Institute for Visualization and Interactive Systems

University of Stuttgart
Universitätsstraße 38
D–70569 Stuttgart

Masterarbeit Nr. 12345

Proxemic Interactions for Interactive Exhibitions

Essam Abdelhady

Course of Study: Master Thesis

Examiner: Prof. Dr. Albrecht Schmidt

Supervisor: Dr. Katrin Wolf
M.Sc. Yomna Abdelrahman
M.Sc. Thomas Kubitza

Commenced: 8. September 2014

Completed: 7. March 2015

CR-Classification: H.5.2

Abstract

This thesis is applying proxemics, a theory defined by anthropologist Edward T. Hall in 1966 that governs our usage of space [Hal66], to human-computer interaction (HCI). Trying to establish a systematic understanding of his theory, Greenberg et al. introduced five dimensions where proxemic interaction takes place: distance, orientation, movement, identity and location [MG12]. In this thesis, we used experiments as our scientific method, to explore whether floor projections affect proxemic interactions between visitors and exhibits in a museum environment. We investigated this potential effect from two proxemic dimensions: distance and movement by conducting two separate user studies, each deals with one dimension.

In a first experiment, where the distance user keep to an exhibit was investigated in a real exhibition space, quantitative results showed that light was able to establish borders around the exhibit where the distances approached by visitors were significantly different. From open ended questions, we came to know that visitors would favor an interactive floor projection in a circular design that uses color and animation to better understand the intension of the projections. These suggestions guided us to the next experiment, where we focused on visitor's movement in front of an exhibit. We wanted to see whether distances approached by a visitor can be manipulated using floor projections. For the floor projection designs, the recommendations of the first experiment were considered. Quantitative results showed that, visitors had lowest response time in case of animations and color changes. Also, understanding and respect levels were significantly higher for the same condition.

These results mean that proxemic zones could also be established in a museum environment using floor projections, where color, animations and design of the projected light dictate its effectiveness to convince visitors to keep distance. Our contributions to HCI, and to proxemic interactions field in particular, include conducting scientific experiments to find fruitful significant results that could be used in studies and applications later on. Several candidate applications and scenarios can benefit from our results, such as navigations guidance systems, train stations, airports and waiting areas in general.

Contents

List of Figures

Contents of Digital Appendix

- Appendix A (Experiment One: Questionnaire)
- Appendix B (Experiment One: Informed Consent Form)
- Appendix C (Experiment One: Quantitative Results, Proxemic Distances Analysis)
- Appendix D (Experiment One: Qualitative Data)
- Appendix E (IR Sensor: Proximity Function Calculation)
- Appendix F (IR Sensor: Output Voltage)
- Appendix G (Experiment One: Four Conditions)
- Appendix H (Experiment One: Plinth Components)
- Appendix I (Experiment One: Quantitative Results, Understanding and Respect Levels)
- Appendix J (Experiment Two: Questionnaire)
- Appendix K (Experiment Two: Informed Consent Form)
- Appendix L (Experiment Two: Qualitative Data)
- Appendix M (Experiment Two: Quantitative Results, Understanding and Respect Levels)
- Appendix N (Experiment Two: Four Conditions)
- Appendix O (Experiment Two: Detailed Time to Approach)
- Appendix P (Experiment Two: Quantitative Results, TTA Analysis)

1 Introduction

1.1 Problem Statement

In 1966, Edward T. Hall studied personal spaces, introducing the term proxemics, a research field to be further explored by scientists and exploited by designers [Hal66]. Founding proxemics as a theory enabled him to develop a deep understanding of the human spatial behavior. In his work, Hall visualised personal spaces as four co-centric bubbles surrounding a person. Each bubble represents the corresponding proxemic zone, where the level of intimacy varies. Hall presented his idea as a multi-dimensional problem, where one needs to look from different perspectives to understand and to formulate governing rules that dictate the proxemic distance of a person. One of his very fruitful contributions was establishing a logical relation between languages, experiences and cultures in a dynamic world. He highlighted the major rule of the cultural background and exemplified this difference. He showed how Germans differ from Americans in their comprehension of spaces.

Ballendat et al. introduced Proxemic Interaction [BMG10], as devices being able to make use of a very detailed set of information about the surrounding environment. This information includes position, identity, movement and orientation of nearby people and devices. Their research was extended by Greenberg et al. to cover five dimensions for proxemic interactions [MG12]. The five dimensions are: distance, orientation, movement, identity and location. These five dimensions expand the solution space to cover digital devices and non-digital objects, including inputs and states to control the proxemic information of a given device in an integrated ecology.

In this thesis, we study how light projections can affect proxemic interaction between exhibits and visitors, in a museum environment. Previous studies attempted to investigate the effect of ambient lighting conditions on human spatial behavior. Adams and Zukerman studied the effect of bright and dim illumination conditions on personal space requirements [AZ91]. However, they did not consider a particular lighting setting, that is, they considered ambient light with brightness as a variable. Also, in their study, they considered person-to-person interactions, which did not incorporate any exhibits.

In this study, we used experiments as our scientific method, in an attempt to find out whether floor projections affect proxemic interactions between visitors and exhibits in a museum environment. We investigate this potential effect from two proxemic dimensions: distance and movement. We performed two experiments to try to approve or refute our hypothesis. Each experiment focused on one of these dimensions.

Next, we will take a look at the motivations behind our study, followed by our contribution included in this thesis. Finally, we mention the outline according to which this thesis is structured.

1.2 Motivation

According to the most recent United Nations estimates, the human population of the world is expected to reach 8 billion people by 2024. This means, our population is expected to increase by one billion by 2024 [Uni13]. An issue that requires a smart and efficient use of space, posing a new challenge for engineers and designers.

Luckily, light offers promising solutions, reshaping our way of understating experiences and opening a new era where future demands can be met more efficiently. With its marvelous ability of controlling the human behavior from a mental and emotional perspectives, light was able to offer innovative solutions and to establish itself in the field. Given its flexibility, adaptability and portability, light is considered to be a competent candidate to deal with the foreseen lack of spaces.

Companies started to build completely Laser generated multi-purpose sports court that can be projected to an urban landscape to convert it into a playground ready to host football games and to switch between different sport courts makings as well [Nik13, Kok13, OY13]. With this scale of flexibility and Real-Time adaptability, Light has proven to be a good medium for communicating our ideas and conveying information.

Demolishing physical barriers and borders, light succeeded to build entire environments, where the location blue-prints are projected on the floor, promoting flexibility and multi-usage scenarios. The same place can be adapted according to the required environment on-demand.

Also, in museum environments, we could harness the power of light to establish borders around exhibits, where the distances can be dictated using light projections. In figure 1.1, a large number of people are gathering around the Mona Lisa. Instead of using physical barriers, we want to adapt dynamically to the crowd level, in a way that is flexible and adaptable. For example, in case of high crowd level, we can expand the light projections so that the space around an exhibit can fit the crowd, and vice versa.

