure 2.6. In comparison to ordinary interfaces a TUI offers more haptic perception. This could increase a user's attention to the interface and as a consequence their involvement with a possibly related exhibit.

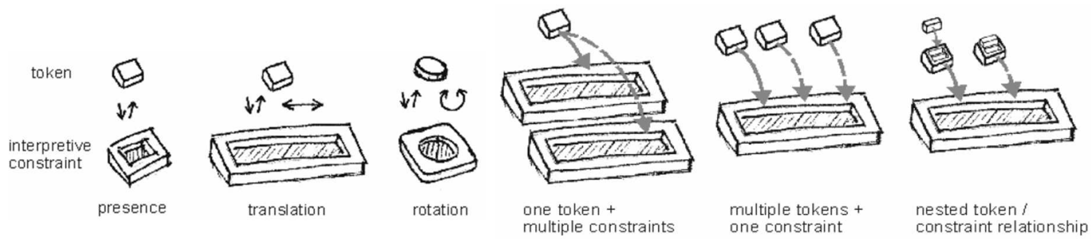

Figure 2.6: Basic and more complex combinations of token and constraints [52].

Apperceptive and playful interfaces might raise visitors' involvement. Groups of visitors tend to spend more time with an interactive exhibit, because the majority wants to make the experience for itself [14].

VR provides a less tangible approach. Contemporary VR-systems offer a way to display and manipulate three-dimensional (3D) data in real-time. Users can be immersed into vast, 3D environments, which are projected on huge stereoscopic displays or shown by a head-mounted display (HMD)[5]. Those systems require a special kind of interaction to either navigate through or select objects in the virtual environment. Therefore, special interaction metaphors were developed. Proper navigation can be realized via any input-device capable of six degrees of freedom (DOF)[6] and is rather familiar. But, since navigating to each object in order to select and manipulate it is inconvenient, a separate metaphor for interacting with objects had to be developed as well. Thus, a pointing device was introduced. In order to calculate its correct position and direction it has reflective markers in a unique pattern, which are then tracked by a system of infrared cameras (see Figure 2.7a) [4]. A virtual ray into the scene is calculated accordingly. Basically, objects can be selected by pointing at them and triggering selection in some way. *A survey of 3D object selection techniques for virtual environments* showed that 29 of 31 reviewed techniques were based on ray-interaction. The remaining two used a hand avatar like in Figure 2.7b. Both of them track a user's hand and one also applies ray-based leverage to extend reach [2].

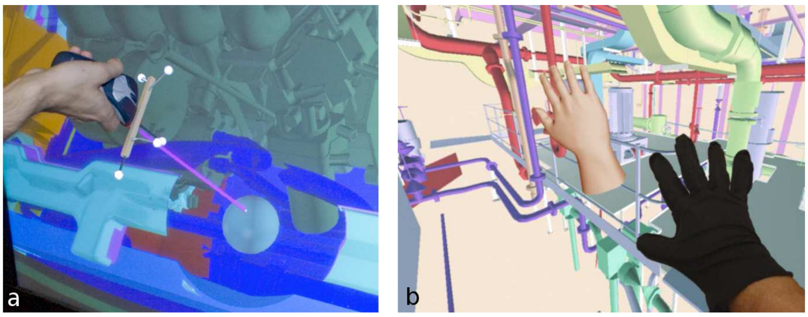

Figure 2.7: a) Pointing device with reflective markers [4]. b) Hand with tracked glove and the respective hand avatar in the VR-environment [2].

5 Recent examples are *Occulus Rift* and *Google Glasses*. While Occulus Rift provides a completely closed solution for VR-environments, the Google Glasses are an Augmented Reality (AR)-approach.
6 One DOF is either translation along or rotation around one spacial axis. Hence, there are six possible movements in 3D space.

As mentioned earlier, keyboard and mouse are established means of input, though there are more natural ways of input though. Humans have been communicating with gestures for ages. With this in mind, *gestural interaction* arose as a concept in HCI. In [35] five basic categories of gesture styles are defined. All those gestures can be applied to two- and three-dimensional interfaces. *Deictic* gestures are defining a location and include all varieties of pointing gestures [ibid.]. They range from the cursor on a desktop PC to the VR-pointing devices mentioned above. *Manipulative* gestures are used for translation, rotation, and scaling [ibid.]. Here, the "pinch to zoom"-gesture for many touch-based devices is probably the most commonly known. More abstract gestures are *semaphoric* and language gestures [ibid.]. They consist of designated signs or movements and can be static or dynamic. The best example for static gestures is sign language. Air traffic controllers use flag waving to guide planes into parking positions by semaphoric gestures. The last category is *gesticulation* [ibid.]. In contrast to semaphoric gestures, gesticulation is purely natural and does not have to be learned. Gestures often appear in combination with speech, why they are also called *coverbial* gestures.

Gestures are naturally motivated. Thus, gesture-based interfaces should be intuitive to interact with. Through the introduction of smart phones and tablet computers touch-based interaction and gesture-based interfaces are getting more and more relevant. In 2003, the *EyeToy for PlayStation2* began to show the possibilities of *free-hand gestures*. A few years later, Microsoft began selling the *Kinect for Xbox 360*. Independent drivers and software for it were developed almost immediately, which enabled developers and researchers to utilize the system's capabilities on regular computers. The official Software Development Kit (SDK) and *Kinect for Windows* followed about half a year later. Other devices like *ASUS Xtion PRO* followed working with the identical internal hardware. The more detailed hardware specifications will be explained in Chapter 4. This development introduced a low cost solution for user-tracking, whilst the aforementioned tracking systems for VR are very expensive. Several interfaces were developed making use of the hardware's potential.
The *Data*^{3} is an interface based in a Kinect sensor to interact with a database [26]. It is an approach to visually handle multidimensional datasets. Therefore, the gestures of a user are interpreted and recognized by a middleware. This middleware then produces events upon which the Data^3-interface changes the view on the 3D dataset or certain properties about it. Although the input data provided by the depth sensor is three-

dimensional, the gestures that are interpretable are restricted to one or two axes [ibid.]. A similar approach is followed by *Kinoogle*, which is a *natural user interface* [7]. Here, several gestures were defined to navigate in *Google Earth* and *Street View*. The four gestures depicted in Figure 2.8 were defined to operate the GUI of Google Earth. Therefore, *panning*, *zooming*, *rotate*, and *tilt* gestures are mapped to mouse and keyboard inputs.

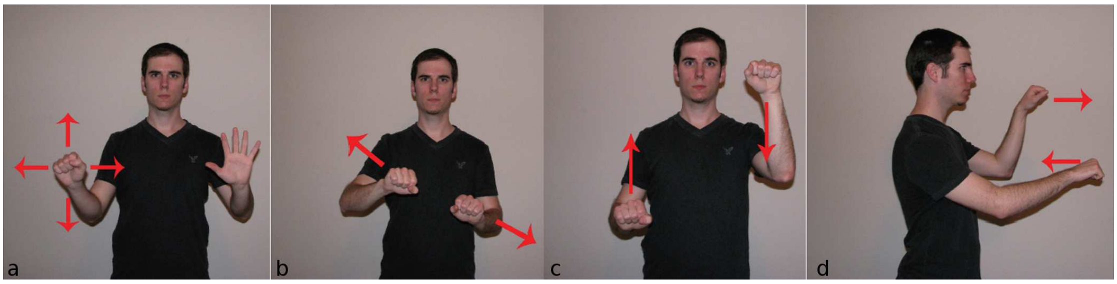

Figure 2.8: Gestures used for panning (a), zooming (b), rotating (c), and tilting (d) maps in Kinoogle [7].

For each gesture, all axes are monitored to recognize an event. However, an event is triggered by certain changes on one or two axes. For instance, the rotation gesture is based on the relation of both hands of the user to each other. Therefore, their x- and y-values are observed and evaluated [7]. The remaining gestures work in a similar fashion. In virtual 3D-environments low cost depth sensors are used as well. Thus, a Kinect can be utilized to track a user inside a Cave Automatic Virtual Environment (CAVE)[7] to calculate correct perspectives for him or her [34]. Figure 2.9 shows a user inside the CAVE once as a standard image and once as depth image.

7 A CAVE is a special VR-setup with multiple screens. This produces more immersion than an ordinary single screen-setup. To provide correct perspectives for a user, its head position and orientation have to be reliably tracked. Otherwise, there might be unpleasant artifacts or even errors between the different screens.

Figure 2.9: User inside the CAVE at HTW Berlin seen with in a normal image (left) and by the depth sensor with the joints of the skeleton tracking (right) [34].

Jung et al. are tracking the shoulders and head of a user. Those tracked points are then combined to form an orientation matrix upon which a *sufficiently correct perspective* can be displayed [34]. If the tracking data is flawed, the perspective is also compromised. Hence, such a system has to be robust and reliable.

As a consequence of these developments, the performance and suitability of low cost tracking solutions for VR-tasks was examined. Ren and O'Neill stated that

> *"More and more information and other content is visualized and manipulated in 3D, bringing a corresponding increase in the importance of effective and usable 2D user interfaces."* [48]

They conducted two kinds of test. First, they looked into two-dimensional (2D) interaction techniques such as touchscreens and *freehand 3D* interaction and described similarities and differences. Accordingly, both techniques' WYSIWYG-approach makes them spontaneous and direct. This natural *walk-up-and-use* interaction style decreases the interaction cost for any possible user. Further, users are able to move freely, because there are no extra devices to pick up and operate [48]. In the second test, the low cost solution was evaluated for common 3D interaction techniques in VR-environments. Thereupon, Ren et al. came up with a *design guideline for 3D freehand interaction* [ibid.].

- Avoid single actions with either high accuracy or keeping the hand up for long.
- Use goal crossing [1] as a trigger.
- Map complex 3D-movements on 2D interaction.

- Use the extra dimension as a trigger.
- Avoid uncomfortable hand or arm positions.

In the end, Ren and O'Neill concluded:

> *"Freehand gestural selection enabled by a single low cost camera is a potentially valuable technique enabling flexible, low configuration interaction in 3D environments, without any requirement for dedicated devices to be worn on or carried by the user. With appropriate designs, freehand 3D interaction can share the appealing fluidity and immediacy of currently popular multi-touch surfaces, [...] enabling walk-up-and-use access to services, holding the promise of wide applications for ordinary users in everyday life."* [48]

2.3 Goal of this Work

After having gathered experiences with several of the aforementioned interaction techniques, I intended to combine those experiences into a unique interface. Especially the intuitive motivation behind tangibles, touch-based interfaces and the immersive nature of VR-environments are interesting fields.

> *"Unfortunately, current user interfaces often lack adequate support for 3D interactions: 2D desktop systems are limited in cases where natural interaction with 3D content is required, and 3D user interfaces consisting of stereoscopic projections and tracked input devices are rarely adopted by ordinary users. The success, both in research and commercial applications, of recent touch-based interfaces raise an interesting possibility. Can the immediacy, control, and expressiveness of recent touch-based natural interfaces be applied to 3D problems?"* [51]

I wanted to answer this question. But before that, several issues had to be dealt with. First, a suitable cooperation partner had to be found. As described earlier, a museum in Weimar was ideal. I needed access to an unbiased audience and topical expertise. Second, we would have to agree on a feasible concept and clarify responsibilities. Subsequently, the system would have to be developed and implemented before the final installation could be evaluated in its real-world environment. Finally, some small adjustments could

be made and larger improvements or augmentations should be discussed.
A museum was found, concepts were made and a TUI or an alternative concept for interaction were required. The *SMSlingshot* already combines a handheld device with 3D interaction to some extend. It is a tangible device, which enables a user to splat short massages onto a facade [17]. The device's affordance is clear, since most people are aware of the functionality of both a phone-sized keypad and a slingshot. Nevertheless, the device can only be used by one user at a time. This is where *Shared Encounters* come into play. There are different types of interrelated spaces, which offer different grades of interaction between a user and either the interface or others [16]. In course of my work, those two key concepts will reappear in more detail.

In the end, my answer was using the most intuitive device there is: a user's body itself.

My focus lied more on the presentation than on the administration software, because it will be used most of the time. Nevertheless, I implemented the whole system to be as versatile as possible and to allow others to use the system almost anywhere. It is not a customized solution for this one installation.

3 Partnering process

The very first step after having the idea of introducing a new way for information to be retrieved in public places was to find a partner to realize it with. In order to find the most promising and suitable cooperation, appropriate properties would have to be defined and considered for each institution before partnering with any of them. Afterward, a suitable exhibit and an agreement on a design for the installation would be found.

3.1 Requirement analysis

To determine an ideal partner for a cooperation, a mutual beneficial system of needs and demands had to be established. Therefore, each party's needs and offerings were identified. As Table 3.1 shows, three major criteria were determined. Possible cooperations would be based on those criteria. In addition, special characteristics would be considered as well.

	Museum	**Me**
Needs	Improvement / Innovation	Access to a public space with exhibits and visitors
	New group of visitors	Authentic content
	Publicity / Awareness	Potential test subjects
Offerings	A public space	Technological expertise
	Factual expertise	Development and testing
	Resources	Motivation

Table 3.1: Needs and Demand.

Museums want to get people interested in their respective topics. Thus, reaching more people and raising awareness is one of their main interests. A good way to attract new groups of visitors is to offer something unique and innovative. Although there are

companies offering services like guide- or information-systems, they are either cosmetic, expensive or high-maintenance. On the other hand, a museum has valuable offerings. Usually, they have a budget for renovation and improvements. The staff is highly skilled and experienced concerning the exhibits and visitors' behavior around them. Finally, a museum offers a public space, where a system can be tested under natural conditions.
The Bauhaus-Universität and specifically the chair for HCI as well as myself wanted the final system to work in a real-life environment, but not as a lab-study alone. Hence, we needed access to a public place in order to reach a broad variety of people. Those would be unbiased toward the nature of interaction and content as well. Meanwhile, we could provide our knowledge of interaction design and the suitability of contemplable technologies. And lastly, I was highly motivated to develop a working system.
After finding a cooperation partner, a FSD would be made, which includes the system's properties ordered by necessity. In addition, a contract between all parties would be drawn up to register each party's contributions and obligations.

3.2 Potential partner museums

According to Museumsverband Thüringen (MVT) [44] there are more than 50 museums in Weimar within a few kilometers distance from the town. Table 3.2 only shows museums registered at the MVT and the three towns with the most of them. Other towns have between one and six registered museums. Further, it is most likely that there are more museums than those in this list. It provides a good starting point, though.

Town	**Museums**
Weimar	26
Erfurt	12
Jena	12

Table 3.2: Museums in and around Weimar.

Regarding the high amount of museums in Weimar alone, it seemed promising to start looking for a suitable cooperation partner right here. Since 26 museums are too many to investigate thoroughly, a preselection had to be made. In the first step, the focus was on flexibility. This meant, only a small administrative apparatus could guarantee fast decisions and less organizational meetings with boards and other decision makers. Hence, all the *Klassikstiftung*'s museums were crossed of the list, narrowing it down to only 10 remaining candidates. Next, and after some further research, museums with less interesting topics or inconvenient concepts were withdrawn. This included the tiny *umbrella museum* and *Weimar Haus*, a place glutted with animatronics. Afterward, the list of candidates was down to five (see Table 3.3). A personal visit to each of these museums was indispensable now.

Museum
Deutsches Bienenmuseum
Kirms-Krakow-Haus
Museum für Ur- und Frühgeschichte Thüringens
Palais Schardt
Pavillon Presse

Table 3.3: Remaining cooperation candidates.

Gathering impressions in person was a process of three stages. In the first stage, I would visit a museum and noted its technical and pedagogical equipment. This was directly followed by the next stage, an informal introduction to some of the staff containing a chat about my plans and the respective person's attitude towards them. The final stage was a formal introduction-meeting between my professor, me and the administrative staff of each museum, that had expressed serious interest. This serious interest wasn't shown by the Kirms-Krakow-Haus and the Pavillon Presse. Hence, the aforementioned meeting only took place at the Deutsche Bienenmuseum, Museum für Ur- und Frühgeschichte Thüringens and Palais Schardt. We introduced ourselves at each venue, because a discussion about what might be done was more efficient directly on site.

3.3 Decision for a partner museum

A formal introduction-meeting went as follows: First, I explained some of my previous projects, related installations in other museums and the general intent of the professor's chair. Next, the staff explained their museum's concept and which subject area they would like to emphasize. After that, we discussed potential concepts. Those ranged from augmentations of existing exhibits to completely new installations.

Deutsches Bienenmuseum The museum is run by the beekeepers association of Thuringia. The staff we encountered was very skilled with the craft of beekeeping, but less professional concerning museum education and design. A part of the exhibition of the museum is shown in Figure 3.1. They listened to my remarks and we had an inspiring discussion about potential topics and their feasibility. Unfortunately, the association's chairman and we could not agree on a specific project. Also, because bees hibernate, visitor attendances are seasonal and also fluctuant. Hence, the Deuschte Bienenmuseum was out of the picture.

Figure 3.1: Impressions of the Deutsche Bienenmuseum.

Palais Schardt The venue is owned by a family, which exhibits multiple collections of art and crafts as well as the building itself. In addition, they operate a cafe and use the adjacent hall for events. The husband is a restorer by trade and gives talks about the building and its historic significance, while his wife handles planning and the cafe. The Goethepavillon shown in Figure 3.2 is the highlight of the venue.

Figure 3.2: Impressions of the Goethepavillon at Palais Schardt.

Further, events at the ball room are regular, and the cafe supplies the venue with casual customers and visitors. Both owners were very interested in a cooperation and had some ideas for installations. But monument protection of the building and minor financial issues complicated the feasibility. Therefore, Palais Schardt also had to go.

Museum für Ur- und Frühgeschichte Thüringens Since the state office for preservation of historical monuments and archeology of Thuringia is the bearer of the museum, all personnel is very competent at their field of work. In addition, the museum employs special staff, that maintains the exhibition, gives tours and is present for arising topical questions during opening hours. Classes of 5th and 6th grade visit regularly for field trips as well as visitors from all age groups. The exhibition was already altered by several media installations. Moreover, the director was very enthusiastic from the first meeting on and had several ideas, of which exhibits to emphasize.

Figure 3.3: Impressions of the Museum für Ur- und Frühgeschichte Thüringens.

Summarizing, the Deutsche Bienenmuseum and Palais Schardt were deemed less interesting and lacking feasibility. The Museum für Ur- und Frühgeschichte Thüringens was chosen as the cooperation partner, because it checked the most boxes of the previous Requirement Analysis (see Chapter 3.1), while the others lacked at least once in the *Needs*- or *Offerings*-category. It was the most professional and ambitious candidate with promising resources and conditions.

4 Concept Development

After the *Museum für Ur- und Frühgeschichte Thürigens* was chosen as a partner, all previous ideas had to be analyzed more thoroughly with feasibility in mind. Thus, impractical, and too complex or too simple ideas were eliminated in two rounds of review. At first, vague ideas were either improved or discarded. Hence, a screen displaying only information about a fossilized fireplace was eliminated. The idea of a system for digitizing stone carvings was considered too complex to realize and therefore discarded as well. Afterwards, some of the museum's staff and I looked at the contents, that could be provided for the remaining candidates. This left us with two remaining possibilities, that were promising enough from an educational as well as a technical standpoint. The first one was the reproduction of the *Fürstengrab von Haßleben*, which contains replicas and original artifacts from a 1700 year old grave of a Teutonic princess. A close second was a workshop, which should have shown how archeologists and restorers work behind the scenes of a museum. Here, the latter consisted of too many single parts and a lot of questions remained unanswered.

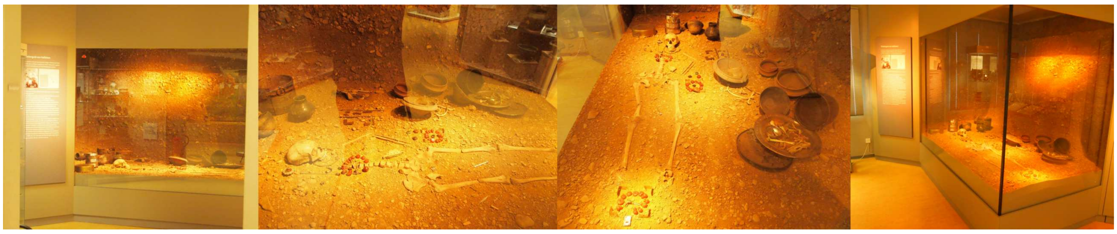

Figure 4.1: Haßleben-showcase prior to the installation of the IMI-system.

According to the aforementioned review, the Fürstengrab von Haßleben was most promising and therefore chosen in the end. It contains many special relics from ordinary, Teutonic pottery to rare, Roman coins and jewelry. There are original artifacts and replicas on display inside the showcase, which I am collectively referring to as *exhibits* throughout this work. Some of these exhibits inside the showcase can be seen in Figure 4.1. The apparent eclecticism is, what makes the grave so special though. It is a sublime showcase for thriving trade and cultural exchange between Teutons and Romans as far east as Thuringia. Further, it proves how Teutons began adapting roman traditions, such as burials. In order to emphasize this insight, an interactive system was to be developed. Unfortunately, the showcase is located on the second floor. Thus, it does not get the attention it deserves. People are often tired after having visited the first floor. Hence, the museum's staff asked for an installation that would reactivate the visitors' attention.

4.1 System Preconditions

The system was to be developed and tested by me, and the museum-staff is responsible for its future maintenance. The full range of visitors' backgrounds cannot be foreseen. Some visitors might not have the proper technical experiences to operate contemporary interfaces. Consequently, it was crucial to design the system with that in mind. It had to be operable by absolute lay persons, who have no prior experience concerning information technologies. Hence, the interface had to be as intuitive and natural as possible. Four major points had to be considered.
First, established and abstract input devices, such as keyboard and mouse, had to be replaced by something more natural. In order to be intuitive, the interaction was designed to capture and use the natural behavior of visitors. Outputs, on the other hand, had to be as discreet and as conservative as possible to not disturb or interfere with the exhibition. Thus, invasive technologies such as speakers and animatronics were excluded by the museum from the beginning. This consideration only left visual and haptic channels for output. The third point was, that daily operations at the museum were not to be compromised. So, it was not possible to develop the prototype inside the Haßleben-showcase itself and a full-size mockup had to be build somewhere else. Furthermore, the showcase and its precious exhibits had to be protected from any possible decay and nothing was to be rearranged. Thus, I measured the showcase and acquired a room

in which a mockup could be placed for the prototype's implementation and testing[8]. Finally, the system's components, in- and output devices, had to be robust enough to cope with daily use. Moreover, they should also stay in their intended place. This meant that they had to be somehow attached to the showcase.

In summary, the requirements for the final system were narrowing down the possibilities right from the beginning. Hence, we came up with several ideas and followed up on all of them, until one promised to be the most feasible.

4.2 Concept Constraints

Developing the system, we followed two initial approaches. They were supposed to lead us to an intuitive, easy to use interface, which would be very naturally operable. The first concept featured the development of tangibles. Interactive objects would be placed outside the showcase and visitors would be able to interact with them. Haptic feedback would enable visitors to experience the exhibits in an unusual way. By touching replicas of otherwise locked up exhibits a deeper involvement is highly likely. Meanwhile, the other concept was based on gestural interaction. With this concept, visitors are enabled to interact with the showcase by pointing. This approach was based on the natural behavior of visitors. Like the previous approach an uncommon experience should raise visitors' involvement and attention.

Tangibles The early idea behind this work was to work with MS Gadgeteer to develop a tangible interface for and with a museum. Thus, we first thought about how to include those Gadgeteer-modules. Therefore, I built the demo device shown in Figure 4.2, which was based on a *FEZ Spider Starter Kit* [20]. In addition, it utilized an RFID-reader [22] and a potentiometer [21]. The RFID-transponders were attached to an old 2,5" Hard Disk Drive (HDD) and a wireless mouse. When the RFID-tags were recognized, an image of the object was displayed on the screen. By turning the potentiometer's knob the angle of view changed accordingly. This gave an impression of the possibilities of the hardware. Unfortunately, we only had two RFID-tags that had the size of a credit

8 For a further description of the lab-setup see Chapter 5.5

card. After some research though, I found some tags for the correct frequency band and in sizes from a grain of rice over credit cards to key chains [29]. Hence, including RFID-tags in tangibles was feasible.

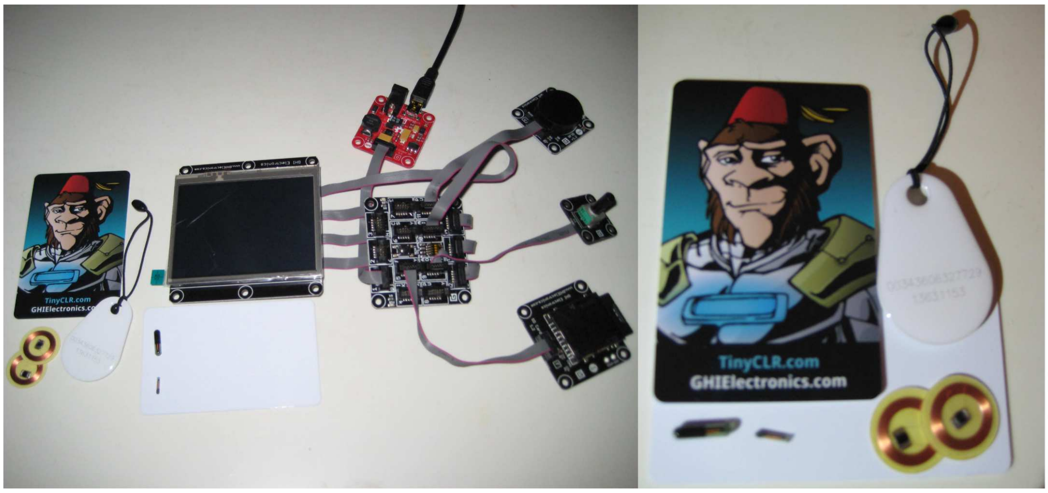

Figure 4.2: Gadgeteer-device for demonstration with various RFID-transponders.

The shape and size of the tangibles were still up for debate. Another point was, whether the hardware would be placed inside or outside the tangibles. This decision dictates the shape and size of the tangibles and therefore the interaction. If it would be placed inside, the tangibles would have to be big. They would have turned out at approximately the size of a box of milk. Such an *active tangible* would be handy and a whole system could be concentrated in one device. On the other hand, they would be prone to damage and maybe even theft. Hence, the tangibles would have to be tough and in some way attached to the showcase. In addition, batteries would have to be either charged or changed. This would take a certain amount of maintenance.
With the hardware outside the tangibles and hidden in a pedestal in front of the showcase, the tangibles could be smaller. Moreover, *passive tangibles* grant more flexibility concerning the shape as well. As described earlier (see Chapter 2.2 in [52]), the tangibles could have different features depending on certain properties. In this case, several RFID-tags could be placed in each tangible. Depending to their *constrained* collocation on the RFID-reader, different reactions of the system could be triggered. In contrast to Ullmer at al., 2005, though, this affordance would be hidden and thus less obvious. The

tangibles would have to be attached to the pedestal as well, although they would be less expensive to replace.

Both approaches had their advantages and disadvantages and none of them was concrete enough to make a decision. Thus, we continued to specify the concepts depending on their strengths and weaknesses. We did this, by anticipating probable relations between the exhibits inside showcase and the behavior of visitors behind the glass. There are several things visitors tend to do, if they are interested in an exhibit. They would like to inspect it up close. First, this means they would like to touch an exhibit and feel it. Second, they want to see it in more detail and from different angles. Next and induced by restrictions, visitors talk about an exhibit or request further information. This could be anything from its age to where and how it was found.
An active tangible could provide nearly all of those qualities in one package. It could - like the demo device - be fitted with a display and an RFID-reader. The corresponding RFID-tags could then be placed close to the device in order to trigger a particular output. Those outputs could be saved either on the device itself or provided by a server. The question of how to trigger different reactions was to be answered next. The device could either be placed on a pedestal equipped with RFID-tags or the tags had to be brought to the reader in any other way. As mentioned earlier, an active tangible would be sizable and it would have to be related to the showcase's topic as well. Hence, it would be reasonable to combine those two criteria and fabricate enlarged reproductions of exhibits from the showcase. In order to fit the whole hardware, an active tangible would have to have a simple shape. This unfortunately excluded several of the more interesting exhibits, such as coins, a golden ring and other jewelry. Some options remained though. There was a skull, pottery and the metal remains of two jewelry boxes.
The passive tangibles did not appear to cause this much consideration. Any exhibit could have been 3D scanned[9], turned into a digital model, appropriately altered to fit an RFID-tag and then printed or milled out. The printed or milled reproduction could be used as a positive to produce casting molds, afterwards. Thus, replacing damaged or otherwise lost tangibles would be more cost-efficient. In addition, it could be done by the museum-staff themselves. One or more RFID-readers could be placed in a pedestal

9 The scans could have been done in the labs of the chair of Computer Vision and Engineering at Bauhaus-Universität Weimar.

in front of the showcase. Depending on the RFID-reader and a tangible's tag, the system would display the corresponding output.
During those considerations, a third possibility came up. A hybrid approach that combined both principles was possible as well. The reproduction of a jewelry box could be turned into an active tangible and passive tangibles could be put inside to trigger an output. The RFID-reader would be placed underneath the box's floor and the display in the lid. In order to provide different types of content, we thought about also producing two different types boxes. A more or less *authentic reconstruction* made of wood and metal fittings could provide authentic information about a passive tangible's cultural background. Meanwhile, the other box could be constructed of transparent material, which would allow the user to see the hardware. This *futuristic reconstruction* could provide statistical content for the same passive tangible.

However, the main problem remained with all approaches. Some kind of pedestal would have to be built and placed outside the showcase to hold the active and/or passive tangibles. Although passive tangibles would have been more cost-efficient to replace than active ones, maintenance was rated too high. Furthermore, if the pedestal was not to obscure the showcase, it would have been too low[10] to grant satisfactory access for any visitor.

Pointing The alternate concept took a completely different approach. It was more related to VR and the interaction in 3D environments, where users are pointing at an object to select it [2]. The underlying idea was to develop an information system that would be based on pointing-based interaction. A user points at an exhibit inside the showcase, the system recognizes the gesture, calculates the intended target and displays the corresponding information.
Since the display should not interfere with the exhibits or occlude them, we had to make decisions about the position, size and type of the display. In order to not occlude exhibits, the display should not be placed in front or above the exhibits. Directly behind the glass panel would also have been problematical. It should have been placed along the visitors' viewing direction as they already would be looking into the showcase. This way, it would still imply coherence through visual proximity. A monitor on the one hand,

10 The height of the showcase floor is about 65cm. For more details see Chapter 5.

and a projector on the other were two possible technologies to choose from. Both came with their own challenges. While a projector would have been easier to conceal than a monitor, a monitor would produce less heat and noise. Because most of the visitors approach the showcase from the long side and tend to stay there for most of the time, the display should be visible from this direction. This meant placing the projection plane or display on the opposing wall. Another solution for a projector came up during this consideration. A Polymer Dispersed Liquid Crystal (PDLC) switchable film [33] could have been placed on the glass panel. Whenever the system was activated, the film and projector could have been activated as well[11]. Unfortunately, this solution would have been too expensive and difficult to install. A projection in the other direction was also disregarded, because the cost and heat issues caused by a projector were considered to high. Heat produced by a projector causes issues regarding the artifacts' conservation and is a safety risk for the sealed showcase. Therefore, we decided to install an LED-screen. It should be placed inside the showcase close to the exhibits.

Object selection in VR-environments [2] and the *SMSlingshot* [17], nearly always use a *pointing device* of some sort. With such a device, a potential user could directly point at the original exhibits within the showcase and trigger the corresponding reaction of the system - displaying related information. As described in detail in Chapter 7.1, I observed interactions between visitors and the showcase as well as between each other. During the pre-study, it turned out that visitors often pointed at the particular exhibits they were talking about. The interface could be designed to emulate this natural interaction between visitors and incorporate of the natural behavior.
The first intention was to rebuild the SMSlingshot with Gadgeteer-hardware. The tangible was equipped with a microcontroller, a small display, a keyboard, a green laser, a wireless transmitter and of course batteries. A PC was used to put all the information together and render the output. Therefore, it had a camera to track the point a user was aiming at and a corresponding transmitter to receive the fired messages [17]. All those modules could be provided by Gadgeteer except the laser. A laser could have been controlled with a *Breakout module* [18] and a relay. However, shooting a laser into the showcase was a delicate issue. Hence, this solution had to be revisited, because for safety

11 A PDLC switchable film can be switched between a transparent and an opaque state. In its opaque state, it can be very well be used as a projection surface [33].

reasons it was not feasible. There could have been injuries of visitors' eyes or some of the precious exhibits might have reacted to the laser's energy in a corrosive way. We did not want to take those risks, but we were very keen on the idea of pointing interaction. Thus, I looked for other tracking methods. We could have used a tracking system similar to the aforementioned ones used in VR. Those systems are expensive to install and maintain, though. Moreover, a proper compatibility with Gadgeteer was doubtful. So, I started looking for alternatives to Gadgeteer, too. Two established systems immediately came to mind. First, the *Nintento Wii*, which uses a wireless device with pointing capabilities and additional inputs. Second, the *MS Kinect*, which is able to recognize free-hand gestures and might not require any device. Both are comparably inexpensive to acquire, have experienced support and communities and use less dangerous infra-red (IR) light. The decision between the two was made according to the same criteria as mentioned above. Pointing with no device should be a more intuitive way to interact with the exhibition and other visitors than any handheld device. Furthermore, the restraint to use the system should be reduced. No tangible or pedestal would have to be created and attached to the showcase, which decreased cost for maintenance. Hence, the MS Kinect was chosen.
There is a Kinect for MS Windows along with a special SDK for MS Visual Studio. As it turned out, the hardware inside the MS Kinect was developed by *PrimeSense* and is also used by the *ASUS Xtion PRO*. This 3D-sensor is less expensive and smaller, which allows to be less intrusive inside the showcase. Besides, we already had some of them at the faculty, which meant that I could start developing right away. Another change was the decision for an open source SDK called *OpenNI*[12], which in combination with its add-on *NiTE* enabled me to use *skeleton tracking*. This was critical for my approach, because I needed to have a 3D vector in order to be able to calculate where a user was pointing. Skeleton tracking would deliver the joints of a tracked person. Hence, I was able to retrieve the directions a limb is oriented in. If this vector was extended, I was able to calculate its possible intersection with an exhibit. More about used software and the exact calculations can be found in the next chapter.

The last topic that needed addressing was *feedback*. Since there would be no haptic or

12 OpenNI was co-founded by PrimeSense, a hardware developer that produces 3D sensing hardware. In November 2013 PrimeSense was bought by Apple, whereupon OpenNI was shut down.

acoustic feedback, and no *glowing dot* produced by a laser either, future users would need another visual feedback in order to be able to see where they were pointing and determine how to correct that. Once more, Gadgeteer could have provided a solution. Our first idea was to replace the laser's dot by a spotlight. The system would calculate the position a user was pointing at and transmit it to a Gadgeteer-system. It would then move a special highlight to this position within the showcase. Only two actuators would be sufficient. The maintenance of this kind of installation could become very complicated though, because the system would have to be installed on the ceiling of the showcase. Actuators need to be calibrated regularly and mechanical gearing will wear out. Hence, this realization concept was dismissed. Nevertheless, the principle should remain the same. Thus, the aforementioned position would now be shown on an overview of the showcase on the display.

4.3 Final Concept

The final system consists of a *depth sensor*, a *PC* and a *display*. All of the hardware is placed inside the showcase. In addition, an active tangible to remotely activate and deactivate the system should be developed as well. It was only intended to be a feasibility study, which determines if and how active Gadgeteer-tangibles might be incorporated into the system, later. Suitable components were recommended by me and provided by the museum after to mutual agreement.

The system requires two pieces of software. The first software is of an administrative nature and allows the museum staff to define and maintain the whole exhibition. The second software is presenting the exhibition to the visitors. Previously defined exhibits are selectable.
The exhibition can be defined by museum-staff themselves. Therefore, an exhibition plane has to be defined and validated first. After that all the exhibits' positions on the plane can be defined and validated. Those positions can be defined in the same way users later interact with the system, by pointing. To exclude a certain inaccuracy when defining a position, it would have to be defined from different angles and validated afterwards. The whole process will be described in Chapter 5 and the technical execution in Chapter 5.3. Furthermore, the corresponding contents such as explanatory texts and

detailed images are provided by the staff. Contents and positions can be changed, removed from or reloaded into the exhibition.
When one or more visitors enter the area in front of the showcase the system recognizes them and reacts in an inviting fashion. A defined interaction space enables the user to interact with the system by pointing at an exhibit. No devices outside the showcase are needed.

Functional Specification Document (FSD) The final concept all parties agreed on was written down by me in an FSD and responsibilities were covered by a contract. The document states, which features of the final system must, should and must not be implemented and working.
The necessary features or *must-criteria* where that the the system would have to have separate modes for administration and presentation of an exhibition. The visual feedback of the interaction would be provided by the display. Visitors would be automatically recognized by the system, but only one user at a time would be able interact with it. The whole system would be maintainable by the museum's staff and will start and shut down automatically.
Preferable features *should* be realized, but would not be mandatory. Thus, there should be a system's manual. For guided tours, it should be further possible to switch the system into a 'blind' mode, where it does not react to people. Extensive exhibits should have a slide show. The system should be operable with either the left or right hand. In addition, statistics about the system's use should be logged for later analysis.
There were also criteria that were not requested, and therefore *must not* be implemented. Any free-hand gestures other than pointing must not be recognized by the system. Further, the lighting inside the showcase must not be controlled or influenced by the installation. Feedback has to be only visual and not auditive or haptic. Hence, speakers or tangibles must not come to use.
Furthermore, the FSD describes system requirements concerning hard- and firmwares, data formats and other organizational parameters.

In addition to the FSD, a contract was drawn up by the university's layer's office. It sorted responsibilities and was later signed by the museum's director, my professor and me. Both documents can be found in the appendix.

5 Processes and Setups

In this chapter I will describe the system in detail. This involves the *interaction paradigm*, the *interface designs* and the *technical principles* behind the system.

5.1 Interaction with the IMI-System

Presentation Software One or more visitors can be involved in a typical *presentation scenario*. At the moment they enter the room of the showcase, the IMI-system recognizes them and changes its appearance. The screen displays a short and explanatory text about how the system should be used. In addition, an ideogram visualizes the description by showing a figure pointing at a plane in front of it. This view can be seen in Figure 5.1. If there are no visitors present or detected, the screen disguises itself by displaying an image of the showcase's background. Because the system can only be used by one person at a time, there is a dedicated spot that the system observes, and footsteps invite visitors to stand on it.

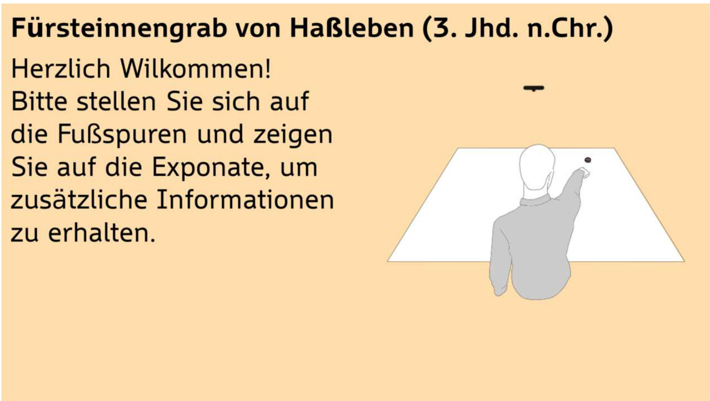

Figure 5.1: Ideogram that describes the interaction upon recognizing and inviting visitors. It shows a figure pointing at a spon on a plane in front of it.

In [16], Fischer at al. describe a variety of spaces around large, public, and interactive installations. I used an adapted approach to initiate interaction between visitors and our installation. Hence, the area in front of the showcase could be interpreted as an *activation* or *potential interaction space*, because at least the system reacts to the visitors' presence and shows itself. This is the initialization of a possible interaction. Here, the *interaction space* is predefined and thus there is no *potential interaction space* [16]. Other spaces such as *gap* and *social space* are also available (see Figure 5.2).

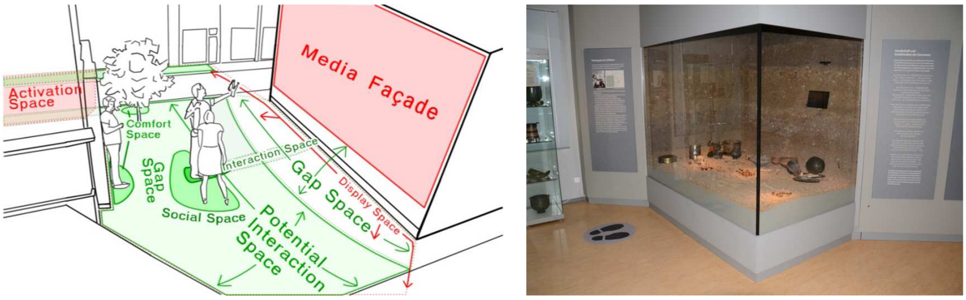

Figure 5.2: Various spaces of interaction with a public interface (left) [16] and the footsteps in front of the Haßleben-showcase.

Once a user enters the interaction space, the system reacts again. This time, the screen will show the outlines of the exhibits inside the showcase. The position of each selectable exhibit is semi-transparently displayed over the outlines. Now, the user can point at exhibits of interest. The system will track a user's movements, and will calculate the position he or she is pointing at. This position is also overlayed on the outlines as it is depicted by Figure 5.3. To be distinguishable, exhibits' positions are highlighted in blue, while the current pointing position is red. This visual feedback can be used to correct gestures in order to 'hit' an intended target.

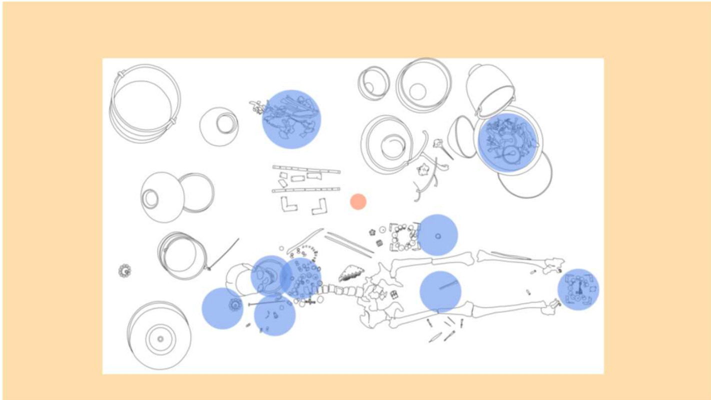

Figure 5.3: Navigational overview of the presentation software of the IMI-sytstem.

An exhibit is selected after the user constantly points at it for over half a second. This *dwell time* prevents unintended selections. Otherwise, any exhibit would be immediately selected, whenever a user's pointing position strokes over it. After selecting an exhibit a corresponding description is displayed alongside detailed images of the exhibit (see Figure 5.4). While the text remains stable, the images are displayed as a slide show. Afterwards, the system goes back to the exhibition's overview again. The user does not have to end a slide show and can wait until it is over or select a new exhibit while the slide show is still running - without visual feedback though.

Figure 5.4: Presentational view of the box brooch (Dosenfibel) of the Haßleben-showcase.

If a user is done or others want to try the interface out for themselves, users can change any time. They only have to switch places on the footsteps. The same applies for ending the session. Visitors can leave at any point during the interaction. As soon as the system does not recognize any visitors around the showcase anymore, it goes back into its disguised appearance again. Again, no additional input devices are needed except people's natural behavior.

Administration Software An *administrative scenario* is more traditional and requires a keyboard and a mouse. Nevertheless, it also makes use of pointing gestures. This software can be used by one experienced staff member alone. But the ones that are less advanced might need a second person's assistance. The administration software can be used to create and edit IMI-exhibitions. Therefore, all necessary data can be defined with it. This data is saved in *configuration files* of XML-format. These files are used by the presentation software and can be reloaded for editing by the administration software. Expert administrators can make changes with a text editor as well.
An exhibition consists of two main components. Both the *exhibition plane* and the *exhibits* are defined by pointing. Upon the application's start, an existing exhibition can be loaded or a new one can be created by naming it. In case of a new exhibition, the first thing to be defined is the exhibition plane. Therefore, the administrative user again has the choice to either load an existing plane or define a new one. Should the admin decide to define an exhibition plane, the procedure will be explained in a short instruction, before the calibration begins.It tells an admin, to point at three of the planes corners from three different positions. Further, the administrative user is told to follow the instructions during the process. To start the procedure, the administrative user has to be recognizable by the sensor. In addition, ideograms like the ones in Figure 5.5 depict the positions to go to and the corners to point at and are shown during the process. Once the process is started it will guide the admin from position to position and corner to corner in fixed intervals between three and five seconds. After having pointed at the corners once, a second run is needed to validate the corners' positions. This is necessary, because a position could be defined wrong. If the validation is successful, the exhibition and its plane are saved. The second main component are the exhibits. They can only be defined or loaded, if a raw exhibition with a valid exhibition plane is already available. The definition of an exhibit's position is similar to that of the exhibition plane's corners.

The admin points at the respective exhibit on the earlier defined exhibition plane from three different positions. Afterwards, the position is also validated. If it validates, the position is saved. If it does not validate, the definition and validation has to be repeated all over again. Another validation round is not sufficient, because the first defined corners or position may be flawed.

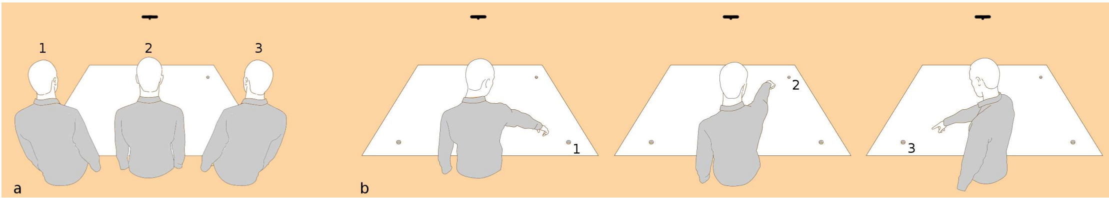

Figure 5.5: Three different pointing locations merged into one image (a), and pointing at three corners from the second pointing location (b).

Another necessary setting is the prospective *user position*. It is one of the exhibition's settings. The admin can choose the option to define the user position from the drop-down menu and confirm with a button press. Subsequently, the administrative user gets the instruction to stand where future users are supposed to be in the interaction space. After confirming and a short wait to get into the user position, the software will safe the user position. For this definition, the hip-joints of the admin are used. This happens for several reasons. First, these joints are visible most of the time. Second, they are not involved in free-hand pointing gestures. Finally, a user might move his or her torso during the interaction, which could then be misinterpreted by the software.
Only visitors standing close to this spot will be able to use the system. When defining the user position, there should only be one person in the scope of the camera.
The remaining parameters of both exhibition and exhibits have default values, which can be edited later. There are specifically labeled buttons, which lead to the corresponding drop-down menus. Only the exhibition plane cannot be changed this way.

5.2 Interfaces of the IMI-System

Presentation Software There are no conventional control elements like buttons or menus in the GUI of the presentation software. It only has four different states.

The first one is the *standby state*. It is active, if no person in front of the showcase is recognized. The corresponding view's task is to mask the system. Therefore, the screen will only show an image of the showcase's background in order to disguise itself.
The next state gets activated, if visitors are present and none of them is inside the dedicated interaction space. This *introduction state*'s task is to make visitors aware of the systems presence and invite one of them to interact with the installation. As shown in Figure 5.1, only a short introduction and an ideogram are needed to explain how the system has to be used. In order to seamlessly integrate into the general style of the museum, the font was chosen to be the museum's corporate font. Further, the background color was chosen to fit with the ambient color of the showcase, and to reduce the contrast between text and background. Moreover, the font size was increased to ensure readability. The associated calculations can be found in the next chapter.
The system gets into its third state as soon as a user is inside the dedicated interaction space. It can be described as an *overview state*. Figure 5.3 shows the selectable exhibits' positions on top of all exhibits' outlines as blue ellipse and the user's pointing position as a red dot. While the exhibits' positions are always marked, the red *feedback position* only appears, if a user is really pointing at that particular spot of the exhibition plane. Otherwise, the red dot will not be shown.
The fourth state is the actual *presentation state*. It is similar to the introduction, but here the text and images depend on which exhibit had been selected. The corresponding texts are limited to approximately 300 characters for two reasons. Because the screen space of the text is restricted to half the display, readability would suffer for more characters[13]. The second reason for this character restriction is that visitors do not have to read extensively long descriptions. Meanwhile, detailed images of the chosen exhibits are displayed on the right half of the screen (see Figure 5.4). They change every four seconds. The time an image is shown can be adjusted either by the administration software of by hand. After all images have been shown, the system will go back to any of the previous states. Where it goes depends on the visitors behavior. If a user is detected in the interaction space, the system will go to the overview. If there are visitors present, but none of them is inside the interaction space, no one qualifies as a user and the introduction will be displayed. As soon as every potential user left, the system will

13 Further explanation of this matter can be found in Chapter 5.3.

go into standby and hide again - even during a presentation.