However, we still need to know whether lighting solutions can be used to control the distance and movements of visitors. That is, is it possible for floor projections to control distances and movements of visitors in a museum environment? Would it be understood and accepted by our visitors? These are the questions we try to answer in this thesis. Through two scientific experiments, we establish interesting scenarios to collect and analyze fruitful sets of data.

Figure 1.1: Mona Lisa crowd, where the painting is surrounded by physical barriers. Photo by Alexander Baxevanis from London, UK (Mona Lisa crowd) [CC-BY-2.0 (http://creativecommons.org/licenses/by/2.0)], via Wikimedia Commons.

1.3 Contribution

In this thesis, we conduct two scientific experiments dealing with two proxemic dimensions, namely distances and movement. In the first experiment, we try to see the effectiveness of floor projections in establishing borders around exhibits in museums. We investigate the distances visitors tend to keep to an exhibit in a museum environment. Then, the results are analyzed, where the distances to the exhibit is considered our independent variable.

In a second experiment, we would like to see what kind of floor projection would better communicate the instructions to keep the distance. We carry out an experiment where the color and animations of a floor projection vary. In the analysis of the second experiment we consider the time taken by visitors to approach the exhibit as our independent variable.

The thesis presents significant results that could be applied by museum curators to enhance the user experience in museums. Moreover, our results could help in organizing waiting areas in airports in addition to exhibition areas. Fruitful conclusions could also be added to the field of proxemic interactions where two dimensions are discussed and analyzed, namely distance and movement.

1.4 Outline

In the next chapter, we discuss some of the related work mentioning significant contributions to proxemic interactions. Then, in the methodology chapter, we take a look at the experiments we conducted during our study. Followed by two chapters where, we present each experiment in detail and discuss the results. Then we conclude our work summarizing the results and mentioning how this thesis contributes to HCI. Finally, we present a new model to be used in future work for further studies.

2 Related Work

Here, we present a comprehensive review of other contributions which are related to our work in this thesis. Since the literature regarding proxemics and its applications is vast and multidisciplinary – ranging from Psychology to Human-Computer Interaction, from Distributed Systems to ecologies of connected devices – this chapter is divided into three sections, each of them takes a different perspective to come up with interesting insights.

Each section reports on significant contributions added by scientists and engineers from each field. First, we start in 1966, when proxemics was originally founded by Edward Hall. Then, we discuss how light was employed in different contexts to guide visitors in various environments. Finally, we mention some techniques that fostered our contribution included in this thesis.

2.1 Proxemics - The Theory

In 1966, anthropologist Edward T. Hall coined the term proxemics to define theories governing our usage of space. He approached the subject from many perspectives, including a cross-cultural one [Hal66]. Hall was very keen on reading other papers, particularly those from different backgrounds.

Theorists argued that space is not absolutely defined in terms of coordinates or locations [Lef74, Fou84]. The literature in this topic is multidisciplinary and limitless. Next, we take a brief and comprehensive view of different fields that shape the way proxemics is seen and dictate parameters that should be taken into account when measuring it.

2.1.1 Cultural and Psychological Aspects

Computer programs can express similar functionalities, however, their core programming languages may be from different paradigms, using totally different constructs. Similarly, Hall discovered the power of languages, and knew their implications on the formation of one's character. Languages play an important role in the formation of one's perception of the world. He posed a very interesting question regarding the implication of this observation on the human free will. Moreover, he organized the arguments for a yet to be very fruitful debate. He wanted to establish a logical relation between languages, experiences and cultures in a dynamic world. Sometimes cultures imply different languages, but essentially, they imply different usage of the sensory data available for one to grasp. In fact, cultures have this effect of manipulating our sensory data as it is received, such that, two persons from different cultures would experience the same action in a different way. A filtering mechanism of the sensory data is employed by individuals from different cultures, taking place at different levels of consciousness.

From a pure psychological perspective, cognitive research fields have focused on space as the basis for abstract thought [Tve01]. A subtle and very important use of space is acting as a memory container: People attach memories to given places, where revisiting the same place again replays some of these memories [Yat66].

People have been able to improve their abilities and develop what is called extensions that enable them to extend their senses to a degree that may interfere or even substitute nature. For example, his inventions of television to extend vision, and phone to extend voice are examples of such extensions. Continuing to shape his environment, man has created a new hidden dimension, the cultural dimension. Indeed, man is actually manipulating the cultural mindset of next generations by changing his environment. It was this that Sir Winston Churchill pointed out to when he said: “We shape our buildings and they shape us”.

Through his dedication and determination, Hall was able to exemplify cultural differences. He devoted two chapters in his book, The Hidden Dimension, to show the consequences of proxemics on people’s behavior as seen from a cross-cultural context [Hal66]. For example, in the first chapter, he discussed how Germans perceive the surrounding environment and how they interpret their private sphere. From another perspective, he showed how Germans consider it rude to step into ones proxemic zone.

2.1.2 Fixed, semi-fixed and informal space features

Hall formulated his theory about proxemics, which transformed our view of the natural world. Proxemics is manifested in three aspects: fixed-feature space, semi-fixed feature space and informal space. Fixed-feature elements convey a solid meaning: not to be crossed. Walls and floors are examples. They are permanent structures that convey an explicit message. Hall discussed the implication of changes in the fixed-feature space on people from different cultures. His observations were astonishing. With the relation between environment and culture in mind, Hall exemplified such implications on people from different cultures.

Semi-fixed elements are objects that are portable where messages regarding the formality and openness of given place are communicated using attributes like color and position. Informal spaces, or non-fixed spaces, are spaces that people maintain unconsciously. Visually, it can be seen as a set of co-centric bubbles carried around people everywhere they go. Hall's observations of the human beings in different situations, and their maintained informal spaces, led to new interesting observations. Proxemic theory is the term used to describe theories about usage of space. Since then, many important scientific works are based on such theory, including this thesis. Founding proxemics as a theory enabled us to understand the crucial relationship between languages, cultures and environment. The depth of this relation is a key point to understand how people perceive, use and react to changes in distances, posture and orientation of other people.

The essence of proxemic theory is that, it correlates social distances to physical distances, taking into consideration the effect of cultural differences. Hall introduced four proxemic zones, through which the degree of intimacy varies. He used a terminology that dictates the progression of intimacy.

The proxemic zones are defined as follows: intimate $(6 - 18'')$, personal $(1.5 - 4')$, social $(4 - 12')$ and public $(12 - 25')$ zones. Proxemic zones can be visualized as concentric bubbles surrounding a person. Figure 2.1 shows these proxemic zones.