The administration software is used to manage all data of an IMI-exhibition. Hence, the interface has to be more complex than that of the presentation software. It is more conventional, too. The amount of different views is low, though.
Since it has to be usable by lay persons, similar tasks share a *view pattern*. For instance, settings of an exhibition and an exhibit have identical controls in an identical layout. Only the header of the views and the contents of the drop-down menus vary as can be seen in Figure 5.6. The same principle applies for any definition of positions. No matter if the corners of an exhibition plane, the position of an exhibit or even the user position are defined, the view is always the same.

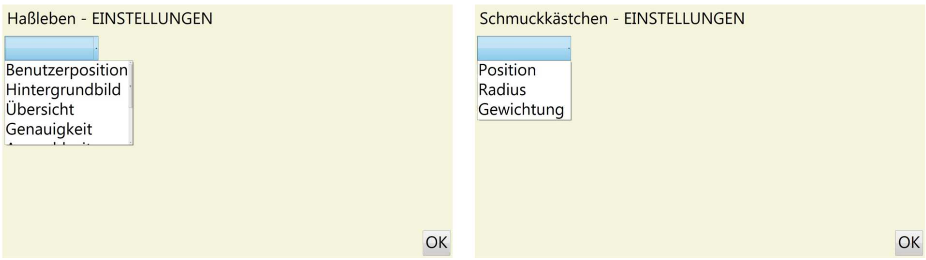

Figure 5.6: View of the settings for an IMI-exhibition (left) and an IMI-exhibit (right).

The interface is designed for task-driven use. This means, that an administrative user probably will have a particular reason to use this software. Such a task includes changing a particular property. Hence, the GUI offers the user to navigate to this property step by step. Therefore, a hierarchical structure is used, which results in less control elements in one view and thus more clarity. There is less choice but a little more actions. For example, an exhibit should get an additional image. A user loads the exhibition, chooses the exhibit from the drop-down menu, chooses "New Image" from the drop-down menu and confirms with a button press. After that, a dialog opens and the user can choose the image to be added. Finally, the image appears in the images' drop-down menu. Images can also be deleted from the exhibit by choosing an existing image and pressing "Delete". From this view, all other properties of the exhibit can be set. By pressing "Back", the GUI goes back to the exhibition's view and the next task can be attended.

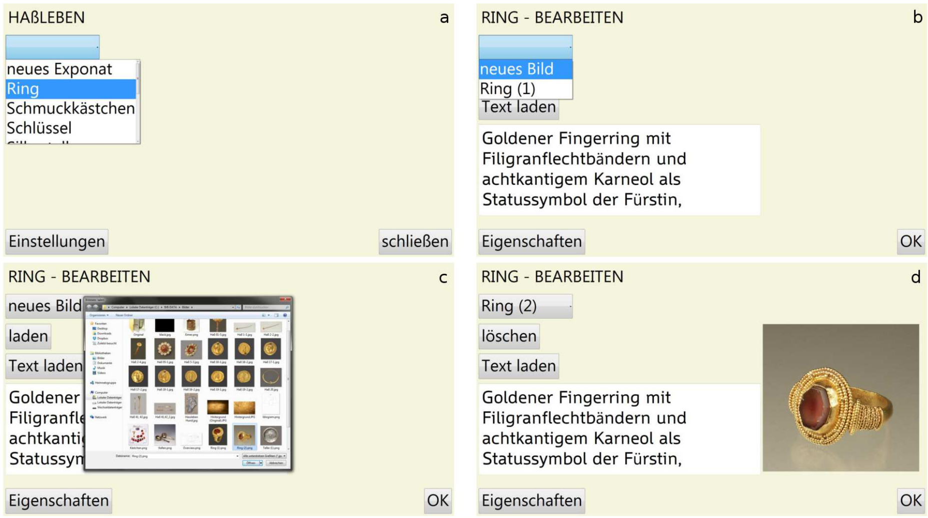

Figure 5.7: Selecting an IMI-exhibit (a), choosing ”New Image” (b), choosing an Image (c), and the image is a new part of the IMI-exhibit (d).

Every time anything is changed, it is immediately saved. There are no undo- or redo-buttons. They are not necessary, because the GUI always shows the current state of all parameters and they can be changed with no more effort than using such a button. Moreover, more control elements could cause confusion. This is why only controls that are required at a particular stage are visible. Nevertheless, there is always the option to go back to the higher level menu.

5.3 Technical Principles

There are certain technical principles, which the system's performance relies on. They range from operations necessary for fundamental calculations to background knowledge involving a proper interface design.
As explained in Chapter 2.2 Ren et al. introduced their *design guideline for 3D freehand interaction* [48].

Pointing Challenges Visitors can walk up to the showcase and point at exhibits. These exhibits are lying on an exhibition plane. A plane, although usually flat and only 2D, can be defined by three Points in 3D space. Thus, to define three corners of the exhibition plane, a way to define a point in 3D space was needed. Therefore, I chose the same type of input visitors would later have to use as well. Each exhibition plane's corner is defined by pointing at it from various positions. To calculate where a person is pointing at, the system needs a vector. A vector can be determined by two points in 3D space. One defines the start and the other the direction.

After observing how people point, the elbow was chosen to be the start of the pointing vector. The pointing direction would be determined by the hand[14] as Figure 5.8 depicts.

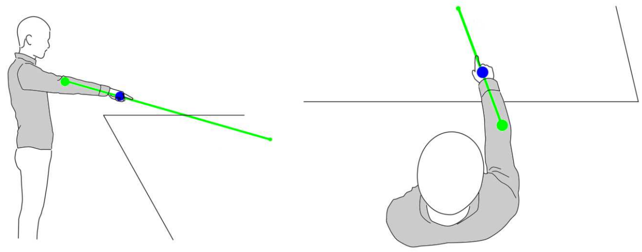

Figure 5.8: Basic principle of free-hand pointing gesture as seen from the side (left) and top (right).

In order to define a point in 3D space, one vector was not sufficient. But, if two or more vectors would target the same point from different angles, their intersection should yield the targeted point. Figure 5.9 shows this concept. Hence, a the point of their intersection could be calculated by equating both vectors.

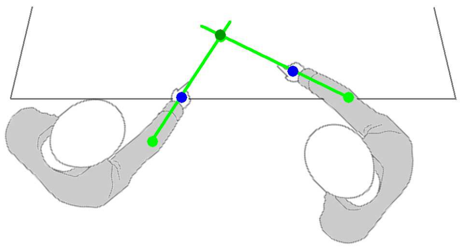

Figure 5.9: Vectors from two different pointing locations intersecting each other in 2D.

14 NiTE's skeleton tracking provides both of these joints, but does not support the tracking of fingers. More details about the implementation can be found in Chapter 6

However, this is a 3-dimensional problem. The possibility of vectors intersecting in 3D space is very low. They are mostly skew, and only their projections on a 2D plane do actually intersect. Nevertheless, there is a solution. Vectors may not intersect, but there is an area where they are closest to each other. Consequently, there is one point that is closest to both vectors. This quasi-intersection is called *pedal point*. It lies in the middle of the shortest line that is perpendicular to both vectors [11]. In case both vectors do meet, pedal point and intersection are equal. Figures 5.10a and b illustrate how the projected intersection and pedal point can vary.

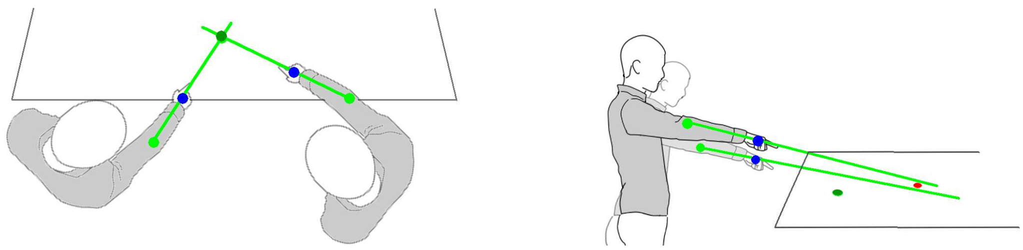

Figure 5.10: Top view of the position of a 2D intersection in dark green (left) compared to the side view of the pedal point in red for the same pointing vectors (right).

The final point in 3D space gets set by the average of all pedal points. A minimum of two vectors is needed to compute a pedal point. This is prone to error, because one bad vector is enough to corrupt the calculation. Hence, a multitude of pedal points can compensate for such a bad vector. Chapter 5.4 shows that three pointing locations and hence three vectors are sufficient.

Users are pointing at exhibits on a flat, horizontal surface. The distance between users and exhibits can vary and so does the accuracy. The further a target is away the bigger the *angular error* gets. This principle can be seen in Figure 5.11. For targets that are further away, the angle of impact on the surface α gets more and more acute. Hence, small variations during the pointing process have a much bigger influence with increasing distance to the target. It is an exponential problem and can be described by the *law of tangents*.

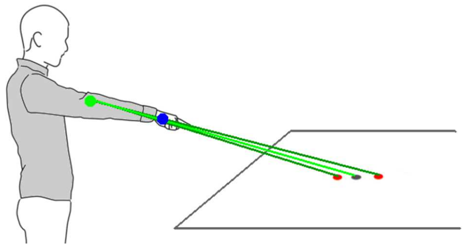

Figure 5.11: Illustration of pointing at a target in gray and the according angular errors in red.

An exemplary calculation shows how big the angular error can get. The scale is an adult user whose shoulder is constantly a = 70cm above the plane. Further, the user stands an arm's length away from the plane and the hypothetical target is 1.3m away from the edge. This results in a horizontal distance of b_{target} = 2m between user and target[15].

$$\tan \alpha_{target} = \frac{b_{target}}{a} \quad \rightarrow \quad \tan \alpha_{target} = \frac{700mm}{2000mm} \quad \rightarrow \quad \alpha_{target} \approx 19.3°$$

The hypothetical target's pointing angle of impact α_{target} is approximately 19°. Due to the fact that humans constantly move their limbs, a user's arm will never be completely still. This movement can alternate one degree in each direction, the pointing under- or overshoots. How much this angular error influences the precision can be seen in the sample calculation.

$$\begin{aligned} \tan \alpha_{point} = \frac{b_{point}}{a} \quad \rightarrow \quad b_{point} &= \frac{a}{\tan \alpha_{point}} \\ b_{short} &= \frac{a}{\tan \alpha_{short}} \quad \rightarrow \quad b_{short} = \frac{700mm}{\tan(18.3°)} \approx 1892mm \\ b_{long} &= \frac{a}{\tan \alpha_{long}} \quad \rightarrow \quad b_{long} = \frac{700mm}{\tan(20.3°)} \approx 2116mm \end{aligned}$$

$$\Rightarrow \quad \delta_{short} \approx 108mm \quad and \quad \delta_{long} \approx 116mm$$

This exemplary calculation shows that a variation of ±1° can cause an error of nearly 120mm in pointing direction. This led me to the conclusion that, if a person can not

15 Here, the shoulder is taken as the rotational joint for illustrative reasons. However, the principle remains the same. Further, this configuration will reappear in Chapter 5.4.

point with pin point accuracy, the system does not have to be calibrated to this accuracy. We would need to define a *sufficient accuracy* though. The angular error would be bigger for shorter users, such as children. It would additionally increase for targets further away. Nevertheless, to define the position of an IMI-exhibit as explained earlier, it has to be defined and validated. This means that both positions have to be within a threshold determined by sufficient accuracy. A radius of 100mm[16] has been chosen as threshold and thus the aspired sufficient accuracy for this system.

Yet another conclusion was to not calibrate each position to its actual position in relation to the depth sensor's coordinate system and measure if users come close to them. It is counter-intuitive to force a user to re-adjust in order to hit those positions. Instead, I chose to use the corresponding positions that were defined by the users themselves. To hit a target, users do not need to point at the real position in relation to the depth sensor, they need to hit the common position defined by other users. Hence, all positions are *virtual representations* of the real positions. Relations do not have to be correct, as long as the majority of users hit their designated target.

Readability Any user should be able to read the instructional and explanatory texts displayed by the installation. Therefore, the font size and the time a text is shown had to be taken in consideration.

The minimal visual angle at maximum contrast is one minute of angle or 0.017° [54]. This only describes the ability to differentiate between a white and black dot. Readability involves whole letters and therefore needs a bigger visual angle. For people with normal vision this means five minutes or 0.083° of visual angle [ibid.]. This value only applies for people with normal vision, which means they are able to recognize a single letter 20 feet away. People with normal eyesight have 20/20 vision. If people have 20/10 vision, they need to be 10 feet away to recognize the particular letter. A vision of 20/15 is more realistic for an average population [ibid.].
This principle can be applied to the Haßleben-installation as well. Given a distance from eye to letter of $b_{20/20} = 2.8$m and the visual angle $\alpha_{20/20} = 0.083°$, the height of a

16 A radius of 100mm matches the dimensions of a football, with the intended position in its center.

recognizable letter would be $a_{20/20}$ and calculated as follows:

$$\tan\alpha_{20/20} = \frac{a_{20/20}}{b} \quad \rightarrow \quad a_{20/20} = b \cdot \tan\alpha_{20/20}$$
$$a_{20/20} = 2800mm \cdot \tan(0.083°) \approx 4.1mm$$

Those 4mm are equivalent to a font size of 25[17]. A text of this size is unreadable for the majority of the population though. Hence, I considered people could have bad eyesight or no glasses at hand and recalculated the font size for 20/10 and 20/5 vision. Since the tangent is not linear, the corresponding visual angles $\alpha_{20/10}$ and $\alpha_{20/5}$ could not be doubled or quadrupled. They had to be calculated according to the definition mentioned above.
$with\ b_{20/10} = 2800mm \div 2 = 1200mm \quad and \quad b_{20/5} = 2800mm \div 4 = 600mm$

$$\tan\alpha_{20/10} = \frac{a_{20/20}}{b_{20/10}} \quad \rightarrow \quad \tan\alpha_{20/10} = \frac{4.1mm}{1200mm} \quad \rightarrow \quad \alpha_{20/10} \approx 0.171°$$
$$\tan\alpha_{20/5} = \frac{a_{20/20}}{b_{20/5}} \quad \rightarrow \quad \tan\alpha_{20/5} = \frac{4.1mm}{600mm} \quad \rightarrow \quad \alpha_{20/5} \approx 0.343°$$

Those visual angles can be used to calculate the correct sizes of letters under 20/10 and 20/5 conditions.

$$a_{20/10} = 2800mm \cdot \tan(0.171°) \approx 8.3mm$$
$$a_{20/5} = 2800mm \cdot \tan(0.343°) \approx 16.8mm$$

The corresponding font sizes are 51 and 105. Unfortunately, neither of the calculated font sizes satisfied our requirements. Texts with a font size of 51 was not well enough readable, but with a font size of 105 there was insufficient room for a proper instructional or descriptive text. We compromised on a font size of 70, which allows for 300 characters and is still well readable.
Font sizes have to be adjusted for displays with other resolutions or sizes accordingly. Also different distances between visitors and display have to result in adaption of the font size.

17 The system's display has a resolution of 159dpi. Thus, font size[pt] := $a_i \div (\frac{24.5mm}{159dpi})$

Another factor influencing the readability of texts is the timespan for which they are displayed. If a text is shown for too long, visitors will get impatient, but if it is displayed too short they will get frustrated, because they could not finish reading. Hence, average reading speed should dictate for how long a text is shown. The average reading speed for German texts is 250 words per minute (wpm) [42]. With an average length of 5.7 characters per word in the German language [13], this results in 1425 characters per minute (cpm). With a maximum of 300 characters per description, an exhibit's presentation should take no longer than 13 seconds. Not every exhibit is described by a text with exactly 300 characters. In case of a shorter text, the presentation should be shortened accordingly.
However, there are also images in an exhibit's presentation. To observe an image, we estimated a default timespan of four seconds. Unfortunately, the system does not know, whether a user reads the text or looks at the images. Hence, there is no way of knowing when to change an image during the slide show. Consequently, the time to inspect those images should be added to the time to read the description. In this case, extensive exhibit presentations would take a long time, which could make visitors impatient. Therefore, an exhibit's presentation takes the maximum time of either the reading task or the slide show. A user can select the exhibit again, if there is further interest in the exhibit.

5.4 Iterative Development

Before anything could be installed or evaluated, the aforementioned principles had to be implemented and their reliability tested. Therefore, I researched suitable environments for an extensible system. Because most SDKs for PrimeSense's hardware are implemented in C++ or C# and Gadgeteer uses Microsoft's .NET framework and C#, the final system should be implemented in C#. However, an SDK written in C# was to be found. After having tried several open source frameworks, the Full Body Interaction (FUBI) developed at Universität Augsburg proved to fit our needs best. FUBI came with a C#-wrapper, which incorporated all functionality of OpenNI and NiTE that was necessary to achieve our goals. Moreover, its leading developer, *Dipl.-Inf. Felix Kistler*, kindly explained how to incorporate FUBI to our new system.
FUBI provides a mechanism to access the coordinates of every tracked persons joints. NiTE tracks and calculates the positions of 25 joints for each person. Further, those

joints can be separately updated in real time. Hence, it is possible to only get the positions of necessary joints. This reduces requests and consequently saves performance. Details about the implementation of updating joint positions and further use can be found in Chapters 6.2 and 6.3.

First Test The first test was designed as a proof of concept. The basic feasibility of the aforementioned principle of pointing gestures and the gestures' accuracy were tested. Therefore, a subject had to define a point in 3D space.
The setup that was used for the this test can be seen in Figure 5.12[18]. The sensor was positioned at about the same position it would later be inside the Haßleben-showcase. Centered in front of it, a turquoise token was attached to the white surface of the *lab setup*. It has a diameter of approximately 2cm. 18 subjects, who ranged from 160cm to 188cm in height, took part. All of them are either students or researchers of the faculty of Media at Bauhaus-Universität Weimar.

Figure 5.12: Lab setup that was used throughout the iterative development process.

The definition of a point in 3D space was tested with each subject. Only one Independent Variable (IV) was changed throughout a session. It was the amount of pointing locations from where the position of the token had to be defined. Five rounds of defining the token in 3D space for both three and five pointing locations were done by each subject. They were shown the token and told to point at it from three and later five pointing locations. Moreover, subjects had to point with their right arm. The pointing locations were marked by metal braces along the edge of the surface opposite the sensor. Subjects were not given any visual aid, but an audible countdown in form of beeps was provided

18 The exact specifications are described in the next section of this chapter.

instead. At the end, a subject either had to point at the target or move to the next pointing location. Subjects had to point straight at the target for one second. During this second of pointing, ten pointing vectors were recorded[19].

As expected, subjects defined points in 3D space by pointing at the given target. However, there were difficulties concerning the accuracy in both conditions. The histograms of the acquired data in Figures 5.13, 5.14, and 5.15 indicate a normal distribution for each axis. There are several outliers, though. Hence, those needed to be reduced or avoided.

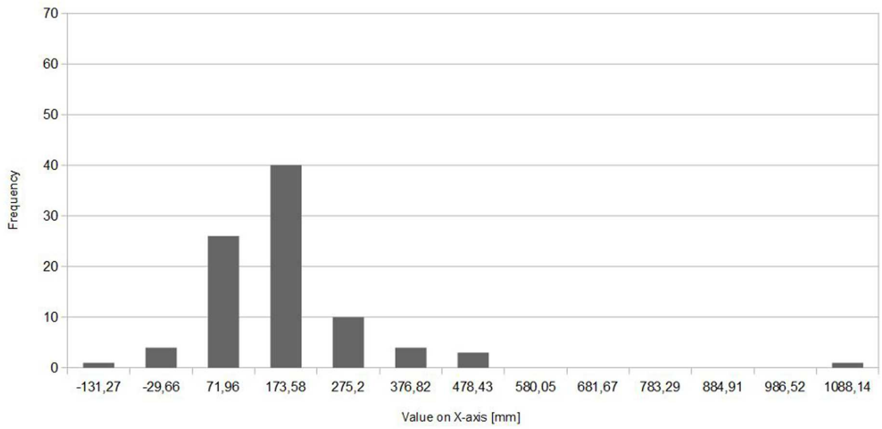

Figure 5.13: Histogram of values on X-axis computed during the first test period.

The lowest calculated X-value was -182mm and the highest was 1037mm. Hence the values are spread over a range of 1219mm. About 74% of values lie between 21mm and 224mm. This is already close to the targeted sufficient accuracy.

19 The sensor has a sampling rate of up to 60Hz.

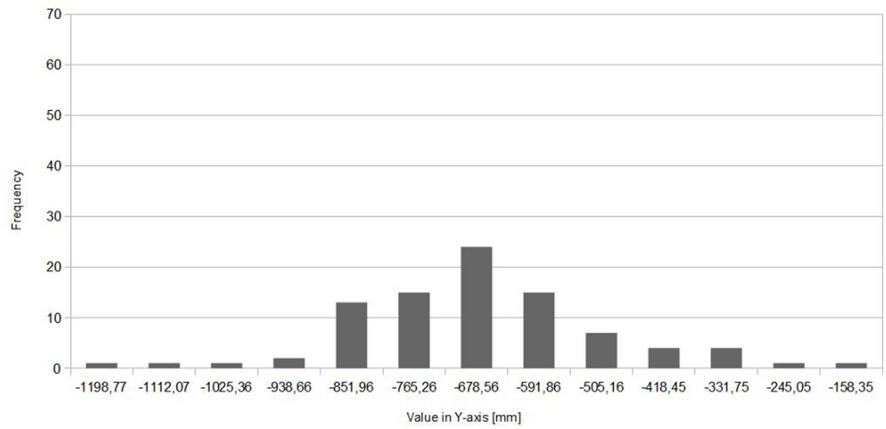

Figure 5.14: Histogram of values on Y-axis computed during the first test period.

Y-values have a similar spread. They range from -1155mm to -115mm. Thus, the range on the Y-axis is 1040mm. The spread os more flat, though. Thus, there are 54 values within an range of 347mm and the Y-values are far from sufficient accuracy.

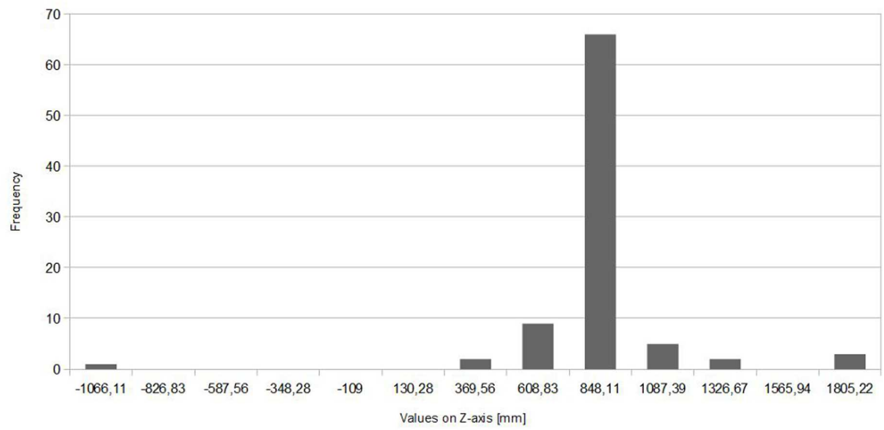

Figure 5.15: Histogram of values on Z-axis computed during the first test period.

The biggest spread was produced by the computation of the Z-value. These values ranged from -1185mm to 1685mm. Hence, the overall angular error was 2871mm. The Z-value, however, has the highest number of values in a bin from 489mm to 728mm. 66 out of 89 values are in this group that is about the size of the aspired sufficient accuracy.

As it turned out, the kind of distribution was not relevant for the further analysis of the outcomes. There was a dense cloud of points for each condition. In the center of each cloud lay the average point for each condition. Unexpectedly, the values for three pointing locations are more densely distributed, than those for five. This impression can be supported by the similar means and medians, but different Standard Deviation (SD) listed in Table 5.1, 5.2 and 5.3 for three and five positions.

Positions	**X-axis**	**Y-axis**	**Z-axis**
3	60.06mm	-674.73mm	604.28mm
5	81.93mm	-666.20mm	669.74mm

Table 5.1: Means for three and five pointing locations on each axis.

Positions	**X-axis**	**Y-axis**	**Z-axis**
3	52.08mm	-681.75mm	566.67mm
5	41.05mm	-659.33mm	577.18mm

Table 5.2: Medians for three and five pointing locations on each axis.

Positions	**X-axis**	**Y-axis**	**Z-axis**
3	98.86mm	155.86mm	203.29mm
5	98,77mm	202.30mm	284.87mm

Table 5.3: Standard deviations for three and five pointing locations on each axis.

Although, means and SDs are no appropriate measures to be drawn from non-uniform distributions, they confirm the observations. Three pointing locations are less prone to error than five. In retrospect, the five pointing locations were closer together. Consequently, the angle between pointing vectors were more acute. Hence, some pedal points had been calculated to be several meters away from the others. This probably led to the higher dispersion in comparison to that of three pointing locations. Accordingly, it was decided that three pointing locations are sufficient to properly define a point in 3D space by pointing. The process still had to be drastically improved though. As Table 5.4 of a *simulated validation* shows, not even 15% of the defined points would have lied within the aforementioned threshold of 100mm with each other. This means, only in 13 out of the 90 cases[20] the target would have been properly defined and validated. Even for twice the threshold, less than half of all points validated each other. Hence, the accuracy was not sufficient enough for all subjects to hit an identical target.

Threshold	Validation
100mm	14.43%
120mm	20.40%
140mm	27.57%
160mm	33.31%
180mm	39.58%
200mm	44.69%

Table 5.4: Successful validations for increasing thresholds.

A positive conclusion can be taken from the *validation maps* depicted in Figure 5.16, in which all validation attempt's results are visualized by color coding. Full validation on each axis is green, two successfully validated axes are yellow, one is orange and none is red. Each small square is one defined point. The points are sorted in ascending height of their defining subjects. It can be seen that the subjects' height has no apparent influence on the validation, although a certain height appears to be more practical, as the density of green dots in the lower left area indicates. Nevertheless, size does not matter.

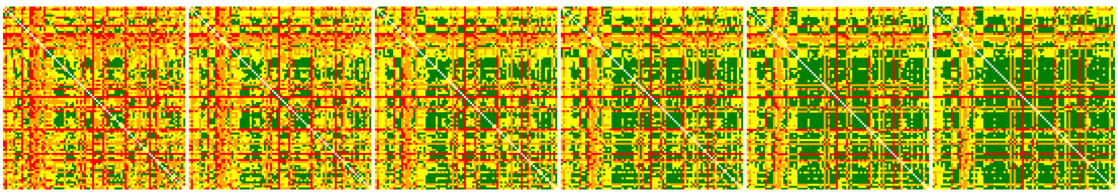

Figure 5.16: Color coded validation maps of every defined point with every other defined point. Thresholds from left to right: 100, 120, 140, 160, 180, 200mm.

Two more observations occurred during the tests. First, there were several defective measurements recorded in the raw data. Second, most subjects appeared to point too

20 18 subjects · 5 rounds per subject = 90 points

high and thus overshoot. Both observations had to be addressed to improve the accuracy of the definition process.
The first observation could be handled by improving the algorithms that were responsible for sampling the pointing gesture of a subject. In some cases, the subject's joints were not updated properly, which led to zero vectors pointing nowhere. Those vectors are filtered out since by an improved sampling mechanism. Another aspect was the aforementioned countdown. Several subjects got confused on what to do next. Thus, they did not point during sampling or were not ready. The issue was addressed with improved feedback on what to do during the next test.
The second observation however, turned out to be more complex and yet helpful than anticipated. What had been observed, was a common issue in VR-environments. It is referred to as the *eye-hand visibility missmatch* by Argelaguet et al. [3]. They explain that VR pointing techniques can be classified in two groups. Namely, they are *hand-* and *eye-rooted* techniques [ibid.]. In 3D VR-environments not only devices are tracked, but also users' heads[21]. Pointing devices' rays and users' view angle are calculated according to their tracked position and orientation. The eye-hand visibility missmatch describes the problem that not everything that is visible for a user, can be reached by the ray from a handheld device. Other objects might occlude the ray, which prevents selection [ibid.]. Argelaguet et al. propose a solution as well. They introduce a *selection* and a *display ray*. The selection ray originates at a user's eye position and has the device's orientation. Any intersection with an object in the scene will be the display ray's point of aim. The display ray provides the visual feedback and originates at the device leading to the point of aim (see Figure 5.17). By implication, Argelaguet et al. introduced aiming as an alternative to pointing.

21 Users wear special 3D-glasses. For a correct stereoscopic view, those glasses are tracked as well to calculate a correct perspective view angle into the scene.

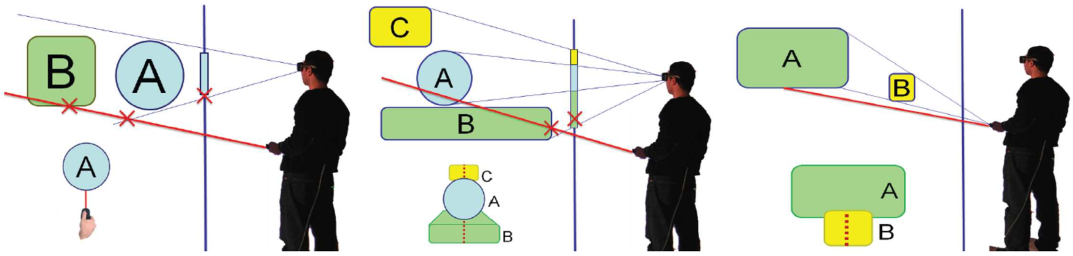

Figure 5.17: Selection of an occluded object instead of visible one (left). Unable to select an object, because the ray is occluded by another object (middle). Object is visible from eye's and hand's location, but no position on its surface is visible by both (right). [3]

As a consequence, I incorporated this principle to my approach and added a second vector to the system. Aiming vectors have a subject's head-joint as origin. The orientation is determined by the head- and hand-joint. Thus, only one more joint has to be updated.

Second Test The following test had to show, if the improvements mentioned above have had a positive effect on the systems performance and precision. The setup and task remained the same. Because five pointing locations had been eliminated as a condition, subjects only had to do five rounds from three positions. Both pointing and aiming vectors as well as the computed points in 3D space were recorded at the same time thus ensuring comparability. This time, 19 subjects participated. Their heights ranged from 157 to 198cm. Although several subjects had taken part in the first test, no learning effects were expected due to the intuitiveness of the task at hand.
In addition to the two pointing paradigms being tested, their combination arose as a solution for an earlier consideration. The *angular error* could be corrected by combining points defined by pointing and aiming. The conjunction of pointing and aiming depicted in Figure 5.18 could increase the percentage of successful validations.

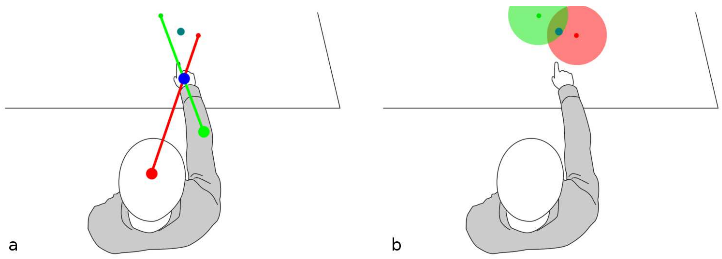

Figure 5.18: Pointing vector in green and aiming vector in red miss the target (a). Target areas of pointing, aiming and the target inside their conjunction (b).

As Table 5.5 shows, the improvements over the first test worked. While the points defined by pointing were successfully validated twice as much as before, aiming was not as efficient as estimated. Points defined by aiming were only about half as often successfully validated than those defined by pointing. However, aiming was still better than the results from the first test. Combining the two pointing paradigms by averaging their values resulted in a combined point between them.

Threshold	Test No.1	Pointing	Aiming	Combined
100mm	14.43%	29.83%	16.55%	23.21%
120mm	20.40%	39.86%	21.86%	31.88%
140mm	27.57%	50.35%	26.72%	39.48%
160mm	33.31%	63.91%	31.28%	45.91%
180mm	39.58%	65.74%	35.83%	51.82%
200mm	44.69%	70.03%	39.78%	56.52%

Table 5.5: Comparison of successful validations for increasing thresholds.

The visual observation of subjects during the test revealed a bias toward one of the paradigms. This indicates that subjects tend to either point or aim at a target. Hence, the combined point has to be weighted accordingly. In order to achieve a proper weighing of the points defined by pointing and aiming a subject's bias has to be recognized first. A weighing of the classified points can then be applied to gain the biased point in 3D space.

Third Test The last test that took place under lab-conditions, was intended to find the most efficient combination of classification and weighing of points defined by pointing

and aiming. Moreover, the three most suitable corners for defining an exhibition plane were chosen according to the results of this final test.
Each of the 24 subjects of this test had to define all four corners of a fictional exhibition plane. These corners were, as depicted in Figure 5.19, marked with colored tokens. Similar to the two earlier tests, they had to point at every corner from each of the three previous positions. During a session, they were given textual advice telling them the position to go to or the corner to point at. The sequence of actions was like in the final definition process of an exhibition plane. Subjects went into position and then consecutively pointed at each of the corners. Intervals between changing positions or pointing at the next target were about 4 seconds. All subjects did five rounds, but this time they defined four points instead of one.

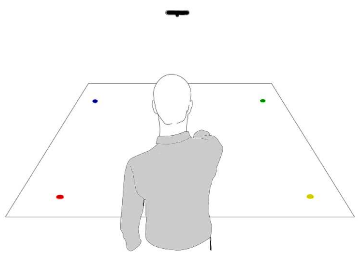

Figure 5.19: The first corner was marked with a blue, the second with a green, the third with a yellow, and the fourth corner with a red token.

After all data had been gathered, they were processed by a tool to generate all possible combinations. Therefore, point-tuples defined by pointing and aiming were classified and then weighted. The previous combination was computed for comparison as well.
Classifications were either static or biased. *Static classification* implies a balanced weighing. There was a progression in static classification, though. Whereas *direct* classification only computed, whether two points were validating each other for a particular threshold or not, *centered* classification was checking if both points would validate a virtual center between them.
Biased classification on the other hand compares each of the defining points axis. If there is a difference larger than a particular threshold, there is a probable bias toward either of the points. The dominant point cannot be determined by the distance between the

two alone. A decisive criterion was needed and the absolute value was chosen[22]. Either the biggest or the *smallest absolute value* of an axis was considered dominant. Hence, it was given a higher weight than the other point's axis' value. The tested weight-ratios in favor of the dominant value are 60:40, 70:30, 80:20 and 90:10. Another type of weighing is *automatic weight calculation*. Here, the ratio is calculated with respect to the actual distance between the points. Thus, if the distance is just above the threshold the weight-ratio is 60:40. For values further than twice the threshold apart, the maximum ratio of 90:10 is used. All other distances in between yield a respective weighing.

Class.	**Weighing**	**Point #1**	**Point #2**	**Point #3**	**Point #4**	$\sum$
Direct	**50%**	3.70%	9.25%	47.97%	28.95%	22.47%
Center	**50%**	17.23%	39.28%	76.21%	59.55%	48.07%
Big	**60%**	19.93%	38.11%	75.47%	61.03%	48.64%
Big	**70%**	21.40%	35.58%	74.41%	62.09%	48.37%
Big	**80%**	21.64%	32.10%	73.79%	61.46%	47.25%
Big	**90%**	21.75%	29.60%	72.85%	59.74%	46.98%
Big	**Auto**	19.56%	26.49%	73.59%	58.72%	44.59%
Small	**60%**	15.77%	39.14%	77.35%	59.43%	47.92%
Small	**70%**	13.87%	38.03%	77.39%	57.98%	46.82%
Small	**80%**	12.03%	36.58%	76.88%	56.38%	45.47%
Small	**90%**	10.31%	34.37%	76.06%	54.03%	43.69%
Small	**Auto**	13.13%	37.56%	77.03%	53.09%	45.20%

Table 5.6: Successful validations for threshold of 100mm. Comparison of classifications and weighing.

As Table 5.6 shows, centered classification alone more than doubled the validations in comparison to direct classification. Here, successful validations were significantly increased for points #1 and #2, which lay in the far left and right corner. Thus, angular error could be drastically reduced for points further away.
Points #3 and #4 were placed at the front edge of the surface. Hence, the angular error was low and these points were defined and validated much more efficient.
The table further shows that both classification types have similar percentages of overall successful validations. Classification by biggest is a little stronger than by smallest

22 A more profound investigation of biased free-hand pointing will be the topic for further research.

absolute value, though. The advantage comes from a better performance in successfully validating the far left corner.
Although "Big60" has the best overall performance, "Big70" was chosen for the final version of the administration and presentation software. The successful validations by this combination of classification and weighing show a more homogeneous distribution. The aspired majority of successful validations within a threshold of 100mm could not be achieved for all corners of an exemplary plane. Pointing accuracy close to a subject is well, though. Nevertheless, subjects were not provided with any feedback about the position they were pointing at and only relied on proprioception alone. Hence, when users are provided with feedback and can adjust their gestures accordingly, the system is operable with sufficient accuracy[23].

5.5 Development Setups

Three installations were build. One lab setup for development, one makeshift setup was placed in the faculty building's lobby, and the final one was installed inside the showcase at the Museum für Ur- und Frühgeschichte Thüringens. The various setups differed in dimensions and were run with different hardware configurations. Testing of technical principles and computations were conducted with the lab setup. The lobby setup was used for a stress-test during an open door-event at the faculty, whereas the final evaluation took place in the museum. Only the presentation software was evaluated.

The Haßleben-showcase was measured. The measurements were then transferred into the groundplan depicted in Figure 5.20. With a width of 439cm and a depth of 344cm, a mockup of the showcase was quiet large and would need an even larger room to fit in and to be still operable. The showcase has a floor-to-ceiling height of 293cm and its exhibition plane is 65cm above the floor.

23 Two actual exhibits in the Haßleben-showcase were defined about 7cm from each other and are distinguishable by users of the presentation software. Further improvements of the determination of points in 3D space are discussed in Chapter 9.

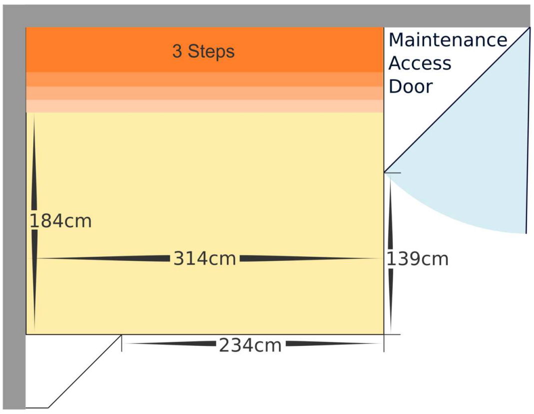

Figure 5.20: Groundplan of the Haßleben-showcase.

The laminated glass is 7mm thick. A main concern at the beginning was, whether the sensor would be able to work through glass or not, because the panels have no anti-glare coating. The images in Figure 5.21 were taken during the fitment of the IMI-system inside the Haßleben-showcase. They confirm that the depth sensor works through the glass panels.

Figure 5.21: Color coded depth image of a pointing person through two panels of glass at an acute angle (left). Adjusting the depth sensor inside the Haßleben-showcase with raw and depth image (middle and right).

Lab Setup A room with adequate dimensions had to be found. Moreover, the mockup had to be build, and equipped with all necessary Hardware.
There were three unoccupied rooms. One at the museum and two at the faculty. The room at the museum was the attic, not insulated, and had no network connection. Hence it was not suitable. Both rooms at the faculty could fit the mockup and an additional desktop to work at. The smaller room was reserved, though. Thus, the big room became

the testing environment. It provided constant lighting and helpful features such as access to the internet and proximity to experts at the faculty.
Until the final hardware was acquired by the museum and available for testing, similar hardware was preliminarily lend to me by multiple sources of the faculty. The museum's carpenter fabricated a pedestal consisting of surface plating and feet. The plating is fabricated from four 9mm-press boards. The feet seemed too unstable and thus were replaced with one desk rack for each board as can be seen in Figure 5.22.

Figure 5.22: Images of the construction of the lab setup during the development process.

The mockup is 315cm wide, 264cm deep and 75cm high. These are not the exact measurements of the showcase. I did not reproduce the whole showcase, but only the exhibition plane within. Therefore, the reproduction is adequately proportioned. The additional height increases the probability of angular error compared to the original. Therefore, the final setup's error is estimated to be lower, because pointing vectors' angles of impact are less skew.
The sensor is mounted on a tripod, which is placed at approximately the position it would later be installed inside the showcase. From there, it faces the subjects at an angle of about 100°. This elevated position is necessary to get reliable readings. Otherwise, a sensor installed at shoulder-height can not properly acquire depth information of occluded joints.
The desktop to the right of the mockup was the main workplace from where the tests were supervised. It provided a good overview of subjects and hardware alike. The computer running the test software was placed on this desktop and so was the screen. For later tests, a second screen was placed beneath the tripod's legs.

There were two hardware configurations used during the development of the system. The first test was conducted on an *ASUS Eee PC 1215B*-netbook [30]. Following tests were conducted on the designated desktop-PC[24].

Lobby Setup The first test under aggravated conditions was conducted during *Summæry*[25]. Therefore, a makeshift setup was built in the faculty's lobby. It consisted of three tables forming the exhibition plane and a cocktail table, on which the desktop-PC and a tripod with the sensor on top were positioned. The interaction space was defined by markings on the floor. There were three targets - a candy bar, a stack of coins, and a stack of fliers - lying on the plane (see Figure 5.23).

Figure 5.23: Trying out the IMI-system as it was setup in the lobby of the faculty of Media during the Summæry.

After assembling the hardware and sample exhibits, a sample exhibition was defined with the administration software. It was given a name, the exhibition plane, user position and exhibits' positions along with images and short descriptions were defined. The whole process took only 45 minutes. Subsequently the presentation software was started.
The lobby presented the system with a densely populated environment. Many visitors walked past it or stopped to try it out. The system crashed several times during this

24 Full specifications of hardware and the development environment can be found in Chapter 6.
25 Summæry is an open door-event at the faculty of media, where all chairs present their work throughout the faculty-buildings.

ordeal. Two reasons could be identified after having observed the events and reviewing the log-files.
First, the system could have had too many people in its sight. As it turned out, OpenNI was designed for 15 users, yet never tested for more than three [12]. It is not clear what happens, if more than 15 subjects are recognized and therefore, I tried to reproduce the error. Unfortunately, we could not manage to get more than 12 persons recognized by the system, whereas the error did not re-occur.
The other problem appeared after having seen some log-files, which implied that non-existent targets were selected by the system after people left. This smaller bug was fixed immediately by checking if a selected target was referring to a valid IMI-exhibit.

5.6 Museum Setup

Figure 5.24 depicts the installation of the final setup at the Haßleben-showcase. The aforementioned desktop-PC was attached behind the maintenance door to the right of the showcase. Because the keyboard and mouse necessary for maintenance are wireless, the only wires were the USB3.0-cable to connect and power the screen and the PC's own power supply.

Figure 5.24: Impressions of the final setup inside the Haßleben-showcase at the Museum für Ur- und Frühgeschichte Thüringens.

The display's prior position was changed after the museum staff had concerns about it having too much influence on the overall appearance of the showcase. There was a fear of it being too distracting or disturbing the overall picture. Hence, it was anchored on the back wall at common eye-height (see Figure 5.24). This compromise was deemed sufficient for the display to still be recognizable in users' peripheral vision when they look inside the showcase.

The footsteps defining the interaction space are not centered in front of the showcase and screen, but shifted to the left. This way, visitors can get closer to the showcase and still read the instructions and look at the ideogram. Moreover, the readability of the display was compromised by reflections in the glass panel of the showcase if users stood right in front of it.

6 Implementation – Interactive Museum Installation

The IMI-system consists of two main parts. First, the hardware, which involves the physical tracking and computing of that data in the background. Second, the software, which includes the IMI-libraries and pieces of software utilizing them.

The hardware consists of and PC, the sensor, a screen and peripheral input devices for maintenance. The designated PC is an *ASUS VIVO VC60-B013M*. It employs a *Intel Core i5 3210M* with a clock speed of 2x2,5GHz and 4GB DDR3 SDRAM [32]. Since the system does not have complex graphics, there was no need for a sophisticated graphics card. Hence, the PC is compact and does not need much electricity.
As a display, an *ASUS MB168B+* with a size of 15.6” and a resolution of 1920x1080 pixels was chosen. The display further houses its own graphics chip, which enables it to be connected to a PC via a USB3.0-cable [31]. This configuration eased the installation, because of the plug the holes drilled into the back wall of the showcase could be smaller than for a usual display-cable. The display is supported by a modified bookend, which is attached to the back wall with two screws. An additional hole has been drilled for the cable. This hole is hidden by the display. Although it was planned to camouflage the display with a foil, it did not seem necessary, because lighting at the new position of the display is already dim.

The soft- and firmware used for developing and running the system is based on *MS Windows 7 Professional x86*. As mentioned earlier, the software was included into FUBI. This framework is available as an *MS Visual Studio 2010*-project. The all software is written in *C#* and hence makes use of the *MS .NET Framework 4.5.1* [38] and further *MS XNA Framework 4.0* [39] for certain functions throughout certain regions of the software. Moreover, FUBI uses the functionalities of *OpenNI 2.2.0.33* [46] and *NiTE 2.2.0.11* [45].

Maintenance is reduced by automatic booting and shutdown. The system's BIOS boots the PC at 8:30 in the morning. A tool shuts the system down at 4:45 in the afternoon. Hence, no staff member has to access the PC to start or shut the system down.

6.1 Libraries

IMI includes a collection of libraries, which can be used to implement interactive applications. At the time the functionality is restricted to free-hand pointing gestures. Other mechanisms can be easily added. An IMI-exhibition is modularly built by those libraries. The Exhibition- and Exhibit-class have structural functionality and manage an exhibition's data. Meanwhile, the Handler-classes use this data to generate and operate the interaction between user and system.

Preliminaries Terms used hereafter are as follows:

- A point or corner is a point in 3D space of type `Point3D`.
- A plane is defined by three points or corners.
- A position is a point on a plane of type `Point3D`.
- A pointing position is the position a user is pointing at.
- A pointing location it the location a pointing user is standing at.
- A kernel is an exhibit's membership function. It has a size and radius.
- A target is an exhibit's representation on the exhibition plane. It is determined by its position and kernel.

Exhibition.cs Members of the Exhibition-class are needed to define an IMI-exhibition. All necessary information is contained and managed in this class.

The `exhibitionPlane` is the most essential component of an IMI-exhibition. All exhibits' positions are defined on this fundamental property. It is constructed by three corners. The structure of such a Plane is declared by the GeometryHandler-class. The

Exhibition-class further holds a list of `Exhibit`-objects. In this `List` all selectable IMI-exhibits of an IMI-exhibition are stored. In addition, the earlier mentioned user position that defines the interaction space is also saved in this class as a point. An IMI-exhibition's name and file path are members of the Exhibition-class, too. So are the images, which are used to camouflage the display against the background and the overview of the exhibition plane with sketches of exhibits in their respective positions. Furthermore, data crucial for interaction is also represented in member variables of this class. So are the default values for the threshold needed for defining exhibits and the dwell time for target selection. Timespans used by the presentation software are `lockTime`, which determines a short period of paused interaction after selecting a target and `slideTime` which determines for how long a single image is shown during an IMI-exhibit's presentation.

The characteristic functionality of the Exhibition-class is provided by its get- and set-methods. They allow for reading and writing all those essential variables.

Exhibit.cs The virtual representation of an IMI-exhibit is structured by the Exhibit-class. This includes data relevant for interaction with the system and an IMI-exhibit's presentation upon selection. Like an Exhibition-object, an Exhibit-object stores its own file path as well. This is necessary for organizational reasons.

The most important member of an IMI-exhibit is its position. In combination with the two kernel-defining members `kernelSize` and `kernelRadius` the SessionHandler-class is able to compute which target a user is pointing at.

Members relevant for the presentation of an IMI-exhibit are its name, descriptive text and collection of images. The images are stored in a `Dictionary` as a pair of an image's file path and the image itself.

The Exhibit-class, just like the Exhibition-class, is of structural nature and therefore only has the same administrative methods that get and set members.