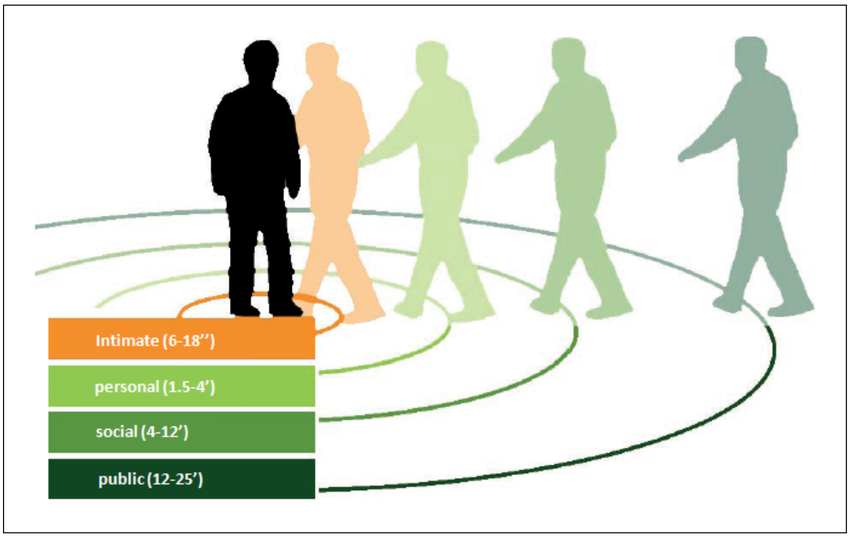


Figure 2.1: Edward T. Hall's proxemic zones – Concentric bubbles are shown describing the progression of intimacy and establishing a relation between physical distances and social distances. Original figure taken from [MG12] and modified.

2.1.3 Demographics

It's rather important to note that such proxemic zones depend, not only on cultural factors, but also on the demographic profile of a given person. For example, age and gender would constitute a noticeable shift in a given proxemic zone [Aie87].

2.1.4 Social Rituals

In his work, Hall demonstrated the relationship between proxemics and social rituals. For examples, the distance between an employee and his boss when having a conversation is higher than the distance between any two employees.

Kraut et al. argued that proximity facilitates collaboration [KFBS02]. It shapes a fabric that degrades as the distance between the people increases. Moreover, they stated that proximity facilitates collaboration. As a matter of fact, proximity increases the frequency of communication.

Subsequent scientists started to grasp the meaning of his theory, and understood potential and meaningful updates that can be added to the principles of interaction design. Triangulating culture, language and experience gained dramatically changed our psychological perspectives. Papers are published regularly quoting his work on proxemics, and considering his contribution a corner stone to proxemics as a research field [Bux96, Rek97, Rek98, JLK08, VB04, BMG10, MG12].

2.2 Proxemic Interactions

Greenberg et al. introduced five dimensions for proxemic interactions [MG12]. The five dimensions are: distance, orientation, movement, identity and location. They included a detailed description of each dimension in their work. Here, we discuss other important contributions that are related to our work in this thesis. Such contributions vary in their application of proxemic ideas, from a holistic approach, trying to cover a lot of dimensions, to one-dimension applications, that deal with proxemics as a measure of distance.

2.2.1 Distance-Centric Approaches

Starting with Ubiquitous Computing, works related mainly to this field capture the idea of proxemics by incorporating spatial relations within their interaction design. Admittedly, they capture physical distances and establish a one-to-one relation with social distances based on Hall's findings. Few act in a binary fashion, namely, they react according to the presence of a person within their range [Bux96, Rek97, Rek98]. However, reacting according to the presence of people deprives the application of other potential dimensions of proxemics.

2.2.2 Holistic Approaches

Later on, Ju et al used the principles founded by Hall and embodied these design principles in a vertical interactive whiteboard with a digital reactive surface [JLK08]. It uses proximity sensing capabilities to change its display mode. In [VB04], Vogel et al introduced a new interaction model that emphasizes the fluidity of transitions between interaction zones. It covers the range from distant implicit public interaction to explicit personal interaction. The model consists of four phases: Ambient Display, Implicit Interaction, Subtle Interaction, and Personal Interaction. The introduced design is implemented in a vertical display to regulate public and private ambient displays. An important idea is that interaction is considered public and implicit if initiated from far distances, and gradually switches to private and explicit on short distances from the interactive display.

[JLK08, VB04] stand out here; both include in their design more potential proxemic dimensions. They react according to, not only the presence of persons, but also the distance approached by them. That's a more holistic approach to deal with proxemic information. Next, we discuss how scientists tried to tackle the problem from another perspective. They fostered their information about the surrounding environment by making use of other proxemic dimensions. This enabled them to introduce a model to regulate implicit and explicit interactions.

Ballendat et al. introduced Proxemic Interaction [BMG10], as devices being able to make use of a very detailed set of information about the surrounding environment. This information includes position, identity, movement and orientation of nearby people and devices. They illustrated the concept by introducing an interactive media player that reacts to the approach, identity, movement and orientation of people. Ballendat et al. extended the view of proxemics beyond pairwise interaction. They considered one or more persons surrounded by a complete ecology of context-aware devices. By context-aware we mean Proximity and Orientation-aware environment.

An important contribution of Ballendat et al. is the introduction of four dimensions for proxemic interactions: position, orientation, movement, and identity [BMG10]. The perspective from which they understood the depth of proxemic interaction established a systematic way to deal with the problem and improve our understanding of proxemics as a theory.

Greenberg et al. extended this and introduced five dimensions to understand the problem, offering possible solutions [MG12]. These five dimensions expand the solution space to cover digital devices and non-digital objects, including inputs and states to control the proxemic information of a given device in its integrated ecology. The five dimensions are: distance, orientation, movement, identity and location. They included a detailed description of each dimension in their work.

In their work, Greenberg et al. answered two important questions that are deeply related to our work [MG12]. The first one is concerned with the notions of affordances of an object, in other words, how an object's visuals can propose scenarios for its usage. In the past, User Interfaces had a subtle assumption that they were capturing the foreground of user's attention. An assumption that should be dealt with more systematically, taking into consideration the holy grail of Ubiquitous Computing and its contemporary advancements [Wei99]. To answer this question, a system should postulate actions that could be taken at a given moment.

From another perspective, a system should provide means for person to correct her unmeant or unintended actions. An interactive system should plan such transitions in a way that makes each step easily comprehensible. Greenberg et al. proposed a solution to this problem, where they recommended inverting the actions performed by an interactive system [MG12]. For example, instead of an inviting animation intended to bring visitors closer, we can use an evacuating animation, in case persons did not behave as expected. This technique makes it clear that something unexpected happened and was sensed by the system and a correction is demanded accordingly. Vogel et al. employed proxemic dimensions, namely distance and movement, to determine the transitions between actions performed by the system [VB04].

From a technical perspective, establishing such seamless connectivity becomes another question, particularly, when the environment contains numerous devices. To orchestrate devices participating in our environment, strict assumptions need to be considered by such distributed system. These assumptions dictate the fluency, reliability and responsiveness of the implemented system. The first assumption is that, devices that want to establish a connection between each other are placed within a given distance. Indeed, a connection is established between those devices found in close proximity [MG12]. Guiding connectivity preferences of devices participating in ecology of devices is a subtle application of proxemics.

In their contribution, Greenberg et al. extended the application of proxemics to include objects. Proxemics as a theory was initially used to organize, dictate and predict distances between people. As distances between devices change, appropriate actions can be applied accordingly [MG12].

In previous work, Thomas et al. introduced the Plinth as a hexagonal prism, with six infrared sensors placed at the center of its vertical sides, as shown in figure 2.2 [KS14]. When used in museum installations, these plinths gather information about the proximity of the visitors nearby, triggering defined actions when a certain distance is approached. In our experiments, we make use of one or more plinths to gather data about the proximity of visitors.

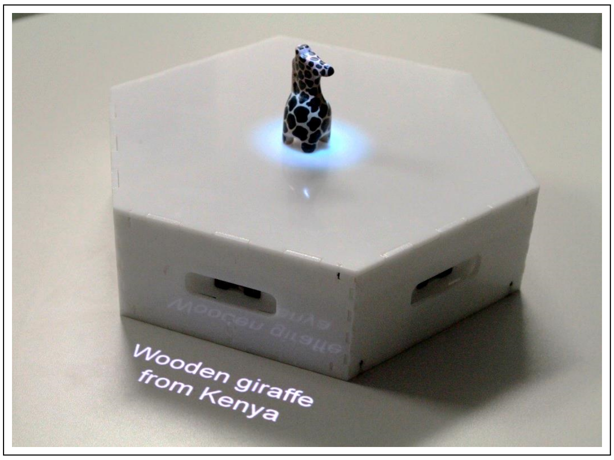


Figure 2.2: Plinth: a hexagonal prism with infrared sensors embedded in its sides, with the exhibit placed on top of it. Figure taken from [KS14] and modified.

2.3 From Spaces To Places – An Enlightening Guidance

"Space is the opportunity; place is the understood reality" [HD96]. Previous attempts were taken to convert this opportunity to become reality. Here, we take a look at previous contributions that are related to our work in this thesis, and we discuss how light projections can be employed to precisely control the properties of this space as it becomes a place, taking into consideration the previously discussed principles of proxemic theory and Proxemic Interactions.

Over the past years, frameworks have been developed to augment the user's sensors as well as actuators with wearable technologies. The holy grail of this development is to engage the user beyond GUI metaphors and encourage them to start collaboration. One way to achieve this is by placing the users in an artificial environment, where their sensors are augmented [Fei02]. Another way is promoting interactions in a shared public place, where a persons's body is used as an input device,or what is usually called "social immersive media" [KGH85, MDBP97].

Social immersive media allows the users to discover the environment without having devices attached to their body, promoting social and physical interactions. Users can control projected media in an environment that is mainly controlled by sensors. Snibbe et al. proposed six design principles as guidelines for social immersive media applications [SR09].

An application promotes the user interaction by employing these design principles: *visceral,* which means that experience is gained through whole-body interactions; *responsive,* in a way that's predictable by the users; *continuously variable,* to simulate our natural motion; *socially scalable,* encouraging other users to engage and interact through a welcoming behavior; *socially familiar,* even to new users; and *socially balanced,* where users interact with the system as frequently as they interact with each other [SR09].

Figure 2.3: Boundary Functions: an application that demonstrates social immersive media design principles. Lines are projected between people depicting their personal spaces: a space closer to her than anyone else. Figure taken from [LS98].

In Figure 2.3, an application that covers these six design principles. Lines are projected from the ceiling where a projector is mounted. As visitors move in, the area is divided evenly to accommodate all visitors. The idea of personal space is visualized by this application using light, emphasizing the relativity of this measure. That is, without our control, personal spaces can only be defined in relation to other personal spaces [LS98].

As far as Proxemic Interaction is concerned, Boundary Functions is a new comprehensive application that covers the six design principles stated above, where light is employed to show the meaning of personal spaces in an environment where visitors are continuously welcomed and encouraged to participate.

From a marketplace perspective, social immersive media - where light is the main actor - is taken more seriously. With its importance in our daily life, light is now able to shape our emotions, build vibrant memories and create outstanding experiences. Artists and designers are making use of the advanced lighting technologies to build innovative uses of light. They come up with socially immersive ideas, where light plays the main role to guide visitors, respond to their demands, and orchestrate the entire ecology of devices in our environment.

Novel approaches are taken to enhance the light experience. INAHO uses standing LED bulbs that lean gently towards people as they approach, switching off the lights once they move away [OY13]. Ben Kokes introduced his LED engagement ring that glows when the fiancé is close [Kok13]. The Good Night Lamp is a good example for enlightened communication [DS13]. It consists of a set of internet-connected lamps that can reflect the status of the main lamp. Whenever the main lamp goes on or off, the same action is applied to other connected small lamps, leveraging the design principles of social immersive media.

Another innovative use of light is its ability to constitute physical boundaries. Such use cases are being explored by designers. By using light to build boundaries that are respected by people, it becomes easier to demarcate new areas on demand, that is, convert spaces to places whenever we want. With this extra level of flexibility, we can redefine our environment according to our changing needs.

In cooperation with Doubleyou, Nike built a completely Laser generated soccer field that can be projected to an urban landscape to convert it into a playground ready to host football games [Nik13]. With this scale of flexibility and Real-Time adaptability, Light has been proven to be a good medium for communicating our ideas and conveying information. Similar contribution done by the German Company ASB Systembau is the multi-purpose sports court, where a glass floor uses hidden LEDs to switch between different sport courts makings. A multi-purpose court is shown in Figure 2.4.

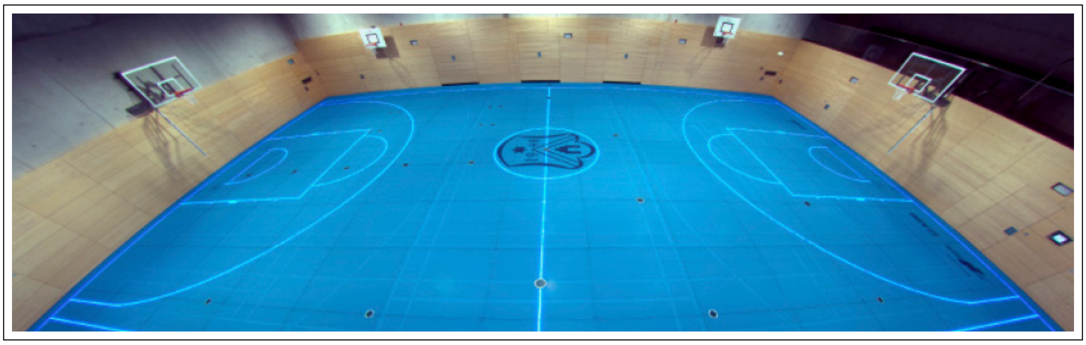


Figure 2.4: Multi-purpose sports court, where LEDs are illuminating the floor, making it adaptable to accommodate different sports in the same field with a single button touch. Figure taken from [ASB13].