FileHandler.cs The objective of the FileHandler-class is *saving* and *loading* data of an IMI-exhibition, its exhibits, and all their properties. Therefore, a temporary Exhibition- and Exhibit-object are needed. Exhibitions along with all related information are saved in *XML-format*. The hierarchical structure of XML-files allows adding, changing and removing elements without much effort.

To save an IMI-exhibition and all its properties several XML-files have to be written. The main file contains the aforementioned defining properties of the exhibition. This means that each IMI-exhibit is stored separately. It is saved as an XML-file as well. Each IMI-file contains all properties as attributes or *forwarding file paths*. Equally, corresponding images are saved as file paths leading to the actual image. The exhibition plane is also separately saved as an XML-file.
Loading works in reverse to this procedure. As an IMI-exhibition is loaded, its properties are either saved into a *temporary Exhibition-instance* or forwarding file paths are followed. A *Temporary Exhibit-instance* is used to load all of an IMI-exhibits.
The modular composition allows the IMI-system to be flexible. IMI-exhibits exist as independent entities and can be easily removed from or added to an existing IMI-exhibition. The same applies for the exhibition plane. Figure 6.1 depicts the whole data-structure behind an IMI-exhibition.

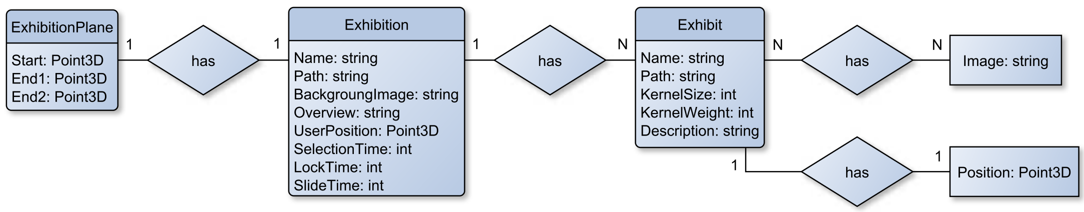

Figure 6.1: Entity-Relationship diagram of the data-strucutre behind an IMI-exhibition.

An additional function of the FileHandler-class is reading TXT-files. This feature is used to load pre-written descriptions of IMI-exhibits.

GeometryHandler.cs The GeometryHandler-class is solving essential computations of analytic geometry-problems. Therefore, the two structs `Vector` and `Plane` are declared, because standard types of C# do not deliver the complexity needed for those computations.
A `Vector`, in contrast to a standard `Vector3D` or `Vector3`, is not only a *direction vector*. It also has a *starting* and a *terminal point*. Hence, a `Vector` V is defined by a starting

point P_S and either an endpoint P_E or a direction vector leading towards it $\overrightarrow{d_E}$, where P_S is either a user's tracked head- or elbow-joint and P_E is its tracked hand-joint. A vector in its parametric form is written like this:

$$V = P_S + \lambda \cdot \overrightarrow{d_E}$$
$$P_V = P_S + \lambda_P \cdot \overrightarrow{d_E}$$

As the factor λ is varied, any point P_V along a `Vector`'s direction of propagation can be expressed.
A `Plane` is defined by one starting corner C_1 and either two additional corners C_2 and C_3 or two additional `Vectors` $\overrightarrow{d_{C_2}}$ and $\overrightarrow{d_{C_3}}$ towards those corners. In short, a `Plane` E is defined by two `Vectors` V_{C_2} and V_{C_3} of identical origin. The parametric form of a plane is defined as follows:

$$E = V_{C_2} + V_{C_3} \quad \rightarrow \quad E = C_1 + \lambda \cdot \overrightarrow{d_{C_2}} + \mu \cdot \overrightarrow{d_{C_3}}$$
$$P_E = C_1 + \lambda_P \cdot \overrightarrow{d_{C_2}} + \mu_P \cdot \overrightarrow{d_{C_3}}$$

Any position P_E on a `Plane` can be expressed by varying λ_{C_2} and μ_{C_3}.

The GeometryHandler-class has two types on members. First, *input-members* are pointing- and aiming points or positions. Second, *output-members* are lists of classified and weighted points or positions.

However, the main task of this class is to calculate *pedal points* between `Vectors` and *intersections* of a `Vector` with a `Plane`.
A pedal points is calculated to define a point. Therefore, a subject has to point at this point in 3D space from two different locations. Vectors from both locations should meet in the point to define. Intersections in 3D space are very unlikely, though. Hence, a substitute point has to be found. The closest two skew vectors come to each other is in the pedal point. Thus, this point is computed instead of an intersection. Given two `Vectors` V_A and V_B with starting points S_A and S_B and their respective directions $\overrightarrow{d_A}$ and $\overrightarrow{d_B}$.

$$V_A = S_A + \lambda_A \cdot \overrightarrow{d_A} \quad \text{and} \quad V_B = S_B + \lambda_B \cdot \overrightarrow{d_B}$$

A normal is a vector, which is perpendicular to its original vector. To get the shortest distance between two `Vectors`, their normals $\overrightarrow{n_A}$ and $\overrightarrow{n_B}$ have to be perpendicular to both `Vectors`.

$$\overrightarrow{n_A} = \overrightarrow{d_A} \times (\overrightarrow{d_A} \times \overrightarrow{d_B}) \quad \text{and} \quad \overrightarrow{n_B} = \overrightarrow{d_B} \times (\overrightarrow{d_A} \times \overrightarrow{d_B})$$

To compute the pedal point, and stay in the metaphor, the two foot points F_A and F_B are needed. These points lie on either `Vector` and in between them lies the pedal point. Hence, the factors λ_{F_A} and λ_{F_B} have to be altered.

$$F_A = S_A + \lambda_{F_A} \cdot \overrightarrow{d_A} \qquad \text{and} \quad F_B = S_B + \lambda_{F_B} \cdot \overrightarrow{d_B}$$
$$F_A = S_A + \frac{(S_B - S_A) \bullet \overrightarrow{n_B}}{\overrightarrow{d_A} \bullet \overrightarrow{n_B}} \cdot \overrightarrow{d_A} \qquad \text{and} \quad F_B = S_B + \frac{(S_A - S_B) \bullet \overrightarrow{n_A}}{\overrightarrow{d_B} \bullet \overrightarrow{n_A}} \cdot \overrightarrow{d_B}$$

An exemplary configuration of the problem is depicted by Figure 6.2.

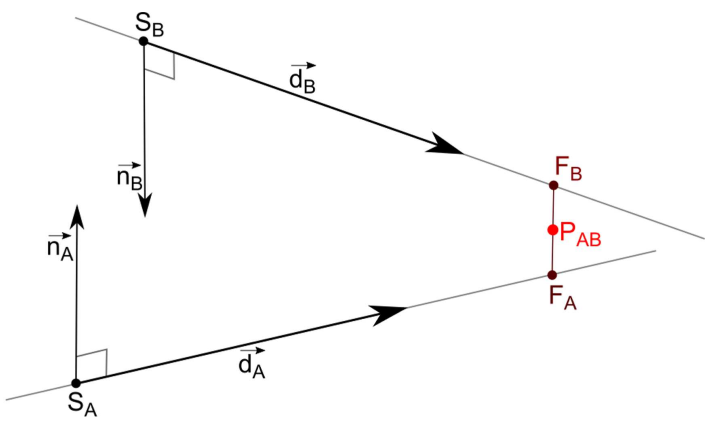

Figure 6.2: Schematics of the calculation of the pedal point between two skew lines.

The only step left is to calculate the pedal point P_{AB} between the two foot points [11] F_A and F_B. Since the feet already represent the points on each `Vector` that are closest to the other `Vector` and P_{AB} is in the middle, P_{AB} is the average of them.

$$P_{AB} = (F_A \cdot F_B)/2$$

The IMI-system's interaction is based in the principle of intersections of a `Vector` and a `Plane`. Positions of IMI-exhibits are defined this way. Furthermore, a user's pointing and aiming position is calculated exactly the same. Thus, this computation is crucial for interaction. Given a `Vector` V and a `Plane` E are not parallel, they intersect in a position P_I, where $P_I \in V \wedge E$.

$$\begin{aligned} V = P_S + \lambda \cdot \overrightarrow{d} \quad &\rightarrow \quad P_I = P_S + \lambda_I \cdot \overrightarrow{d} \\ E = C_1 + \mu \cdot \overrightarrow{d_{C_2}} + \nu \cdot \overrightarrow{d_{C_3}} \quad &with \quad \overrightarrow{n_E} = \overrightarrow{d_{C_2}} \times \overrightarrow{d_{C_3}} \end{aligned}$$

A `Vector` $\overrightarrow{u}$ between P_I and any other position on E has to be perpendicular to E's normal $\overrightarrow{n_E}$. Further, a `Vector` $\overrightarrow{w}$ from V's origin to any position on E is needed. It describes V's origin with respect to E. In both cases, C_1 can be taken as a known position on the `Plane`.

$$\overrightarrow{u} = P_I - C_1 \quad and \quad \overrightarrow{w} = P_S - C_1$$

As Figure 6.3 shows, going from C_1 to P_I by $\overrightarrow{u}$ is the same as by $\overrightarrow{w}$ and then along $\overrightarrow{d}$. Hence, both terms are *linear dependent* on each other. Since $P_I \in E$, $\overrightarrow{n}$ also stands perpendicular on $\overrightarrow{u}$. Hence, it is also perpendicular to its equal path from C_1 to P_I.

$$\begin{aligned} \overrightarrow{u} = \overrightarrow{w} + \lambda_I \cdot \overrightarrow{d} \quad and \quad & 0 = \overrightarrow{n_E} \bullet \overrightarrow{u} \\ \Rightarrow \quad & 0 = \overrightarrow{n_E} \bullet (\overrightarrow{w} + \lambda_I \cdot \overrightarrow{d}) \end{aligned}$$

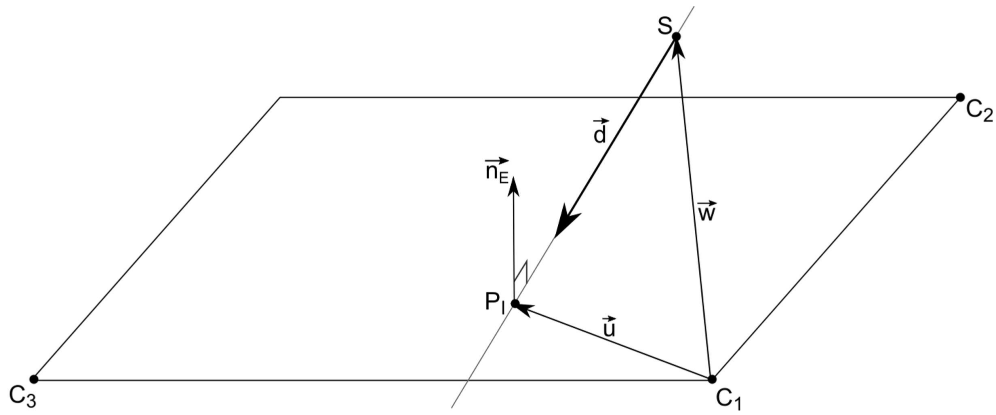

Figure 6.3: Schematics of the intersection between a plane and a line.

This equation can be solved for λ_I, which is then put back into the pointing `Vector`'s equation.

$$\lambda_I = \frac{\overrightarrow{n_E} \bullet \overrightarrow{w}}{\overrightarrow{n_E} \bullet \overrightarrow{d}} \quad in \quad P_I = P_S + \lambda_I \cdot \overrightarrow{d}$$
$$\rightarrow \quad P_I = P_S + \frac{\overrightarrow{n_E} \bullet \overrightarrow{w}}{\overrightarrow{n_E} \bullet \overrightarrow{d}} \cdot \overrightarrow{d}$$

The GeometryHandler-class utilizes the MS XNA framework. It features specialized analysis functionality such as computation dot and cross products and the normal of a plane. These functions replaced manual calculations and increased the efficiency of the class.

The third feature of the GeometryHandler-class is classifying and weighing points and positions. As mentioned in Chapter 5.4, the focus of this work is not the investigation of *biased free-hand pointing*, but the development of an interactive system using free-hand pointing.
Pointing and aiming points and positions are classified by comparing each axis' values separately. In the current state, the biggest absolute value is considered the dominant value. The combined point or position is then computed by weighing the two inputs 70:30 in favour of the dominant value.

CalibrationHandler.cs Points, planes and positions of an IMI-exhibition are defined and validated by the CalibrationHandler-class. Therefore, two members are used. The first stores the samples per position from which an administrative user is pointing. It is needed to organize the inputs of aiming and pointing `Vectors`. The other member saves the threshold for which points, planes and positions are defined and validated.

To define a `Plane`, three corners are needed. Those corners are points in 3D space. A Point is defined by pointing at it from different pointing locations. This way `Vectors` from various angles define what can be described as a *cloud of intersections*. They are pedal points between every `Vector` with every other `Vector` and computed by an instance of the GeometryHandler-class . Since there are three pointing locations, there are also three `Vectors` for each corner. Hence, each corner's cloud consists of three pedal points. These pedal points are averaged to form a center point.

This process is repeated to validate the once defined corners. Therefore, an administrative user defines the same corners again and the previously defined corners are compared to the newly defined validation corners by checking, whether they lie within the saved threshold. If every pair of corners validates each other, the `Plane` can be saved as the corresponding member of the IMI-exhibition.

Defining the position of an IMI-exhibit is similar to the definition of a corner. An admin points at the exhibit on the earlier defined exhibition plane. This is done from three different pointing locations. Only this time the GeometryHandler-instance does not calculate a pedal point, but the `Vectors`' intersections with the `Plane`. After that, a center of the three points is computed.
A position on an IMI-exhibit has to be validated as well. Hence, the defining processes is repeated and the two centers are compared according to the threshold of the respective IMI-exhibition. If they validate each other, the position is saved for the particular IMI-exhibit. Should corners or a position not successfully validate, the whole definition process has to be repeated.
The definition and validation for both corners and positions are done for pointing and aiming. Thus, there are always two values for each corner or position. These two get classified, weighted and combined into one corner or position after validation. Hence, the reliability of a corner or position is higher, because only validation of both pointing modes yield validation of the combined corner or position value.

SessionHandler.cs All data necessary for interaction is computed by the SessionHandler-class. It determines a user from surrounding visitors and calculates whether a target is pointed at or not. Furthermore, this handler also calculates a user's *feedback position* on the exhibition plane. Thus, a user is able to adjust his or her way of pointing.

For all these calculations the SessionHandler-class needs various members. To determine who is a user amongst visitors, the class stores the predefined user position of an IMI-exhibition as a member upon initialization. Along this particular point it further saves the radius of the interaction space around the user position.
Additional members that are necessary for interacting with the IMI-exhibition are the

exhibition plane, the screen and canvas[26] size. The size of the feedback buffer is a constant member for smoothing a user's feedback position on the display.

A short but important function is the determination of a user. Without the identification of a user, all further interaction is not possible. All trackable visitors recognized by the depth sensor get an Identificator (ID). A `Dictionary` with this ID as `Key` and the respective person's hip-joint position as `Value` is given to a function. This function checks if any of the visitors' hips is within the interaction space defined by the `userPosition` and `radius`. It then returns the ID of the user closest to the IMI-exhibition's user position. Hence, the software knows the ID of the user to further track and hence interact with.
Intersections of `Vector` and `Plane` are calculated by the GeometryHandler, but the intersection is not enough. It has to be checked, if some target was hit or not. This task is done by the SessionHandler. It is very hard to hit just the position of an IMI-exhibit. This is where the aforementioned kernel of an `Exhibit` comes into play. As depicted by Figure 6.4a the kernel defines an *Area of Affinity (AOA)*. The closer an intersection is to the center of the AOA, the higher the affinity for its corresponding `Exhibit`. Thus, the actual size of an IMI-exhibit does not influence its selectability. Only its AOA's properties determine how selectable an IMI-exhibit is. Especially for densely arranged exhibits, this is a useful feature. A small but important object can be given a big kernel size and radius and hence attract more selections than a less important object in its direct proximity (see Figure 6.4b).

26 A canvas is an XAML-element on which the overview, exhibits' positions and later the feedback position are drawn. More about the process in Chapter 6.3.

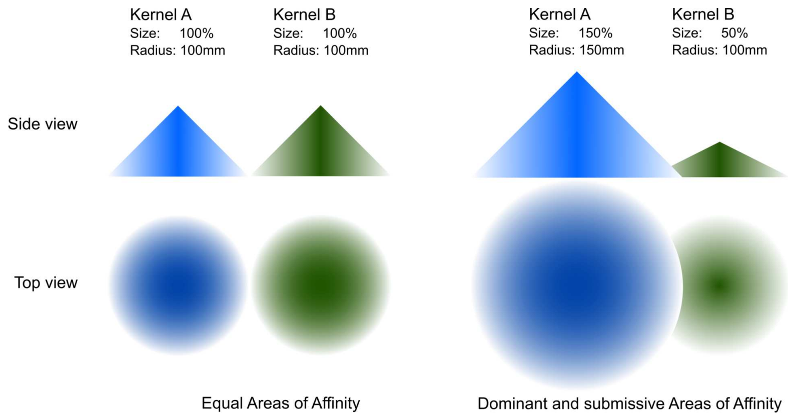

Figure 6.4: The basic principle of a kernels. Two targets with equal kernels (left) and two targets with a big and small AOA (right).

AOAs can overlap each other when IMI-exhibits are very close to each other. In this case, a more dominant kernel with bigger size and radius increases the AOA of the respective IMI-exhibit. Hence, the wider AOA attracts more selections than the one of its neighbor.

To select a target, it has to be determined which AOA has the strongest affinity for the position in question. Therefore, the affinity of each `Exhibit` at this position has to be calculated and it has to be distinguished which one's is the highest. To do that for the whole exhibition plane and all exhibits on it in real turned out to require a lot of computing power. Hence, the efficiency was improved by using a *pre-processed lookup-table of all AOAs*. Therefore, the `Plane` is rasterized by 1000 steps in each direction. In this case each step between the matrix dots is about 3mm. Then, the affinities for each of the matrix dots are calculated. Subsequently, the index[27] of the `Exhibit` with the highest affinity is stored in a *lookup table*. This lookup table is a `Dictionary` with a position as `Key` and the corresponding `Exhibit`'s index as `Value`. After all positions are processed, all positions referring to no IMI-exhibit are removed from the lookup table. Thus, in this case, the number of *pre-determined affinities* is reduced from 1.000.000 to about 50.000. Thereafter, affinities do not have to be computed each frame, but positions are

27 All `Exhibits` of an `Exhibition` are stored in a `List`.

compared[28] with those in the lookup table. If there is a match, the corresponding index is returned.
Every position a user is pointing at is buffered and a smoothened *feedback position* is returned. This feedback position is already converted in `Canvas`-coordinates to match the dimensions of the overview. `Plane`-coordinates have to be converted into `Canvas`-coordinates with the ratios of `Plane` to `Screen` to `Canvas` in mind. Depending on the ratio of the `Plane`, the ratio between `Screen` and `Canvas` changes. This `planeCanvasRatio` is used to calculate the correct position for the representation of the feedback position in an IMI-exhibition's overview. Moreover, it is also used to correctly scale and display the AOA of each `Exhibit` it in the defined position on the overview.

StatisticsHandler.cs Statistical calculations are done by the StatisticsHandler-class. It computes the *mean*, *variance*, *(empiric) standard deviation* and standard error for a sample of `Point3D` or `double`-values. This feature was used for informal analysis of raw data during the iterative development-process. Nevertheless, it might be used for more representative long-term evaluation.

DataLogger.cs The DataLogger-class can be used for saving all kinds of data of the IMI-system. It was developed to write log-files in TXT-format. Therefore, it is possible to initiate an instance with only a file path. After that, new paragraphs can be set up with either a headline or no headline. These paragraphs can then be addressed with an index. Thus, new lines are addable at any point during the runtime of an IMI-application. A logs can be saved as TXT-files anytime, too.
The DataLogger-class was used during the iterative development-process to log pointing and aiming `Vector`s as well as defined points and positions in one file for each subject along with related statistics of these values.
The presentation-software, uses the DataLogger-class to save all events during a session. Thus, the museum is able to keep track of its visitors' behavior and interests. These session-logs can be further analyzed by the IMI-statistics tool described in Chapter 6.4.

28 Pointing positions might not appear in the lookup table. Therefore, the closest position is interpolated.

6.2 Administration Software

An IMI-exhibition and its exhibits are defined with a special application. This software furthermore enables an administrative user to edit any IMI-exhibition or its exhibits. Therefore, the administration software incorporates the functionality of the IMI-system's depth sensor in order to define points and positions. External files such as images and texts can be loaded to enrich IMI-exhibits. Moreover, properties crucial for interaction are also individually adjustable.

To define any point or position, the depth sensor's tracking date has to be usable in real time without compromising the GUI. Thus, the sensor is only activated when it is needed. For the rest of the time, it is shut off. If tracking data is needed, a special thread is started. The tracking-thread is the standard `while`-loop provided by the FUBI framework. During each cycle of the loop the depth sensor updates its tracking data. This data is then accessible by the GUI-thread via functions of the FUBI framework. However, it is not enough to define an exhibition plane or user position of an IMI-exhibition or the position of an IMI-exhibit. For defining any of these yet another thread is needed to make use of the tracking data. Therefore, the `calibrationThread` is used. It is one thread that starts either of the definition-methods mentioned above. Namely they are `definePlane`, `defineUserPosition` and `definePosition`. The definition of the exhibition plane and the definition of an exhibit's position both work quiet similar, whereas the definition of the user position is less complex. For the latter, an administrative user stands at the designated user position and the coordinates of the admin's hip-joint are saved. Defining a position on the exhibition plane or the plane itself is a more involving process.
To define an exhibition plane, an administrative user has to be trackable by the depth sensor. Otherwise, the button to start the process is not visible and thus cannot be pressed. When everything is in order and the button has been pressed, the `calibrationThread` calls the `definePlane`-function. This function is responsible for initiating the sampling-function and determine whether the `Plane` is defined for the first time or to validate the first attempt. In both cases, the function `sampleVectors` is called. To run, it needs the amount of points to define, the amount of pointing locations, the amount of `Vector`s sampled per pointing location and the *sampling mode*. This mode determines, which

kind of samples are taken[29]. The `sampleVectors`-function then initiates the definition process. Therefore, two nested `for`-loops are passed. Both loops provide the instructions for the admin on what to do next. They are displayed on the GUI along with the corresponding ideograms. The outer loop addresses the pointing locations, while the inner one loops over the points to define. This means that the outer loop does three cycles, one for each pointing location. The inner loop does one cycle for each of the three corners. Hence, an administrative user has to go to a pointing location, point at each of the three corners and the move to the next pointing location and repeat the process until each corner has been pointed at from each pointing location. After the first definition, the whole routine to define the exhibition plane is repeated. For the second time the same exhibition plane is defined in order to validate the definitions given in the first step. If either of the corners does not lie within the sufficient accuracy, the whole procedure has to be repeated.

The same procedure applies for defining the position of an IMI-exhibit. Only this time, there is only one position to define and not three points. Hence, the position is pointed at from three pointing locations twice to define and validate its value as described by Figure 6.5.

After a definition the depth sensor is not needed anymore. Hence, both threads can be stopped. First the `calibrationThread` and then the `trackingThread` are aborted. The order is important, because otherwise there will be not tacking data to access and thus memory violations, which might cause the software to crash.

29 Either pointing or aiming `Vector`s are taken. The third sampling mode is to sample both, pointing and aiming `Vector`s simultaneously. The final IMI-system works in this combined sampling mode to compute weighted points and positions as described in Chapter 5.4.