From entertainments to safety applications, Light usage reached a lot of areas and expanded across different perspectives. Softstop is another safety oriented innovation, where stop signs are projected on water to produce a pseudo-holographic message as shown in figure 2.5. By creating an illusion of concrete surface, drivers are no longer ignoring the stop sign, promoting the safety considerations in our environment [DS13].

Figure 2.5: Softstop: a safety oriented application where stop signs are projected in a pseuso-holographic way in front of drivers. Figure taken from [Las13].

2.4 Summary

Emphasizing the principles shaped by researchers in proxemic theory and visualizing the idea from different perspectives have made it clear that *proxemics* as a theory has an influential and far-reaching effect on people.

Through its different applications and outstanding innovations, it became a fact that *light* has an impact on people, affecting their well-being, both from mental and emotional views. However, it remains unclear how lighting has an impact on human spatial behaviour. In this thesis, we would like to investigate whether lighting has an effect on the outcomes predicted by the proxemics theory.

Experimental research method is used to prove our hypothesis, where different light animations will be a part of understanding light's effect on spatial behaviour. Because of its flexibility and portability, museum curators and designers can use light projections in order to dictate proximity levels to an exhibit.

3 Methodology

In this chapter, we take a brief look at the experiments conducted during our study. Also we consider important dimensions that had to be handled carefully during the study. We take a look at important psychological factors. This description includes an overview about the environments and the participants who took part in our experiments.

3.1 Experiment One

In his definition of proxemic zones, Hall established a predictive person-to-person model that can prospectively dictate distances people maintain in their everyday life [Hal66]. He founded the proxemics as a theory, paving the way for other scientists and engineers to make interesting conclusions and innovative solutions. One of the basic axioms of proxemic theory is that the participating entities are only humans. In our experiment, we extend this view to include exhibits in a museum environment. Mediated by light projections, we want to establish a logical relation between floor projections around an exhibit and visitors proxemic distances in a museum environment. In essence, we want to know whether such proxemic zones exist in a visitor-exhibit setup. And, if so, we would like to know if they are equally understood and respected by visitors.

Visualized by floor animations, we project animated borders around an exhibit depicting the assumed allowed proxemic distance. We study the effect of an animated hexagon, projected on the floor around an exhibit, on the distance approached by the visitors. Through our quantitative and qualitative studies, we want to know whether visitors clearly understood floor projections to be barriers, not to be crossed. Also, we want to know whether visitors respected such projections.

We focused on distance as our proxemic dimension, where the independent variable in this model was the radius of floor projection around the exhibit. We want to detect whether such projections are respected by the visitors. In other words, we want to know if light projections succeeded to establish a physical barrier around the exhibit.

3.1.1 Visitor Identity and Museums

Cultural dimensions play an important role in the way people deal with distances [Hal66]. In his work, Hall mentioned and exemplified these differences on many cultural contexts. Guided by Hall's work on proxemics, it became clear how people from different cultural backgrounds would act differently given their prior established interpretations of proxemic zones. In a museum environment, these differences from a proxemic perspective become very significant. For example, according to Hall studies on proxemics, Arabs would consider the entire set of proxemic zones as a personal zone, as long as it is a publicly shared area.

Moreover, our experiment appreciated that each visitor is a unique individual, who emphasizes her personal experiences in a way shaped by her cultural background. In order to make sure that our measures stay consistent with the previously mentioned implications, in analyzing the results of our experiment, we only considered Germans. Nevertheless, visitors from all countries were allowed to participate. After participants came out from the exhibition room, we asked them to fill a questionnaire (Appendix A). It contains demographic details about the visitors. Questions about their age, gender, profession, and nationality were asked.

3.1.2 Environment

In our application scenario, it is important to understand what motivations visitors would have that make them visit museums. Usually, such motivations are shaped by previous personal experiences and memories. Collectively, these experiences derive our expectations prior to a museum visit. This deep and multi-dimensional picture makes it difficult to develop a model to describe and predict museum visitor experiences.

In our experiment, we tried to meet these expectations by carrying out our experiment in a specialized place for exhibitions and art shows. The study was organized by Akademie Schloss Solitude, where appropriate room was allocated for the exhibition. The chosen environment was suitable for our exhibition, because of its location, welcoming shows, talks and music performances. Also, it was capable of simulating a museum environment, where visitors are expecting to explore new artifacts, making sure their behavior is not altered by the chosen environment.

Moreover, visitors going to museums are usually expecting to explore more than one exhibit during their visit. That was another challenge that we handled very carefully. In our experiment, we included another set of exhibits in addition to ours, ranging from paintings and sculptures to multimedia shows and interactive displays. We tried to build a complete environment, in a sense that makes it easy for visitors to meet their expectations, regardless of their demographic profile.

Also, after they visited our exhibition room, visitors were offered free drinks that they can enjoy while exploring the rest of the exhibits in other rooms. Framed through this new lens, our experiment was concluded in a place that affords all the benefits expected by the visiting public, making it easier, for them to enjoy their visit without altering their expectations, and for us to have coherent and noise-free data to analyze.

3.2 Experiment Two

During the second experiment, we explored the capability of floor projections to manipulate the positions of visitors in a museum environment. In other words, we wanted to see whether light is able to guide the movements of visitors; telling them to keep distance from, or inviting them to come closer to an exhibit. This means, in case visitors overshot the maximum allowed proxemic distance relative to an exhibit, light projections should interactively try to change their behavior, in a way that is understandable by the visitors.

This time, the user study was performed in Stuttgart University at a lab that was well prepared to host this kind of experiment. Each user study was carried out at a time where there was no noise, and when light luminosity was controlled. This enabled us to make sure that visitors are not disturbed at all by external factors, such as shadows of passer-bys or varying luminous intensity due to unstable weather conditions.

Participants were welcomed and notified that they were going to participate in a user study, where data is to be collected and analyzed anonymously later on. Before they entered the room where we ran our experiment, participants were briefed about their role and were explicitly aware that the data captured during their presence will be analyzed later on. Moreover, they had the opportunity to go for a free hot drink together with a cookie from the university cafeteria. Eighteen visitors took a compensation of 5,- EUR for their participation. We had to make this offer in order to encourage more people to participate in our experiment, and to make sure that the sample size is large enough to avoid any sampling bias problems. It was also noticed that, in case of compensation, participants will gladly and thoroughly provide feedback in form of comments and answers to our questionnaires. Moreover, they also try to verbally explain their emotions felt during the experiment.

After a given participant is done exploring the exhibit, she was asked to fill out a two pages questionnaire. The questionnaire is included in Appendix J. The aim of the questions included in the questionnaire is to know whether participants understood the light guidance as a motivation for her to come closer or to keep distance. The set of questions included in the questionnaire was always the same, regardless of the condition to which she was exposed.

As mentioned in our first experiment overview, the importance of the effect played by cultural differences is taken seriously in our second experiment [Hal66]. That is the reason why we considered it a right decision to include only German participants in our experiment. Other nationalities were also welcomed, however, during the final analysis, Germans were the only considered participants.

4 Experiment One: Distance

4.1 Rationale

4.1.1 Research Question

In this experiment, we want to establish a logical relation between floor projections around an exhibit and the proxemic distances between visitors and exhibits. By conducting an experiment, we establish a causal effect between these two factors. Are there any significant differences between proxemic distances approached by the visitors using floor projections? By changing the radius of the projected shape, is there any effect on the proxemic distance that visitors keep to an exhibit? Is such projection understood and accepted as a barrier?

In the next sections, we present our first experiment conducted using scientific methodology, where its results are then analyzed and presented. Reproducibility and transparency are cornerstones of the scientific methods. We start by explicitly and formally mentioning all details included in our first experiment, in a way that makes it reproducible and prove its correctness.

4.1.2 Hypothesis

We stated a clear and precise hypothesis that is tested through an empirical investigation. The null and alternative hypotheses are mentioned below:

H(0): "An animated hexagon, projected onto floor, has no effect on the proxemic distance between an exhibit and a visitor"

H(A): "An animated hexagon, projected onto floor, has an effect on the proxemic distance between an exhibit and a visitor"

Formally, the goal of the experiment is to refute the null hypothesis, a significance test is to be done and represented in the results section to determine whether it is reasonable to refute the null hypothesis and the likelihood of being wrong in such case.

Variables and Conditions

In our study, the following variable has been identified as an independent variable: the radius of the floor projection around the plinth. The dependent variable is the actual distance approached by the visitor in direction of the exhibit. Through this experiment, we would like to find out whether a logical relation exists between these two factors

- Independent variable: radius of the floor projection.
- Dependent variables: Actual distance approached by the visitor, visitors recommendations.
- Number of conditions: four conditions, where the radius of the projection changes
  1. Condition 0: no projections at all,
  2. Condition 1: 30 cm, approximately equals 1 foot,
  3. Condition 2: 45 cm, approximately equals 1.5 feet and
  4. Condition 3: 95 cm, approximately equals 3 feet.

Using in-between design approach, where each participant is exposed to one condition, we make sure that learning effects are isolated.

A bright white-colored hexagon was projected onto the floor. An inviting animation was included; where three more hexagons, in addition to the static one displayed at the radius of the intended condition to be applied; start shrinking from a relatively bigger radius than the static one till they combine with the static one. This used animation has the metaphor of sea waves that invite the visitor to come closer to the exhibit till the static, fully bright white colored hexagon.

4.2 Methodology

4.2.1 Subjects

In our experiment, fifty-three participants served as subjects. All of them were offered free drinks after they completed the task. For each participant, the task was simply to go separately inside the exhibition room, take a look at the exhibit. With the atmosphere of the environment of being at a museum or an exhibition, the mindset of the visitors was accordingly perfectly implied to match the required attitude.

Recalling Hall's experiments and conclusions regarding the cultural effect on proximity and how human spatial behavior is influenced by cultural differences, we considered Germans only in our experiment. This makes sure that our data is coherent and no outliers are detected as a result of cultural discrepancies.

Out of fifty-three subjects, thirty-six were finally considered. Before and after the experiment, participants were asked to fill a questionnaire, shown in appendix A. In our experiment, we had four different conditions (C0, C1, C2 and C3) through which the radius of the floor projection varies. Visitors were randomly assigned to conditions such that in each condition we had exactly nine visitors. By doing this, we avoid any inappropriate sampling and we make sure that our samples are matching the entire population to a high degree. Also, assigning participants to conditions at random will significantly reduce the possibility of making this kind of error in our study and suppress the possibility of having any potential confounding variable between independent variable and dependent variable.

In the results section, significant tests are conducted in order to show how confident we are that our results collected from the sample population can be generalized to match the whole population.

4.2.2 Materials

Exhibition Room

The testing was performed in a room with dimensions 6.8 m * 5 m * 6.4 m * 4.6 m. The room had three windows and one entrance door. The windows and shutters were closed during the experiment to make sure the perception of the floor projections is not affected by outside ambient light. The luminosity of the room was measured using a photometer, whose reading was recorded to be 23 lx. The luminosity of the room was measured before and after the experiment to make sure that it stayed the same. The textures of the walls and ceilings were mutt that did not produce any light reflections generating noise that might affect our sensing devices. The floor plan of the room is shown in Figure 4.1

On the ceiling, seven Philips 3610 pico-projectors were installed. The operating system of the projector is Android. The OS platform is 2.4. The projectors were positioned in a pattern that could cover the largest possible area. The area covered by the projectors is shown in figure 4.2 3D models of the exhibition room are presented in Figures 4.3 and 4.4.

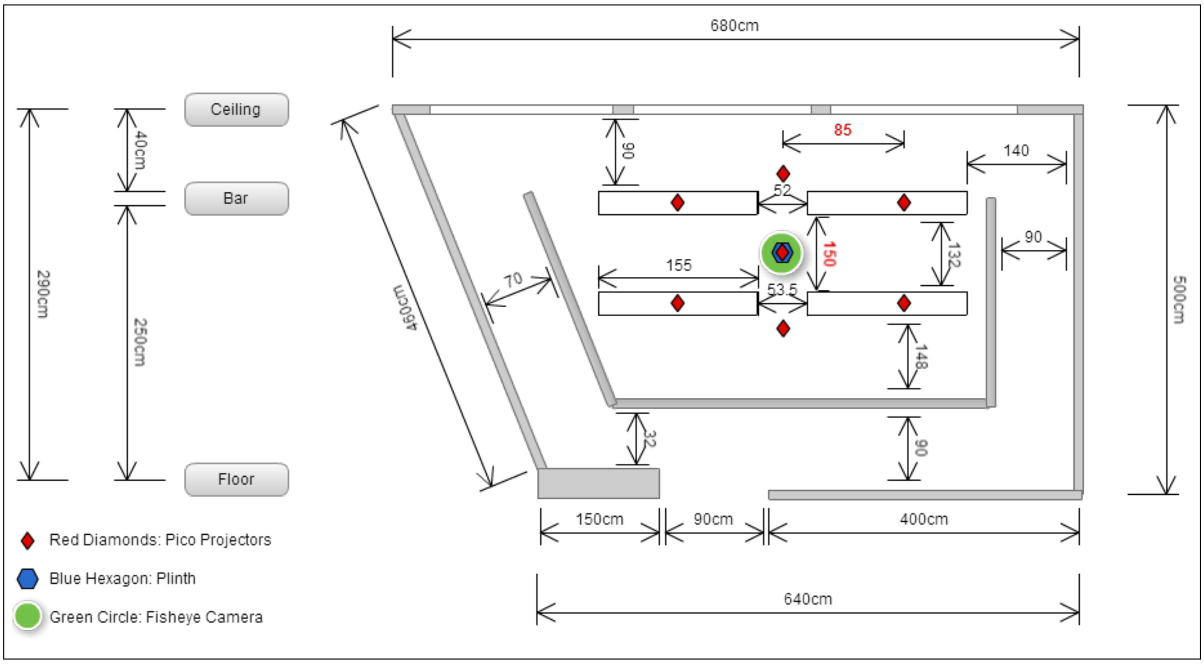


Figure 4.1: Floor Layout of the Exhibition Room.