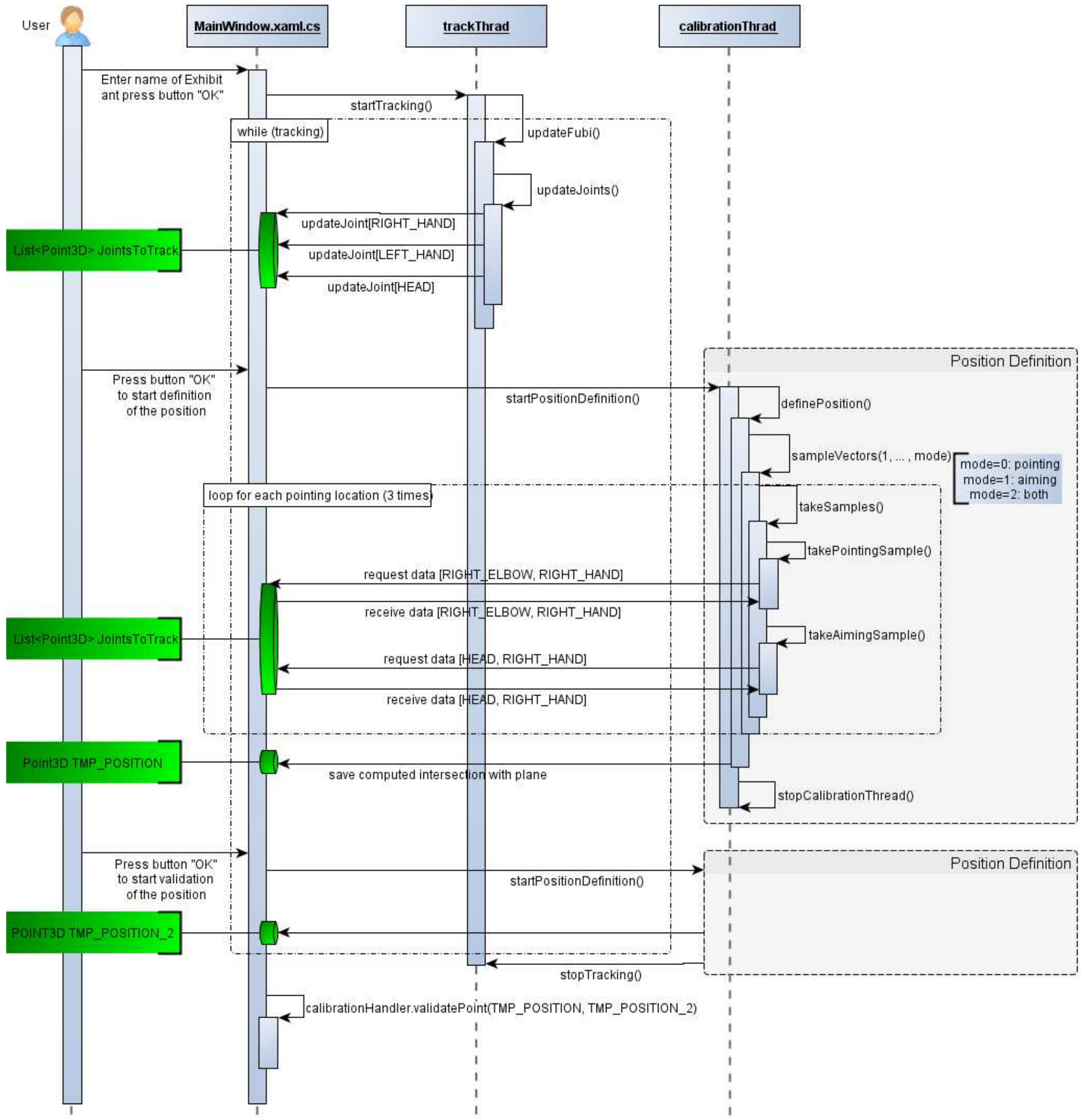

Figure 6.5: Sequence diagram of threads being started and aborted during the definition and validation of a position.

Not only exhibition planes and the position of an IMI-exhibit can be defined with the administration software. The application also enables an administrative user to load particular files to enhance an IMI-exhibition. While all changes are saved automatically, external files have to be explicitly loaded. Files that can be loaded include images, text

files and whole IMI-exhibits as well.
Images are used as the background for the stand by mode and the outlines of the IMI-exhibition for the navigation mode of the presentation software. Furthermore, any detailed photograph of each IMI-exhibit also has to be loaded manually. Images have to be of BMP-, JPG- or PNG-format.
Instead of writing a description for an IMI-exhibit, a previously constructed text can alternatively be loaded into the `textBox`. All files should be TXT-files and coded in UTF-8 to guarantee flawlessly displayed characters.
It is possible to load already existing IMI-exhibits as well. Even if they where defined in the context of another IMI-exhibition, they can be loaded. Afterwards, they will be a valid part of the administered IMI-exhibition. Nevertheless, certain changes might have to be done to properly include them into the new context. Their position might have to be re-defined in order to be selectable, if the exhibition plane or location of the depth sensor are different than before.

All properties of an IMI-exhibit can be edited with the administration software. This includes the aforementioned properties that can be loaded, but also various other ones. Therefore, a special "Properties" section offers each editable property in a drop down menu. The properties vary in type. On the one hand, there are the radius and size of the kernel. Although these are continuous values, the input is restricted to three discreet states to avoid confusion. They are presented as textual entities "low", "normal" and "high" and hence more imaginable representations of a certain percentage of the default value. The low value is 50%, the normal value is 100% and the high value 150% of the respective default value. On the other hand, there is the position of the exhibit itself. This value can be set by defining and validating it again like it is described above.
The view displaying the properties' drop down-menu of an IMI-exhibition can be reached with the same "Properties"-button in the lower left corner of the GUI's view of the exhibition. An IMI-exhibition has more properties than an IMI-exhibit, because it has to regulate the interaction. Here, three types of values are editable. First, there are the two images that can be loaded from this view. Next, continuous values are adjustable as "low", "normal" and "high". They are the threshold to validate new positions, the dwell time for target selection, the time the tracking is paused after selectig a target and the time a slide is shown for. The final property is the user position. This value can be set by a person standing in the user position. Like the definition of any other point or

position, the process can only be started, if the person is trackable.

6.3 Presentation Software

The presentation software is the main interface of the IMI-system. On the very first start of the application, an administrative user has to load the IMI-exhibition that has to be presented from that moment on. The file path to the definition file of the IMI-exhibition is then saved to a local text-file. To change the exhibition, the file path has to be changed to the definition file of another IMI-exhibition. The old file path can also be deleted and the presentation software restarted to load the alternative IMI-exhibition.
After the start of the program, all the IMI-exhibition are loaded. This includes all IMI-exhibits and their external images as well. For proper interaction, the lookup table is computed and all the IMI-exhibits' positions are converted into the corresponding positions on the overview of the exhibition plane to guarantee correct feedback.
When all components of the IMI-exhibition are initialized, the tracking thread of the depth sensor is started. Finally the application goes into the standby mode and waits for visitors.

When at least one visitor enters the sensor's field of view and is recognized, the system reacts. The instructions and ideogram are displayed to invite visitors to actively interact with the system and the `DataLogger` of the presentation software starts the recording of a new session. Furthermore, the software permanently updates a list of all trackable visitors. This list contains their IDs. If a visitor is no longer trackable the corresponding ID is removed from the list.

The software is in a state of active waiting. This means, every time the trackable users are updated so are the coordinated of their hip-joints. If a visitor follows the instruction and gets into the declared interaction space, he or she becomes the active user of the presentation software. The interaction space is marked by foot steps and defined by the `userPosition`-member of the IMI-exhibition.
Once there is a user, several things happen. First, the user's head-, elbow-, and hand-joints are updated by the software to compute pointing and aiming `Vector`s. In addition, the `DataLogger` records a "Start Session"-event along with the exact time, ID of the user and amount of trackable visitors. Next, the navigational view is displayed to provide

visual feedback of all the positions of IMI-exhibits on the exhibition plane and the pointing position of the user, if it lies on the plane as well. Finally, the head,- elbow-, and hand-joints are updated to compute pointing and aiming `Vector`s.

For each cycle of the main tracking thread, the pointing and aiming `Vector`s' intersections with the exhibition plane are calculated and combined into a biased pointing position. This position is then twofoldly analyzed.
First, the pointing position is put into the `feedbackPositionBuffer` and a buffered feedback position is displayed on the overview of the exhibition plane on the display. A buffer is necessary, because otherwise raw pointing positions tend to jitter a lot. This might irritate users and cause frustration. The other process happening with the pointing position is to check, whether it hits a target. Therefore, the lookup table is checked by the `SessionHandler` as described in Chapter 6.1. If there is an entry and a corresponding index of an IMI-exhibit, the index is returned as *temporary target*. Else, the temporary target gets invalidated.

With updating the feedback position on the display, it is also checked, whether the target has changed. Therefore, the temporary target is checked against the actual state of the *marked target*. This actual state can either be invalid when no particular target is marked or the ID of a marked target. Figure 7.1 depicts the evaluation process for marking a new target.

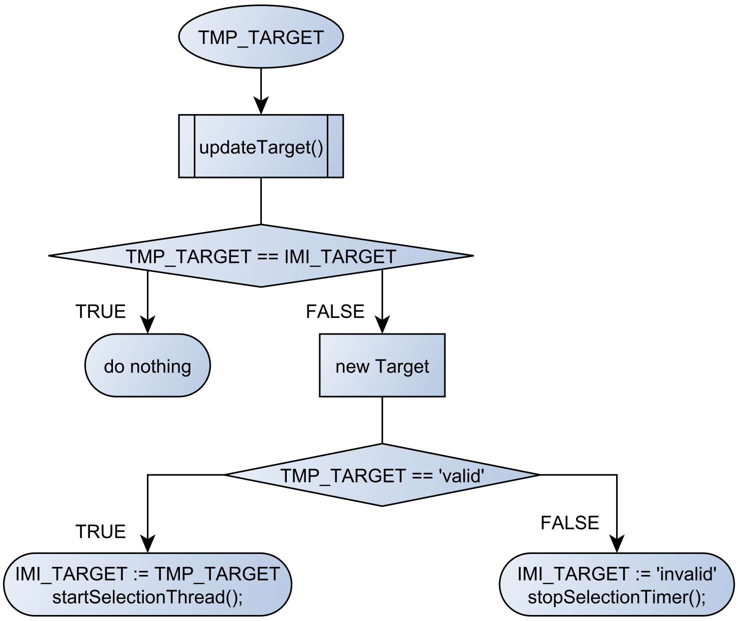

Figure 6.6: Flow chart of the presentation software updating a target for selection.

If the temporary and marked target differ, the temporary target becomes the new marked target. Consequently, the `selectionThread` is started for valid targets. In this case, a ”New Target”-event is saved including the exact time, name of the target, ID of the user and amount of trackable visitors. However, if the `selectionThread` is already running for a previous target, it is aborted and restarted for the new marked target. And the corresponding ”New Target”-event is logged[30].

Before a target gets selected, it has to get marked to start the dwell time defined by the IMI-exhibition. The `selectionThread` selects the IMI-exhibit referred to by its target ID. This happens after waiting for the specific dwell time. During this wait a new target might get marked and the waiting begins all over. When the waiting period is over, the IMI-exhibit is loaded for its presentation. First, the selected IMI-exhibit is set as the program's *temporary IMI-exhibit*. Then, a ”Select Target”-event is stored with the exact

30 This is succession of at least two ”New Target”-events will later be analyzable as a transition. More about the analysis of IMI-events can be found in the *Statistics Tool*-paragraph of this Chapter.

time, name of the target, ID of the user and amount of trackable visitors. Afterwards, the presentational view is loaded with the images and description of temporary IMI-exhibit. Finally, the `presentationThread` is started, the tracking is paused for a few seconds to avoid further selections, and the `selectionThread` is aborted.

The `presentationThread` is loading the name of the IMI-exhibit as headline and its description into the presentation `label`. Further, an image of the IMI-exhibit is loaded into the presentation `pictureBox`. The images are changed after a specific `slideTime`, which is a definable property of each IMI-exhibit, until each picture has been shown. After everything has been displayed and the necessary time to read has elapsed (see Chapter 5.3), the presentation is over and the software switches back to the navigational view. Therefore, the temporary target and IMI-exhibit are reset to be invalid.

Once the list of trackable visitors is empty, the "End Session"-event is stored along with the corresponding timestamp. After that, the duration of the whole session is combuted by calculating the difference between the first "Start Session"-event and the final "End Session"-event. This duration is also logged and the file is stored by the `DataLogger` as a TXT-file. To organize the files in an ordered fashion, the file names include the time of storage along the label as a log-file.

Presentation Remote A remote control to stop and resume the presentation software during guided tours was requested by the museum's staff. Therefore, it should be possible to switch the sensor off and stop tracking visitors. Hence, the presentation software would stay in its hibernation mode and the display would remain camouflaged.

A working prototype of this remote was not finished by the completion of this work. Hence, its functionality could not be properly implemented or tested. The hardware however is already acquired.
The remote is based on MS Gadgeteer and includes a *FEZ Spider Starter Kit* [20] and a *Bluetooth Module* [19]. Because the PC on which the current IMI-system is based supports bluetooth connectivity, the prototype will use similar communication as the *Gadgeteer device*[40] described by Minerva and Dodaro.
In case the limited range of any bluetooth transmitter is insufficient or the shielding of the Haßleben-showcase is to strong for the IMI-remote to work properly, a second option is also possible. This solution could use a *WiFi Module* [23] and work more like the

Gadgeteer Robot [41] also described by Minerva and Dodaro, excluding the additional phone.

6.4 Statistics Tool

The presentation software saves a log-file of each session for review purposes. These files can be analyzed with the statistics tool. Therefore, the tool only has two buttons. By pressing ”Load”, one or more log-files can be loaded into the tool and the amount of loaded files is displayed in a small label. All loaded files get analyzed by pressing ”Analyze”. Consecutively, the tool reads all files and parses them for relevant information. This process takes a few minutes. After parsing all files general statistics of the combined files are computed. The results are displayed within a label of the tool and written to a TXT-file.

The results include the *involvement relation*. It is the relation between empty and evaluable sessions. In an empty session no interaction with the IMI-system occurred. Inferences about the system's recognizability can be drawn from the involvement relation. A low quotient implies a low rate of interaction with the system and appropriate measures should be taken to increase recognizability.
Afterwards, *relevant times* are analyzed with respect to the longest, shortest and average length. The relevant times are the *initiation time*[31] and the *total length* of a session measured from activation to departure. The first time indicates the visitors' inhibition to use the system, while the latter gives an overview of visitors' involvement with the system.
Finally, *exhibit selection* is reviewed. Therefore, two separate values are inspected. The amount of *absolute selections* shows how often each IMI-exhibit was selected over all. The ranking of selections implies visitors' general interest. *Target transitions* are computed as well. A transition occurs when a target does not get selected, but instead another target gets marked. In this case, an *external transition* between the two targets occurs. It might also happen that the pointing position of a user leaves a kernel and re-enters it immediately. Thus, the target also does not get selected, and there is an *internal*

31 Here, initiation time is the time between activation of the system and the first interaction of a user.

transition. Transitions indicate difficulties in selecting certain targets. These targets are either hard to hit on their own or too close to another one. In both cases, however, kernels of the IMI-exhibits in question can be altered and the positions of those exhibits can be re-defined.

7 Evaluation

The IMI-system in its final configuration was developed to be a reliable for every day use and easy to maintain. Although tests in the controlled environment of the lab were promising, it had to proof itself in a realistic scenario. Therefore, the IMI-system was installed inside the Haßleben-showcase. Afterwards, the IMI-exhibition about the showcase was defined by the museum staff and me. The staff was responsible for descriptive texts, detailed images and the overview sketch for proper feedback. Meanwhile, I assisted during the definition of the exhibition plane and the exhibits' positions.
However, in order to determine, whether or not the IMI-system raised awareness for the topic of the showcase a pre-study had to be made. Therefore, the behavior of visitors around the un-augmented showcase had to be observed. In addition, their awareness of the showcase's contents had to be found out as well. Upon this baseline, behavior of visitors with the IMI-system present can be evaluated.
A true insight can only be gained by examining how the IMI-system is accepted by visitors over a longer period of time. Furthermore, they should not be influenced by as less unusual circumstances as possible.

The observation and questioning of visitors mostly leads to qualitative data. This data has to be evaluated differently than quantitative data gained from experimental research. In experimental research, a hypothesis leads to a study that produces data, which is then used to either accept or reject the hypothesis. Methods of grounded theory are more applicable to qualitative data, which is collected before a conclusive theory is shaped [36]. A comparison of the two different evaluation methods can be seen in Figure **??**.

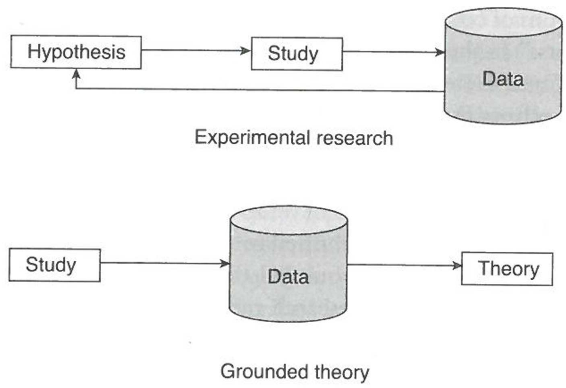

Figure 7.1: Comparison of experimental research (top) and grounded theory (bottom). [36]

The qualitative data of the studies conducted at the Haßleben-showcase consists of descriptive notes of the behavior of visitors and transcripts of their answers during the subsequent interview. The grounded theory method consists of four general stages [36]. The first stage is *open coding*. Here, the texts are analyzed and interesting characteristics are identified. Each characteristic is then coded by a distinctive term. In the next stage, related terms are combined as a concept. After the *development of concepts*, those concepts can be further grouped during the *categorization*-stage. The fourth and final stage is the *formation of a theory*. In our case, however, a weak theory was already available. Nevertheless, this theory could be improved after the pre-study.
In retrospect, we followed a hybrid approach of experimental research and the grounded theory method, where qualitative data is evaluated to specify and improve an existing theory. Furthermore, the pre-study did have an influence on the implementation of the IMI-system and the definition of the IMI-exhibition of the Haßleben-showcase itself.

The observations of visitors around the Haßleben-showcase already had the purpose to gain a basic understanding of visitors' interaction. In contrast to grounded theory, the basic theory that **interaction with exhibits of a showcase raises the awareness about it and its contents** had already been assumed. This means, that casual engagement with a topic increases the knowledge about it.
Related observations have been made with an interactive installation at the Science Museum in London, where visitors, mostly children, were invited by the installation

to interact with it. Therefore, a user had to perform different gestures to trigger an animation. Feedback was given in textual and verbal form [25]. After analyzing their observations with the methods of grounded theory, Haywood and Cairns among other things concluded that

> *"engagement with the exhibit does have parallels with what is needed for successful learning, and this was not previously known."* [25]

Since, the Museum für Ur- und Frühgeschichte Thüringens is regularly visited by classes learning about the Roman age, a similar learning effect was striven for.

During the observations of the studies, the interaction of visitors with the showcase itself and amongst each other was observed and noted. Further, the size of a group of visitors along with their age were noted as well. In some cases the age of visitors had to be estimated. The time visitors spend around the Haßleben-showcase was also measured to be later taken as an indicator for the engagement of the visitors. A correlation of time spend with the showcase as a measure for engagement and the elaborateness of the answers could reveal supportive conclusions, later. When visitors left the Haßleben-room, they were asked about the showcase. The intention was to gain information about their grade of awareness considering the Haßleben-showcase. Therefore, a *semi-structured interview* with each group of visitors leaving the Haßleben-room was conducted.
I further stated that the awareness considering a showcase can be graded into the following three stages:

1. Awareness of its **mere existence**.
2. Awareness of its **general composition**.
3. Awareness of its **specific composition**.

Hence, my questions were intended to grade each group of visitors with respect to those stages. In the end of the interview visitors were asked about their visiting habits concerning museum.

The questions were:

- "Can you remember the grave of the princess of Haßleben?"
- "What can you remember? – What objects were on display?"

- ”What is, in your opinion, shown in the image?”[32]
- ”What would you change (positive or negative)?”
- ”What were you especially interested in? What would you like to know more about?”
- ”Did you read the grave’s explanatory text?”
- ”On what occasions do you usually visit museums and how often?”

All observations and answers were noted in a protocol-sheet. A summarizing table of all the answers can be seen in the Appendix of this work.

7.1 Pre-Study

The Haßleben-showcase is at the beginning of the second room on the second floor of the museum. Visitors approach it from the long side when they walk through the door. There are several related showcases in the room; among them a coffin right in the middle. In the following room, the topic changes. The layout of the rooms can be seen in Figure 7.2. There is a pottery oven in the corner and a bench on front of it. From the bench, I observed visitors in the previous room with the Haßleben-showcase in it. To disguise myself, I had one of the museum’s audio guides[33] with me.

32 An image of a *jewel box* positioned by the feet of the princess from the Haßleben-showcase was shown to the visitors.

33 The Museum für Ur- und Frühgeschichte Thüringens offers audio guides for free. Visitors only have to leave a deposit. The audio guide is an app installed on an iPod Touch. It provides brief information about certain showcases and exhibits. They are identified by a sticker with the number of the corresponding audio track on it. The audio guide has German and English versions of each track.

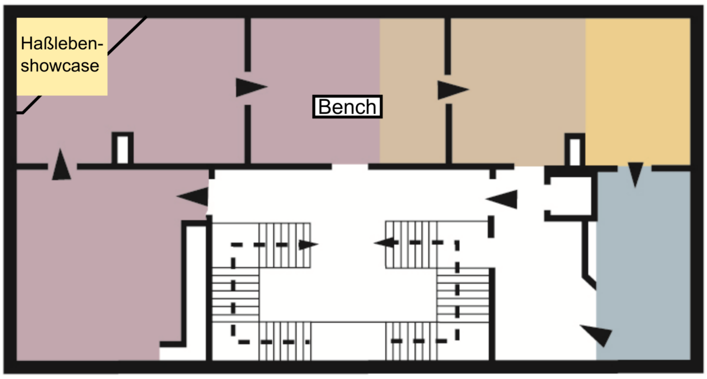

Figure 7.2: Groundplan of the second floor. Topics of the rooms are color coded. The Haßleben-showcase is situated in the first area of the floor.

Observations The pre-study took place from December 18th to 20th 2013 and on January 2nd and 3rd 2014. As museum staff explained, according to their experience the museum is usually well frequented during these dates. During the time of the pre-study, there were two school classes visiting the museum on field trips. A fifth grade could only be observed while walking through the museum. A sixth grade on the other hand, used a workbook provided by the museum. At the time, their topic in class was the Roman age. After their visit of the second floor, they were divided into groups of three or four pupils and given the protocol-sheets as a questionnaire. However, their answers are not taken into consideration here, because the class spent 45 minutes on the 2nd floor and the were not interviewed as the remaining subjects. Nevertheless, both classes' feedback is still noted in the summarizing table, but will not be included in the following analysis. In total, 53 visitors were encountered during the observations. The oldest visitor was 70 and the youngest 4 years of age. All visitors together had an average age of 31 and a half years. The distribution of the whole sample is depicted by the scatter plot in Figure 7.3.

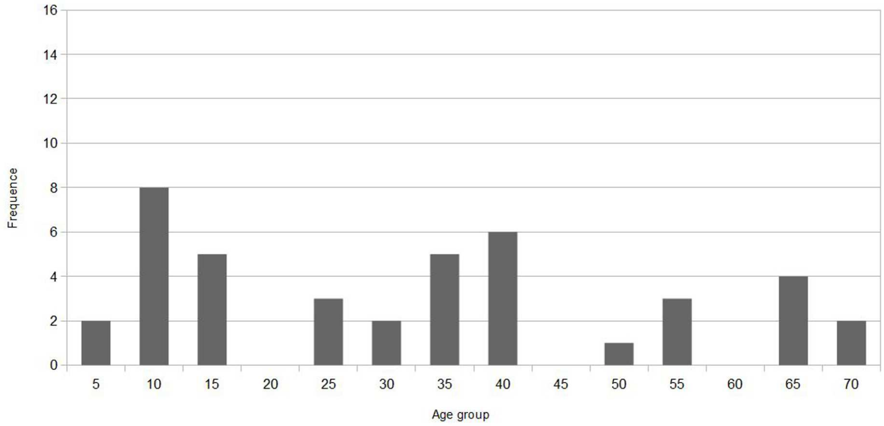

Figure 7.3: Age distribution of visitors and participants of the pre-study.

Those 53 visitors were distributed over 19 groups. Here, the smallest group was a single person, while the largest group included six visitors. The average group size lay between two an three members.

Visitors were observed and interviewed as a group and not individually. Thus, the following answers were given by all individuals of a group and evaluated as the answer of the group. In some cases multiple answers were allowed.

An accurate measurement of the Length of Stay (LOS) for each group was not feasible. Hence, the groups' time with the Haßleben-showcase were categorized into intervals. Table 7.1 shows the distribution of LOS of all observed groups. For one group, a LOS was not specified (n/s).

Length of stay	Occurrence
0s	1
0-30s	4
30-60s	7
1-2min	6
n/s	1

Table 7.1: LOS of groups during the pre-study.