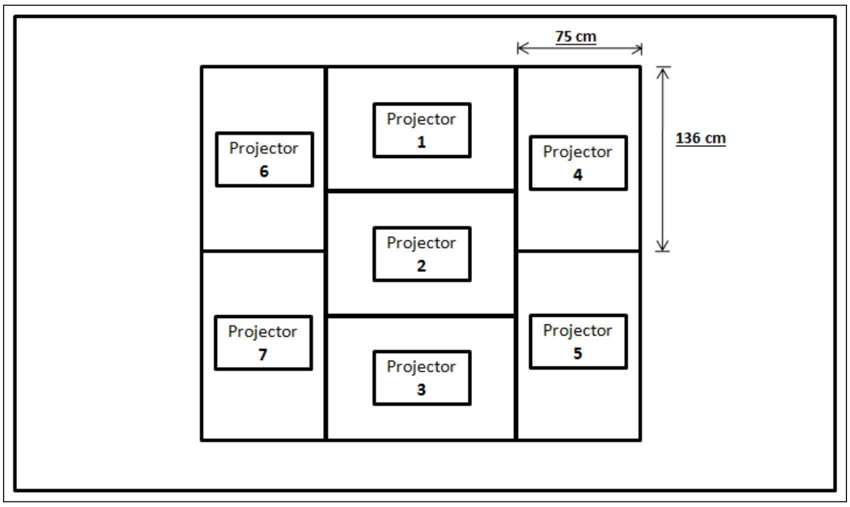


Figure 4.2: A top view of the distribution pattern of the projectors, as they were installed on top of the exhibit. The projectors were positioned in a way that could cover the largest possible area.

In our experiment, the results were gathered using the plinth and a fish-eye camera, and analyzed using computer vision techniques. Accordingly, the exhibition room had to be somehow enhanced to adapt and include all these equipments. By installing four metal bars to the ceiling, we were able to attach the projectors and the fish-eye camera to the ceiling, as shown in Figure 4.3.

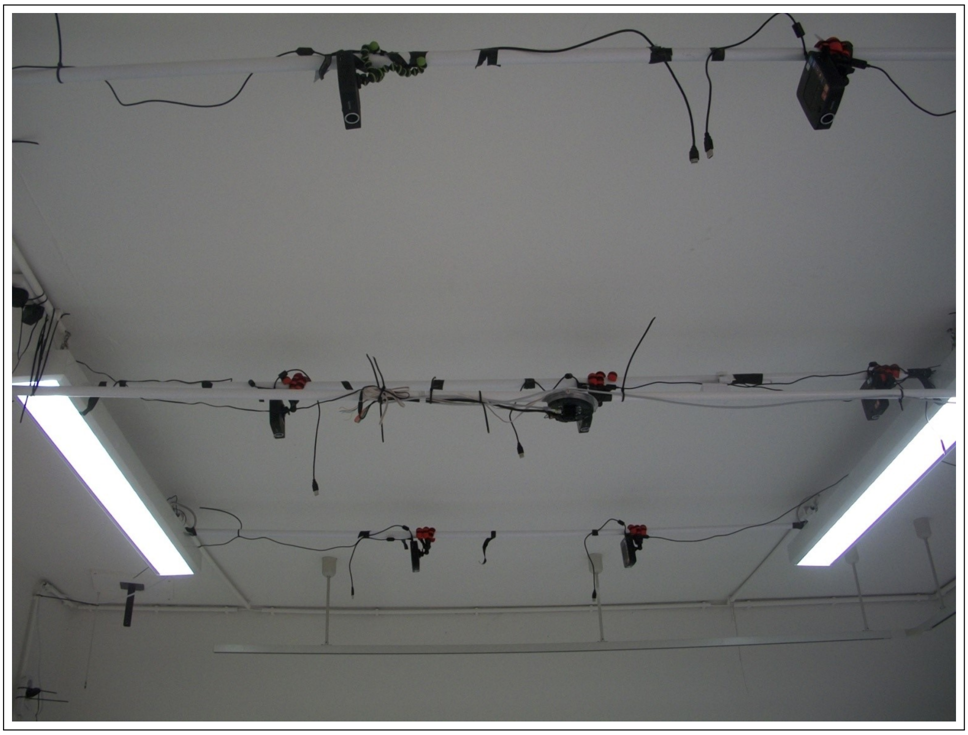


Figure 4.3: Pico-Projectors Mounted on Metal Bars.

A complete framework was implemented to enable us to detect changes in our dependent variable (the actual distance approached by the visitor towards the exhibit).

Data Acquisition Tools

For collecting our data we used two methods. The first method was using the Plinth shown below. Six Infrared distance measuring sensors are embedded into the walls of the plinth. According to the datasheet provided by the manufacturer, the sensor (SHARP GP2Y0A02YK0F) measures distances from 20 cm up to 150 cm. Also, the sensor is not affected by environmental temperature or the operating duration, which was beneficial for our case. However, the output voltage, which correlates to the Proxemic distance of the detected objects, is not linear.

Moreover, frequent noise signals were detected during the analysis of the sensor output using oscilloscope. Noise signals are shown in figure 4.6.

The second method is to capture videos using the fisheye camera, to be then analyzed (discussed in the analysis section).

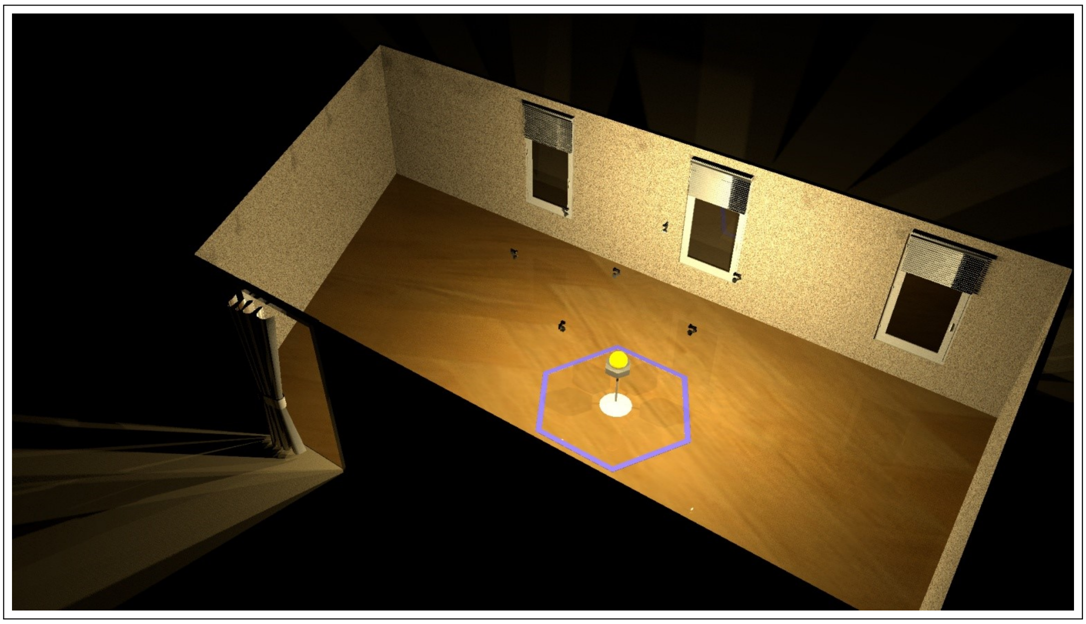


Figure 4.4: Exhibition room: Aerial view.