Overall, the observed groups tended to spent less than a minute at the Haßleben-

showcase.
The interaction of visitors with the showcase can be put into three categories. They imply ascending engagement with the exhibits and hence the topic. The first classified observations can be categorized as *indifferent engagement*, where visitors appeared tired or uninterested. The second category includes *appropriate engagement* in the showcase. Here, visitors were looking at the exhibits, but did nothing further. Lastly, *increased engagement* was also observed. Different members of a group act differently around the exhibition. Hence, there are more values than groups in this section of the evaluations.

Interaction with showcase	**Occurrence**
Indifferent Engagement	
Brief glance	1
Hands in pockets	1
Appropriate Engagement	
Looking from broad side (front)	16
Looking from narrow side (feet)	4
Increased Engagement	
Reading the explanatory text	7
Thinking	1

Table 7.2: Interaction of visitors with the Haßleben-showcase during the pre-study.

Visitors interact with each other more than with a static showcase. Again, there is more than one way of interacting within a group of visitors. There might also be no observable interaction at all. Moreover, there were two lone visitors among the observed groups. Hence, there was no possible interaction with any one else and only the interaction between 51 visitors from 17 groups is listed in Table 7.3.

Interaction within groups	**Occurrence**
Movement	
Closed group	31
Clustering in particular places	13
Individually	7
Verbal Interaction	
Explaining	7
Asking Question	4
Discussing	3
Read aloud	1
Gestural Interaction	
Pointing at Exhibits	9
Others	2

Table 7.3: Interaction within groups of visitors during the pre-study.

Like the interaction with the showcase, classified behavior has been categorized into two main categories. The first regards the *movement of groups*. They can move as a closed group or break up into sub-groups and then reunite somewhere. Moreover, lose connections between visitors were also observed, where visitors mostly moved as individuals. The second category is *interaction* and is divided into two sub-categories. First, *verbal interaction* includes all spoken forms of interaction. The other form of observed interaction is *gestural interaction*. Visitors were mostly pointing to emphasize what they were talking about. Also other gestures like describing the shape of an exhibit were observed.

Interviews After a group left the area of the Haßleben-showcase, they were approached and asked, whether they would answer a number of questions. Since, the majority of visitors was German, all questions were asked in German. Five groups did not participate in the interview. Thus, there are only evaluable answers from 14 out of the 19 groups that were observed.

The first question was if they would remember the gravesite of Haßleben. Twelve groups answered that they would remember it and only two admitted that they did not. When I followed up on the positive answers to check if they were correct, it turned out that three groups referred to another showcase on the first floor. Six of the groups were not quite sure and needed a hint.

Remembrance of the showcase	**Occurrence**
Yes	3
Yes (uncertain)	6
Yes (incorrect)	3
No	3

Table 7.4: Participants of the pre-study that remembered the Haßleben-showcase.

All visitors of groups that did not remember the Haßleben-showcase were shown the correct showcase, so every interviewee knew what the actual topic of the questionnaire was.

After the topic was clear, the groups were asked to name as many objects from the Haßleben-showcase as the could remember. In two cases the visitors could not remember anything. Two main categories emerged from the classified answers. First, *jewelry* and second *everyday objects* were identified.

Recalled objects	Occurrence
Jewelry	
Jewelry	8
Necklace (pearls/gems)	7
Ring	5
Torc	2
Jewel box	2
(Hair-)pins	1
Fibula	1
Everyday Objects	
Bowls and pottery	7
Coin(s)	3
Bones on a plate	3
Comb	2
Belt buckle	2
Metal objects by the leg	1
Bucket	1
Skeleton	4

Table 7.5: Objects from the Haßleben-showcase participants of the pre-study's recalled.

Noteworthy about the referred objects is the fact that many of them were rather described than explicitly named. Hence, the explanations of those objects had to be interpreted to be classified.
The visitors imagination and expertise was tested when were shown an image of the remains of the jewel box that is placed by the feet of the princess. The groups were then asked what was in the image. The wood of the jewel box had deterred and only its metal fittings and content, a necklace and fibula, were left.

Interpretations of the image	Occurrence
Jewel box (and content)	7
Necklace and fibula	2
Bracelet and pendant	2
Jewels	2
I don't know	1

Table 7.6: Interpretations of an image of the jewel box by participants of the pre-study.

Half of the groups gave the correct answer and two more groups described the correct content, but did not mention the jewel box itself. Four more groups also tried to describe the content and were less precise. One group could not tell what was depicted on the image.
When asked about the improvements one third of the visitors answered that everything was well end they would not change anything. The remaining recommendations were diverse.

Improvement suggestions	**Occurrence**
Maps of the site of the find	3
More suitable for small children	2
Informational video	2
Better illumination of the showcase	1
Difference between original and replicas	1
Temporal classification	1
Being able to touch things	1
More data	1
Nothing / good as it is	6

Table 7.7: Improvement suggestions for the Haßleben-showcase by participants of the pre-study.

Interests in contents from the showcase	Occurrence
Epoch	
Procedures (daily routines, crafts, rites)	5
Romans and Germans (Tacitus)	1
Historic relevance (3rd - 5th century A.D.)	1
Haßleben	
Date of the excavation	6
Site of the find	5
Princess of Haßleben	4
Further remains (DNA samples)	3
Others	
Pottery	6
History of humankind	6
Reproductions and originals	3
Curb information flood	2
Nothing	11

Table 7.8: Further interests in contents from the Haßleben-showcase by participants of the pre-study.

To get further insight of the engagement of the visitors, they were asked if the have read the explanatory text, which is positioned to the left of the Haßleben-showcase. Eight groups admitted to not having read the description. One lone visitor did not read the text, but knew it from prior visits. The remaining five groups had read the text. Two of those skimmed it.

Read explanatory texts	Occurrence
Yes	3
Yes, skimmed it	2
No, but known	1
No	8

Table 7.9: Participants of the pre-study that have read the explanatory text of the Haßleben-showcase.

At the end of the interview, visitors were asked on why and how often the visit museums. The reasons were sorted into two categories. The visitors go to see museums on *special occasions* and out of certain *interests*.

Occasions for visiting museums	Occurrence
Special occasions	
Trip with family and friends	16
Weather	8
Special exhibitions	2
Interests	
History of humankind	8
General interest	4
History	2
Archeology	1
Museums	1

Table 7.10: Occasions on which participants of the pre-study visit museums.

The frequency at which the groups visit museums varies and the answers to this final question were vague. The two groups that gave precise descriptions also visit museums out of special interests.

Frequency of museums visits	Occurrence
3 to 4 times a year	1
Biannually	1
Once a year	1
Seldom	7
n/s	4

Table 7.11: Frequency of visits to museums by participants of the pre-study.

In succession of the pre-study, the IMI-system was implemented and its technical principles were tested under controlled conditions of a lab (see Chapter 5.4). The subsequent *main study* at the Haßleben-showcase was due when the final installation was ready to work in its real world environment.

7.2 Main Study

The main study was conducted from July 23rd to 27th 2014. The basic procedure of the observation was the same. The behavior of regular visitors and invited participants[34] was noted. After their interaction with the IMI-system, they were interviewed under similar conditions as visitors from the pre-study. Interviews were conducted with all members of a group at once. Thus, answers were given by a group as a unit and hence evaluated as such.
In addition to the questionnaire, the usability of the presentation software of IMI-system was evaluated. Therefore, the Standard Usability Scale (SUS) was determined. The SUS-test is used to gain insight into the subjective usability of a system [24]. It consists of ten statements and users have to rate to which extend they do agree or disagree. The rating is based on agreement of each statement. The scores range from 0% (strongly disagree) to 100% (strongly agree). The average of all ratings combined yields the score of the SUS. A score below 50% indicates problems with a systems usability, whereas a score above 70% is seen as good. Excellent usability of a system begins around 85%. For the main study, the scoring was based on a Likert-scale from 0 (strongly disagree) to 10 (strongly agree) for better orientation.
After the interviews, each visitor was given a form of the SUS-test to fill out. Because most of the participants of the main study were German, the statements of the SUS were in German [47].

Observations In contrast to the pre-study, I did not rely on casual visitors alone. Thus, people were invited to participate in the evaluation of the IMI-system of the Haßleben-showcase. In total, 58 participants took part in the main study. 36 of them were invited participants, while the remaining 22 were regular visitors. The average age of all participants was 31 and 5 month. The youngest visitor was 6 and the oldest 61 years of age. The age distribution of the whole sample is depicted by the scatter plot in Figure 7.4.

34 Invited participants were friends, fellow students and staff of the university and museum.

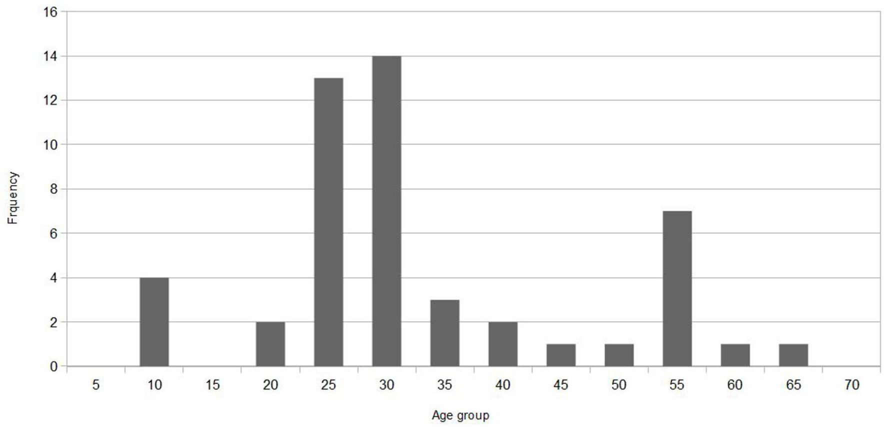

Figure 7.4: Age distribution of visitors and participants of the main study.

Participants and Visitors were distributed over 32 groups. The biggest group had nine members. This time there were 15 lone participants.

The LOS was logged by the presentation software of the IMI-system and evaluated by the statistics tool. The tool revealed an average LOS of 5:25 minutes. The shortest session was over after 48 seconds. However, the longest session took 13:11 minutes. The range of the time participants spent with the system was wide, but half of the groups stayed between two and six minutes. Thereby, it made no difference, whether the participants were casual visitors or invited participants.

Length of stay	Occurrence
0-2min	3
2-4min	9
4-6min	7
6-8min	6
8-10min	3
10-12min	2
12-14min	1
n/s	1

Table 7.12: LOS of groups during the main study.

All observed groups pointed at the IMI-exhibits as it was intended. Nevertheless, there were some unintended ways of pointing as well. Participants attempted *other interaction* in addition to pointing gestures alone. A category of *readability issues* combines observed and reported difficulties that arose during the interaction with the presentation software. The final category of observed behavior of the participants includes *unintended behavior*. The visual feedback was intended for fine adjustments and a general overview. However, many users were predominantly using the visual feedback to hit a target and relied less on their own perception.

Interaction with IMI-system	**Occurrence**
Pointing Issues	
Pointing with left arm	3
Trembling	2
Pointing at display	1
Other Interaction	
Think-aloud	3
Other gestures	1
Readability Issues	
Insufficient time for reading	3
Text too small to read	2
Unintended Behavior	
Over-fixated on visual feedback	16
Indistinct affordance / rash actions	4

Table 7.13: Interaction of visitors with the IMI-system during the main study.

Some participants tended to rash actions as they estimated how the IMI-system would work and started right away without reading the instructions.

Interaction within groups can be ordered into two categories. *Verbal interaction* has been observed in several variations throughout all groups of visitors. A form of non-verbal interaction was categorized as *movement*.

Interaction within groups	Occurrence
Verbal Interaction	
Talking	9
Explaining	4
Discussing	3
Whispering	1
Reading out	1
Movement	
Individually	2
Pointing participant changed	2
Crossed Arms	1
n/s	16

Table 7.14: Interaction within groups of visitors during the main study.

Additional interaction within the group was not observable for lone participants.

Interviews All groups of visitors were interviewed after their interaction with the IMI-system. They were asked the same questions like the groups of the pre-study. Thus, again the first question was, whether they would remember the gravesite of Haßleben. All groups except one did remember the Haßleben-showcase.

Remembrance of the showcase	Occurrence
Yes	31
No	1

Table 7.15: Overview of how many participants of the main study remembered the Haßleben-showcase.

The following question targeted the memory of the groups. Hence, visitors were asked to name as many things inside the showcase as they could remember. The answers can be assigned to one of two main categories. Participants recalled *jewelry* and *everyday objects*. Additionally, they named a few things that were not inside the showcase.

Recalled objects	**Occurrence**
Jewelry	
Jewelry	12
Hairpins	12
Golden ring	12
Necklace	12
Box brooch ("Dosenfibel")	11
Jewel box	5
Torc	4
Fibula	4
Earrings	3
Everyday Objects	
Bowls and pottery	22
Coin(s)	13
Silver plate	12
Key (to the jewel box)	7
Belt buckle	4
Personal and household items	2
Comb	1
Skeleton of the princess	16
Skeleton of the dog	14
Dirt and stones	2
Not in the showcase	
Silver box	1
Bag	1
Spear head	1

Table 7.16: Objects from the Haßleben-showcase participants of the main study's recalled.

Re-organizing the categories by other properties of the exhibits that were remembered reveals, that more than half of the objects mentioned by the visitors were IMI-exhibits. Table 7.17 shows the exact relation of normal and interactive exhibits.

Recalled object	**Occurrence**
IMI-exhibit	80
Other exhibit	67

Table 7.17: Relation of interactive to non-interactive objects from the Haßleben-showcase recalled by the participants.

When presented with an image of the jewel box placed by the feet of the princess of Haßleben, 12 out of the 32 groups recognized the jewel box. 11 others groups described the correct contents of the jewel box, while the remaining nine groups' answers were not correct.

Interpretations of the image	**Occurrence**
Jewel box	12
Remains of a necklace	11
Pearls	1
Bracelet	1
Ring	3
I don't know	2
Key	1
Earring	1

Table 7.18: Interpretations of an image of the jewel box by participants of the main study.

In succession of questions concerning the memorability of the exhibits, participants were asked what they would change about the showcase. Their feedback could be of a positive or negative nature. The participants identified *general aspects* about the showcase and its contents that needed improvement. Further, participants gave feedback concerning the IMI-system. It is categorized as *feedback*-, *readability*-, and *interaction*-relevant.

Improvement suggestions	**Occurrence**
General Aspects	
Visibility of exhibits (occlusion, reflections)	13
Less trivia and more background information	2
Reconstruction of the jewel box	1
Feedback	
Improve feedback on exhibition plane itself	6
Reduce trembling	3
Additional instructions (sign or note)	3
Readability	
More time to read / general Readability	6
Bigger display in another position	4
Optimize layout (text and images are too much)	1
Interaction	
Free movement	4
Further gestures	3
Pointing for multiple users	1
Improve recognition for children	1
Pointing for left-handed users	1
Others	
More interactive exhibits	4
Clear separation of exhibits	2
Music or sounds	1

Table 7.19: Improvement suggestions for the Haßleben-showcase by participants of the main study.

Participants were also asked what they would like to know more about after having seen the Haßleben-showcase. The categrories for interest of the visitors are about the *general topic* of the exhibition and about the *showcase* and its particular *exhibits* as well. Some groups of visitors requested more interactive exhibits.

Interests in contents from the showcase	Occurrence
Showcase	
Historical significance of the findings	8
Information about the princess	4
Information about Haßleben	1
Exhibits	
Skeleton of the dog	4
Box brooch (Dosenfibel)	2
Information about grave furnishings	2
Skeleton of the princess	2
Information about the jewelry	1
Information about the coins	1
Information about the comb	1
General Topic	
General information about the topic	4
Live back then (Roman age)	3
More IMI-exhibits	3

Table 7.20: Further interests in contents from the Haßleben-showcase by participants of the main study.

During the main study, three groups have read the explanatory text of the Haßleben-showcase, while the remaining 29 groups did not do that. Three groups however already knew the text and thus did not read it again.

Read explanatory texts	Occurrence
Yes	2
Yes, skimmed it	1
No, but known	3
No, because of audio guide	2
No	24

Table 7.21: Participants of the main study that have read the explanatory text of the Haßleben-showcase.

Toward the end of the interview, participants were asked under what circumstances they usually visit a museum. The majority replied that *spacial occasions* and certain *interests* were their motivation, but also *fees* were identified as one of the decisive categories.

Occasions for visiting museums	Occurrence
Special occasions	
Vacation (city trips)	21
Special exhibitions	8
Trip with family and friends	4
Open museums' night	3
Weather	2
Interests	
Topical relevance	6
Art exhibitions	3
Work	3
Fees	
Free admission	3
Special prices	3
Others	
Boredom	3
Novelties	1

Table 7.22: Occasions on which participants of the main study visit museums.

The final question was how often participants do frequent a museum. The answers were varied from monthly over biannually and up to once in a decade.

Frequency of museums visits	Occurrence
Once a decade	1
Seldom	2
Once a year	2
Two or three times a year	10
Biannually	4
Once a quarter	3
Two or three times a quarter	4
Monthly	1

Table 7.23: Frequency of visits to museums by participants of the main study.

Usability Test The evaluation of the presentation software was done after the interview. Therefore, each participant was given a copy of the SUS-questionnaire. They filled it out and gave it back after finishing it. I stood a few meters away in order to not influence the participants and being available in case of uncertainty about one of the statements. 36 SUS-questionnaires were handed in at the end of the main study.

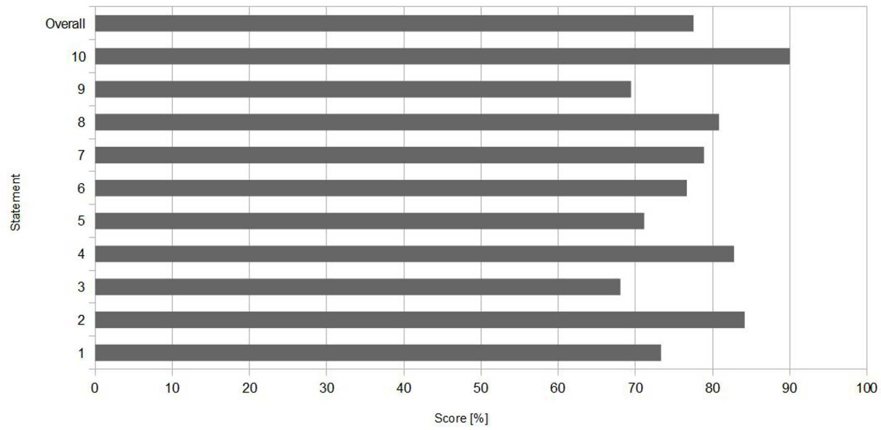

Figure 7.5: Results of the SUS-questionnaire.

Figure 7.5 depicts the separate scores for each statement of the SUS-questionnaire alongside the final score. The statements od the SUS-questionnaire are alternately formulated positive and negative. The depicted scores are already compensating for that. The overall score is 77,53%, which is a good score. The scores for the separate statements ranged from a satisfactory 68.06% to an excellent 90%.

7.3 Post-Study

The final IMI-system has been installed at the Haßleben-showcase prior to the main study. Since then, it runs on a daily basis and is used by visitors of the museum. Meanwhile, log-files of each session are created and stored.

From July 29th to September 1st, the data of visitors using the IMI-system was evaluated as a long term post-study under real life conditions. After this period of about two months, the log-files were evaluated with the statistics tool of the IMI-system to gain information about the acceptance and usage of the system.
Overall 410 sessions were recorded during this period. 206 of them were *empty sessions*,

which means that no interaction was recorded[35]. However, the remaining 204 sessions included the recordings of events during *active sessions*. Hence, probably more than half of the visiting groups interacted the system to acquire information about the exhibits inside the Haßleben-showcase.
On average the interaction lasted for 1:34 minutes. Meanwhile, the variation of the time visitors used the IMI-system varied between 11 seconds and 11:43 minutes.
During those 204 active sessions a total of 392 IMI-exhibits were selected by users and presented by the presentation software. The share of each IMI-exhibit is depicted by Figure 7.6.

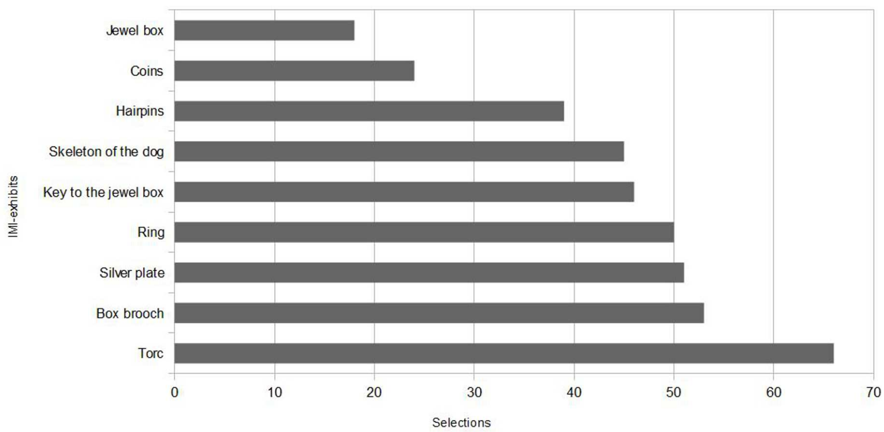

Figure 7.6: Overview of selected IMI-exhibits during the post-study.

The difficulty of selecting a target can be described by a *selectivity quota*. Here, this is the relation of events for selecting and marking a target. This quota indicates how well a certain target can be selected. A high quota indicates a good selectivity. If the quota is too low the position or kernel of the respective IMI-exhibit have to be adjusted to compensate, because the pointing position too often leaves and re-enters the kernel of the target. In the case of this long term post-study the selectivity quota for each IMI-exhibit of the Haßleben-showcase is shown in Figure 7.7.

35 Empty sessions occur when visitors are trackable by the depth sensor but did not interact with presentation software. Moreover, groups of visitors do count as well as staff that is passing by the showcase while doing their daily work.

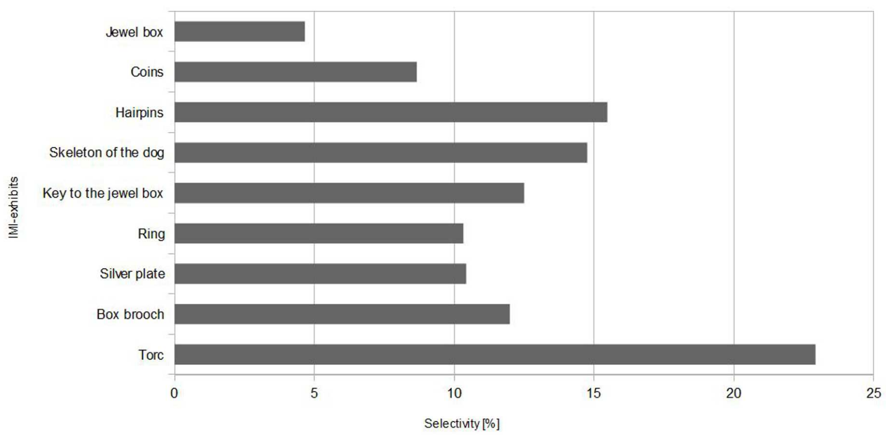

Figure 7.7: Overview of the selectivity for each IMI-exhibit during the post-study.

Another sign for an intricate selection of targets is a high rate of transitions between two different targets. There are many transitions between certain pairs of targets. This indicates that the IMI-system has difficulties in distinguishing between the intended targets. These pairs of targets either lie very close to each other or it can be the same target twice (selectivity quota). A high number of transitions of the first constellation tells that the respective IMI-exhibits need to be separated more clearly from each other. Also stricter separation by the kernels is a way to improve on that matter.

Out of 72 possible transitions between different targets only 36 actually happened. The most common transitions are listed in Table 7.24. From this ranking it is clear that distinguishing the torc from the hairpins is the most difficult task of the IMI-exhibition inside the Haßleben-showcase.

Transition	Occurrence
Torc $\leftrightarrow$ Hairpins	777
Coins $\leftrightarrow$ Torc	517
Coins $\leftrightarrow$ Hairpins	374
Key $\leftrightarrow$ Ring	198
Silver plate $\leftrightarrow$ Ring	92
Box brooch $\leftrightarrow$ Coins	85
Box brooch $\leftrightarrow$ Hairpins	82
Key to the jewel box $\leftrightarrow$ Silver plate	67
Skeleton of the dog $\leftrightarrow$ Torc	64
Hairpins $\leftrightarrow$ Skeleton of the dog	36

Table 7.24: Transitions between targets during the long-term post-study.

The age of the visitors that used the IMI-system could not be resolved. Assuming the demographics offered by the sample of the pre-study was representative for casual visitors, logged sessions can be associated with this sample. Further, the museum is also visited by school classes on excursions and the population has to be adjusted accordingly. Hence, the complete table of all observed visitors during the pre-study, which included to school classes, can be seen as representative for the age distribution of the post-study. This results in a lower average age of

8 Discussion

The pre- and main study were conducted during a period of five days. They both compare the awareness of visitors concerning the Haßleben-showcase and its exhibits. Therefore, visitors were observed during their time around the showcase and interviewed afterwards. The questions aimed at the participants' *stages of awareness* introduced in the previous chapter.
Moreover, a post-study was evaluated to gain an idea of how the IMI-system was used by visitors when they did not feel monitored. Furthermore, the stored data can give an insight into necessary improvements of the current IMI-exhibition of the Haßleben-showcase. Visitors were monitored over a period of 35 days. During this time, 410 sessions were stored. About half of them included records of active interaction. This means that there were between 5 and 6 sessions of visitors interacting with the IMI-system inside the Haßleben-showcase per day.

Samples and Comparability During the pre-study 53 visitors participated in the interviews. They were distributed over 19 groups. That is an average group size of about 2.8 visitors per group. Their average age was 31.51 years. The properties of average age and group size of pre-study and main study are approximately the same. In the main study, 58 participants from 32 groups were participating. The average group size of 1.8 was considerable lower. The age was nearly identical. The average age of participants from the main study was 31.43 year. Participants of the pre-study were 31.51 years on average. However, the median of the pre-study was 33 years of age, whilst the main study's participants had a median age of 28 years. A juxtaposition of the two age distributions can be seen in Figure 8.1.

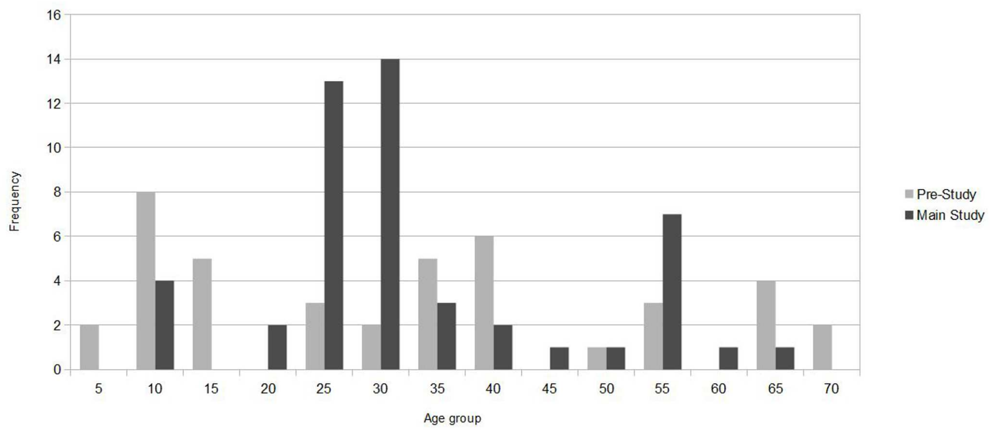

Figure 8.1: Age distribution of participants from the pre- and main study.

The studies can not be treated as a between-subjects test. Reason for this restriction is the distribution of the participants' ages. Both samples do have the same average age, yet the distribution of their ages varies. While the sample of the main study is mostly normally distributed, the sample of the pre-study is not. This distribution is trimodal, because the visitors were children, adults, and seniors. Meanwhile, participants of the main study were mostly students and research assistants. This means that both studies' participants might have had a similar average age, but the reason for this fact is different. Hence, the samples are not statistically comparable when it comes to that particular criteria.

The majority of all casual visitors and invited participants of both studies were on an identical level of knowledge about the Haßleben-showcase. Thus, their engagement with the IMI-system can be seen as impartial. There were sufficiently less casual visitors among the sample of the main study and, therefore, more technical experienced participants. Those pre-recruited participants might have been less restrained in using novel technologies. Their technical expertise, however, was of little use, because no devices had to be operated and the GUI of the presentation software had not been shown to anyone prior to the main study. Hence, all participants, casual and invited, had to rely on their physical capabilities alone. Furthermore, only a few had prior knowledge of the contents of the IMI-exhibition inside the Haßleben-showcase. Consequently, the answers of both samples can be seen as equally impartial, while the interaction of several pre-recruited participants is more experienced.

Observed Interactions The first value observed about groups around the Haßleben-showcase was the LOS, the duration visitors and participants were addressing the showcase. Due to the way visitors were observed, a precise timing for each group was not possible. Hence, the LOS was categorized in intervals of thirty seconds or by a minute. The average time visitors spent with the showcase was around one minute. The longest stay that was observed did not last longer than two minutes, while the shortest was between 0 and 30 seconds long. The shorted session during the main study was 48 seconds and the longest session took 13:11 minutes. On average the LOS was 5:25 minutes. However, the pre-recruited participants were present to evaluate the presentation software and, therefore, stayed longer and were more engaged with the IMI-system. Hence, the average and maximum LOS of this sample is so much longer. Nevertheless, the post-study was conducted under daily circumstances and it revealed that the average LOS was 1:34 minutes. This means an increase of the average LOS of about 50%. The difference between the longest (11:43 minutes) and shortest (11 seconds) stay was similar to that of the main study, whereas the observations from the pre-study only showed a small range of only two minutes. Thus, the shortest stay could not be improved by much, but the longest stay was increased nearly sixfold.
In conclusion to these observations, visitors spent significantly more time with the Haßleben-showcase than before. Hence, the visitors are more engaged with the Haßleben-showcase. This should raise their awareness of its existence, as stated in Chapter 7.

During the pre-study visitors perceived the Haßleben-showcase like any other showcase of the museum. They approached it and looked at the exhibits inside the showcase. Visitors did that from the broad and narrow side, whereas the narrow side was used four times less than the broad side. Seven groups out of 19 read the explanatory text. One visitor seemed to think about something and tried to look it up in the text. Some visitors went past the showcase or only glanced at its contents. The main study introduced the IMI-system to the showcase and all visitors and participants were looking into the grave. The display drew their interest and they started interacting with the IMI-system. Nearly every participant gave it a try and started pointing. Thereby, some issues arose. The main observation was that half of the 32 groups were over-fixated on the visual feedback

given by the navigational view of the presentation software. Thus, they did not use the feedback to fine tune their pointing, but completely relied on it. Because the display was raised and not in their direct view on the exhibition plane, the feedback positions of the users began to tremble. The movement of their head to look up had changed their aiming position and consequently the feedback position as well. Additionally, some participants perceived the interface to be more natural than it was, and pointed with their left arm or tried other gestures such as a swiping move to change the images during the presentation of an IMI-exhibit. Another fact that could be observed was that the readability was compromised by two factors. The letters or the display were too small and previously calculated time for reading was too short.
It was not feasible to observe interactions of visitors during the post-study. Nevertheless, the amount of active sessions shows that the IMI-system is used on a day to day basis by the regular audience of the museum. The quote of about 1:1 between active and empty sessions, however, does not have to necessarily mean that only 50% of all visitors take notice of the exhibits inside the Haßleben-showcase. When the durations of empty sessions would be evaluated as well, they should show for how long non-interacting visitors stay around the showcase. Their LOS might also be longer than it was observed during the pre-study.
Conclusively, it can be said that the presence of the IMI-system has increased the engagement of visitors with the Haßleben-showcase and the IMI-exhibits inside it. There are indicators for issues that need to be addressed to improve the interaction of visitors with the presentation software.

After the augmentation of the Haßleben-showcase with the IMI-system, visitors were more engaged with the exhibition. This involvement also influenced the interaction between visitors. Thus, their behavior among each other changed as well. During the pre-study, visitors moved in closed groups, clustered in particular places or walked through the museum floor individually. 31 out of the 51 visitors that were observed moved as a closed group. That is 60.8% of all visitors. 25.5% moved individually and clustered in particular places and the remaining 5.7% (seven visitors) were moving detached from their group. In the main study only two cases of individual movement were observed. Moreover, verbal interaction within the groups increased. 15 cases of verbal interaction by 17 groups of visitors of the pre-study were observed. Meanwhile, 18 cases of talking, explaining, discussing, whispering and reading out loud were observed

among the 17 groups. Lone visitors and participants were not taken into consideration, although at least one lone user was overheard thinking aloud during the main study.
In summary, visitors and participants of the main study showed more interaction overall. Modalities of the interaction with the IMI-system were a topic, but also the contents of the presentations were discussed. Altogether, the possibility of interacting with the IMI-system increases the engagement of visitors with the IMI-exhibits inside the Haßleben-showcase and promotes the interaction within a group.

Interviews Visitors of both the pre- and the main study were asked if they would remember the grave of the princess of Haßleben. Nine groups from the pre-study did remember the Haßleben-showcase correctly, whereas the rest did not, recalled a wrong showcase or did not take part in the interview. This means that 60% correctly remembered the showcase they had seen a few moments earlier. During the main study, 31 out of 32 interviewed groups recalled the Haßleben-showcase. This confirms the aforementioned first stage of awareness, which refers to the awareness of a showcase's existence. Hence, the engagement through interaction with the IMI-exhibits inside the showcase increased the visitors' awareness of it.
Unfortunately, this conclusion can not confirmed. Only four of the 32 groups of the main study were not previously informed, what the study was about. The remaining 28 groups were either invited or museum staff. It cannot be said with certainty how many of the positive answers were given under the influence of the invitation itself. In order to get a valid and comparable result to this question, casual visitors will have to be asked after leaving the area of the Haßleben-showcase.

The following question aimed at the next stage of awareness. All Participants were asked what they could remember about the Haßleben-showcase and what objects were on display. In both studies, two main categories included most of the objects inside the showcase. They are jewelry and everyday objects. During the pre-study all kinds of jewelry were remembered 26 times and 19 everyday objects were named. additionally, the skeleton itself was recalled 4 times. That is 39 objects in total by 14 groups taking part in the interview. For the same quota, participants of the main study would have had to remember a total of 89 objects from all categories and the skeleton. However, the participants of the main study recalled 178 objects. That is exactly twice as much as their predecessors. 75 jewelry-related and 61 everyday objects were named. In addition,

the skeleton of the princess was named 16 times. This is four times more often than during the pre-study. Participants of the main study might have been more alert due to their motivation for being at the museum. Nevertheless, this could also be the effect of increased awareness caused be engagement with the IMI-system.
Moreover, participants remembered more IMI-exhibits than other exhibits from the Haßleben-showcase. In total, 80 IMI-exhibits were named by the 35 groups, whereas only 67 non-interactive exhibits were recalled. This is still more than the total amount of the pre-study. Furthermore, participants of the main study were able to name objects that were never mentioned by the previous groups. For instance, no one of the interviewed participants from the pre-study named the box brooch, silver plate, key to the jewel box or the skeleton of the dog. These IMI-exhibits alone were named 44 times.
Summarizing, participants of the main study were able to recall distinctly more exhibits than those of the pre-study. Pre-recruited participants were informed about the evaluation of the system, but not about the contents of the interview. They were prepared to test a novel kind of interaction. This statement was confirmed by a number of invited participants after the main study. Hence, it can be concluded that the engagement with the IMI-system increased the participants' awareness of composition of the Haßleben-showcase.

In succession of the remembering task, all groups of participants were shown an image of the jewel case located by the feet of the princess of Haßleben and asked what they think it was. The necessary information was given by the explanatory text, the audio guide, and by the presentation software of the IMI-system upon selection of the jewel box. Seven groups of the pre-study and 12 groups of the main study were able to name the object in the image correctly. That is about the same rate for both studies. However, only two groups of the pre-study identified the remains of the contents of the jewel box. During the main study, 11 groups managed to name at least the content of the jewel box.
After all, the jewel box itself was equally as often recognized by participants of both studies. The content of the jewel case, however, was correctly identified by the groups of the main study about three times as often as by those of the pre-study.

When participants where asked what they would change about the Haßleben-showcase, the answers varied. Participants of the pre-study asked for a map of the site of the find. There is a map of the site above the explanatory text. The three groups that

gave this answer did not see it, though. The next topic was suitability for children. Parents criticized the height of the showcase. The visual angle at which small children look at the showcase does not allow a good overview. The most frequent answer was that everything was fine and nothing should be changed. This reaction either indicates a bias towards conformity with the current state of the Haßleben-showcase or participants were not motivated any more. This lack of motivation might have been induced by the time they had already spent at the museum beforehand.
Participants of the main study, however, were more critical. They addressed their issues with the IMI-system. According to them, certain aspects of the feedback, readability and interaction should be improved. Furthermore, they also mentioned general aspects about the Haßleben-showcase. The visibility of exhibits was most commonly addressed. Occlusions, reflections, and other lighting-related issues were mentioned. Further, it was observed but never mentioned that small children were not recognized by the system. Hence, the suitability for children is another issue that needs improvement.
In summary, participants of the pre-study were more concerned about topical facts, whereas participants of the main study gave more feedback about their experience with the IMI-system.

After the general feedback, the interview got more precise and participants were asked what they were especially interested in and would like to know more about. Again, the groups of the pre-study gave rather general answers. The epoch and its procedures were mentioned seven times, more information about the whole gravesite of Haßleben were requested 18 times, and other topics were mentioned 17 times. The most frequently given answer was "nothing". Participants replied eleven times that they would not like to know anything more about the Haßleben-showcase.
During the main study, participants would request further information about the historical significance of the findings eight times. Information about particular exhibits were mentioned thirteen times. Six of them were the skeleton of the dog an the box brooch. As mentioned above, those IMI-exhibits were not even named by the groups of the pre-study, when the were asked to recall objects from the Haßleben-showcase. In addition, three groups asked for more IMI-exhibits inside the showcase.
In conclusion, the IMI-system increased the awareness of the contents of the Haßleben-showcase. This is done to such an extent that several groups from the main study reached the third stage of awareness and requested more specific knowledge about cer-

tain exhibits. These *exhibits of increased interest* were not only interactive, but also a comb that was recalled only once.

When participants were asked whether or not they had read the explanatory text, five members of groups of the pre-study and three of the main study did so. The rest did not read the related information about the gravesite of Haßleben. Hence, only a few participants were willing to read additional information. Nevertheless, as answers of the previous questions revealed, the participants of the main study were better informed about the Haßleben-showcase than those of the pre-study were.

In the end, participants had to tell their usual reasons for visiting a museum. Here, the answers of groups of the two studies were alike. Both named special occasions and interests as main categories for their visits. Participants of the main study further referred to reduced fees as an appealing reason for visiting a museum.
Finally, members of all groups were asked how often they do visit a museum. The participants of the pre-study were vague about their answers. "Seldom" was the major answer followed by no concrete answer. Only three groups gave a definite stretch of time. They stated to visit a museum once a year, biannually and three to four times a year. The participants of the main study were more precise and their answers raged from "once a decade" to "monthly". The majority, however, said they would visit museums two or three times a year.

Standard Usability Scale-Questionnaire The SUS-questionnaire was done by 36 participants of the main study. The presentation software of the IMI-system installed inside the Haßleben-showcase achieved an overall score of 77.53%. This is a good score and pleads for a good usability of the presentation software of the IMI-system.
The difference between the highest and lowest score is 21.94%. However, the lowest score is 68.08%. This is only a little below the threshold of 70%, which implies a good value. The statement that caused the lowest score was the third: "I thought the system was easy to use." This means that some users thought the presentation software was not easy to use. Four of them rated this statement with 30% and one user gave it 20%. Without their verdict, the score would have been 74.52%. At this point, it has to be mentioned, that the presentation software of the IMI-system froze with two of those users. Since

then, the error has been identified and fixed[36]. The ease of use could be further improved by addressing the feedback, participants gave regarding the visual feedback and readability of the IMI-system.
The best score of the SUS-questionnaire was the tenth statement. It says: "I needed to learn a lot of things before I could get going with this system." This statement was confirmed with only 10%, which yields a compensated score of 90% for this statement. Hence, the users felt the presentation software was very intuitive to use and did not require a lot of prior knowledge.

The SUS-questionnaire is a *quick and dirty*-method for gather information about the usability of a system. Moreover, it only represents the subjective perception of the usability. Nevertheless, it yielded promising results for possible further investigation of interaction via free-hand pointing gestures.

Conclusion The IMI-system reliably works in a real world environment and on a daily basis. Hence, the developed system complies to our initial ambitions.

The three stages of awareness described in Chapter 7 were recognizable with the participants of the main study. However, the groups of both studies were similarly treated and had about the same level of prior knowledge about the Haßleben-showcase. Concerning their background and motivation of visiting the museum during the days of the different studies were not comparable, though. Hence, further investigation of regular visitors is necessary to gain completely conclusive results.

Finally, interaction by free-hand pointing gestures is as natural and intuitive as previously estimated. Observed visitors not show great shyness or restraint to use the system. Because the IMI-system is an augmentation and not a fundamental part of the showcase, the exhibition is not disturbed. With low cost and little effort, the IMI-system is able to augment a showcase of an exhibition or other presentable setups.

36 The system unintendedly paused the `trackingThread` and did not resume it after the `lockTime` was over. Similar to the description of the definition and validation of a position in Chapter 6.2, the thread responsible for tracking was aborted by a thread, that also aborted, before it could re-start the tracking thread.

9 Future Work

During the development and implementation of free-hand pointing gestures as input for a public interface, new and interesting perspectives on this style of interaction appeared. The IMI-system as such reliably works and has become an established part of the Museum für Ur- und Frühgeschichte Thüringens. My initial theory has been proved by the pre- and main study thus far. The presence of an interactive installation increases the engagement of visitors with the Haßleben-showcase and their awareness of the topic. Whether the interaction is successful or not did not seem to matter that much. The attention it creates provokes engagement with visitors, because they look at the exhibits more carefully once they are pointing at them.
Nevertheless, there is room for improvements and further research. Talking to staff of the museum and the university, fellow students and participants of the studies revealed many exciting ways to extend or improve the IMI-system.

While developing the basic functionality of free-hand pointing interaction, some problems were encountered and overcome with sufficient success for the IMI-system to work properly. Yet, these issues present opportunities to improve the interaction.
The first technical issue is the *angular error*, which is explained in Chapter 5.3. The pointing position of a user is prone to error, which is directly related to the angle of impact of the pointing vector onto the exhibition plane. To minimize this another aspect of improper pointing was utilized as a counter measure. *Eye-hand missmatch* makes a user point and aim at two different positions on the exhibition plane. The IMI-system computes an average position of the two. To calculate the position, it is assumed, that either of the vectors is dominant and the combined position is biased in favor of this vector's pointing position. The dominant vector, however, is determined by each of its axes absolute value in comparison to the other vectors values. Future research might find a more reliable way of this determination. Subjects could be observed more closely while pointing and physiological aspects could be taken into consideration as well. As

Figure 9.1 depicts, pointing with the right arm results in a drift of the pointing position to the left, whereas the aiming vector tends to go to the right.

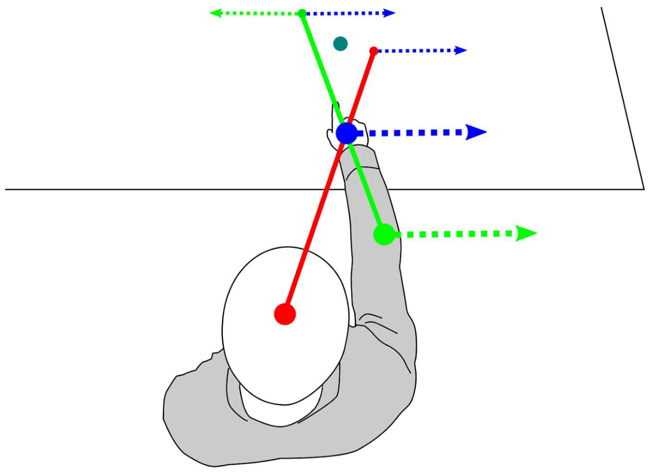

Figure 9.1: Leaver effects of free-hand pointing gestures.

As the elbow moves outwards, the pointing position moves to the left. Here, the hand acts as a pivot point. The same applies for the head and hand. Only if the hand moves outward, the aiming position moves with it. This time, the head is the pivot point. Hence, each joint can act as a pivot point. Recognizing and compensating those effects can result in a more reliable computation of a pointing position.

Kernel functions were not entirely investigated. The current IMI-system uses a basic triangular function. The linear characteristics of affinity might be a problem in target selection. Dominant and submissive properties are modulated by the maximum value and the radius of the kernel. Non-linear functions could improve on these properties.
Towards the end of the implementation functionalities of the MS XNA Framework were used to calculate intersections. The XNA Framework defines basic geometrical shapes like planes, spheres and boxes [39]. Those shapes could be used to define new kernel functions. Furthermore, IMI-exhibits could be defined in 3D space with a bounding sphere as a kernel around it. Hence, the exhibition plane might be obsolete. This would present many of new possibilities for public interaction with free-hand pointing gestures.

Discussions with fellow students and staff of the museum and faculty brought up the question of combining the IMI-system with *tangibles* and *mobile devices*. A possible inclusion of tangibles is introduced in Chapter 4.2 under 'Tangibles' and in Chapter 6.3 by the concept of the *presentation remote*.
Mobile devices could also be addressed by wireless communication like bluetooth or WiFi. For instance, the audio guide at the Museum für Ur- und Frühgeschichte Thüringens is based on an iPod Touch. These devices could be utilized by another IMI-application to display the specific information of an IMI-exhibit in addition to the main screen of the IMI-system inside a showcase.

The studies confirmed the request for the aforementioned improvements and led to further possible alterations and upgrades of the IMI-system. The two most frequently mentioned aspects of the IMI-system that need revisiting is the feedback and the readability of the presentation software. Participants of the main study communicated that the visual feedback presented on the display was helpful, but to inconvenient. They further suggested to present the feedback directly on the exhibition plane as it was initially proposed in Chapter 4.2. Moreover, participants perceived the position and size of the display as hindering, because they had to switch their focus of attention between the intended target and the visual feedback on the display. The size of the display can also be seen as a reason for some of the readability issues. Hence, a bigger display that is closer to the actual IMI-exhibits could get rid of those problems. The second readability issue is lack of time. Participants could not finish reading the text and looking at the images. Thus, another layout for the presentation of the IMI-exhibits should be considered. The parallelism of text and images is too confusing and users either get frustrated or have to start the presentation all over again. This leads to another proposition from several participants of the main study. They requested additional gestures as commands
One implicit feature participants wished for was to allow for mobility of a user. The pre-determined interaction space restricts the visibility of the exhibits. It was not clear, that a user only had to stand in the interaction space for the selection process. When the presentation of an IMI-exhibit was running, there was no need to stay on the footsteps. Since there is one display, only a single input can be processed by the IMI-system. It can not handle a multitude of users pointing at different IMI-exhibits. Currently, there has to be a mechanism to identify one user from a group of visitors, who is in charge of the interaction. Nevertheless, the location of the footsteps could be used to mark

a certain user, who is then able to move around the IMI-exhibition and interact with the IMI-system. The mark could then be reassigned once another user steps inside the interaction space.
An issue that was already mentioned during the pre-study was the improvable suitability for children. The exhibition plane is to high for small children to see all the exhibits properly. Furthermore, the recognition of a user only works for a certain height due to the definition of the user position of an IMI-exhibition. If the location of a child's hip is too much below the hip location of the defining admin, the child can not be recognized as a user. A number of parent asked for a step to provide a raised view angle. This solution could also solve the recognition issue.

Certain adjustments to improve the interaction could be made right away. As mentioned in Chapters 5.4 and 5.5, minor modifications were done right away during the tests of the technical principles and different setups. In addition to that, the trembling of the feedback position in the navigational view of the presentation software was reduced by buffering. In succession to the main study the Haßleben-showcase was equipped with additional spot lights. They especially highlight areas where IMI-exhibits are positioned.

Finally, the IMI-system is a novel way of interacting in public spaces. The Haßleben-showcase at the Museum für Ur- und Frühgeschichte Thüringens is an example of how the presence of a natural walk-up-and-use interface influences the perception of an ordinary showcase. The awareness about its topic and contents is raised through natural engagement.
The IMI-system requires certain improvement and further testing. Yet it has successfully proved itself as a prototype for a public interface that needs no more input than a pointing user. And to the question, if the immediacy, control, and expressiveness of recent touch-based natural interfaces can be applied to 3D problems [51]?
-Yes, they can!

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