In the next section, we present a solution for linearization of the output voltage function, also using software approach we discuss the method we used to suppress noise signals. Then, we present the architecture of the software framework we used to carry out our experiment.

Noise Suppression

By analyzing the output signal from the SHARP GP2Y0A02YK0F Infrared sensor, we get the signal depicted in Figure 4.6. To solve this issue, we employed a software solution, where the average of ten successive measurements from IR sensors was recorded. The period taken by the sensor to provide a new output is 38 ± 10 ms. Considering a 38 ms period, by waiting for 500 ms, we are sure that we collected at least ten values that correspond to ten different measurements from the IR sensor. Averaging the result by ten, we obtain a noise free output which can be directly used by the server to direct other entities in our architecture.

Figure 4.5: Exhibition room: Side view.

Proxemic Function Calculation

In Appendix F, the output voltage function of the IR sensor is shown. Given that, we should compute a function that is able to calculate distances. Using trendline analysis, we could obtain a power function whose output is associated with the actual sensor voltage output values to a high degree.

Under the same luminosity conditions, we performed tests in order to collect per distance data that could help us calculate the trendlines. Starting at ten centimeters, proxemic distances are collected using one sensor. At each distance, ten values are calculated and then averaged by ten, in order to make sure that the collected results are noise free as much as possible. A colorful piece of cloth was used in this test as an obstacle. Results are shown in Appendix E.

The sharp sensor provides its output in two forms. The first one is presented as a voltage output value, whose outputs are depicted in appendix F. The second method is using a

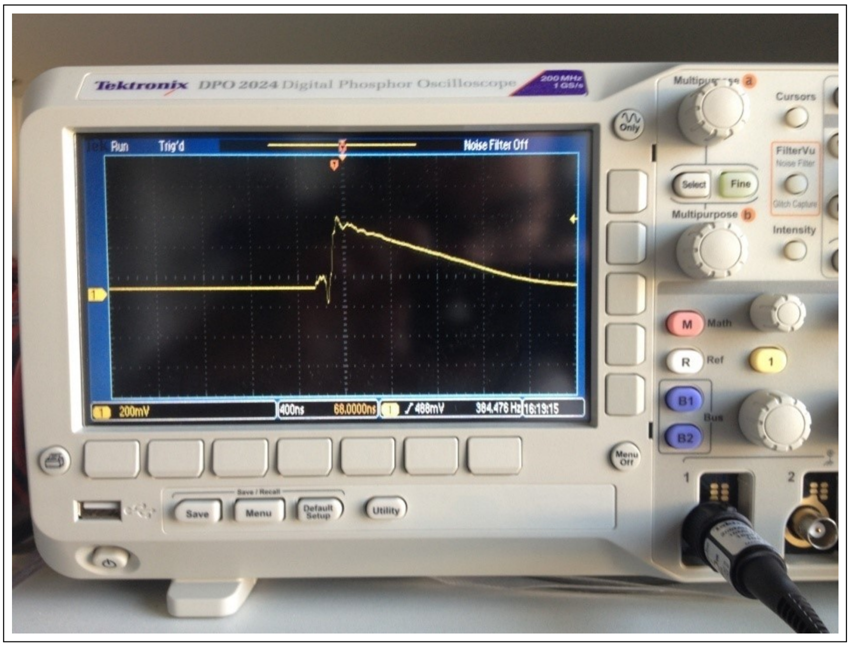


Figure 4.6: Damping noise level: Output signal from the infrared sensor, depicting noise detected in the sensor output. The screenshot was taken in a lab when any signal generating device was not found. The settings of the oscilloscope for capturing this information was as follows: 200 mV and 400 nanoSecond per division.

normalized proportional value that corresponds to the proxemic distance to the nearest obstacle. Since our dataset does not contain negative or zero values, we could obtain trendline power functions as shown in figures 4.7, 4.8, 4.9 and 4.10. For accuracy reasons, we obtained two different power trendlines for the sensor voltage output, in order to precisely depict our values. Similarly, two trendlines are calculated for the normalized proportional value. We can then switch between any of these two functions using conditional statements in the server processing side as shown in algorithm 4.1.

Now, the plinth is capable of collecting proxemic data of nearby visitors. Simply by employing the functions provided above, we could calculate the proxemic distance accurately. From a performance perspective, we compared the running time of the power function calculations in Javascript with other equivalent traditional multiplication. Performances were similar, with no significant differences.

The stand of the exhibit is made of metal. Once touched, the lamb illuminating the brain switches off. We measured the degree of brightness offered by the lamp during the calculation of the sensor power function to make sure that our function is performing as expected.

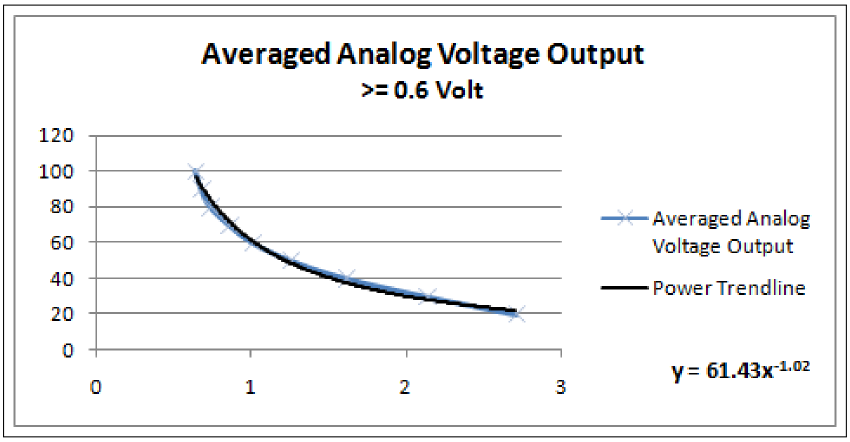


Figure 4.7: Proxemic distances plotted against voltage output for inputs greater than or equal to 0.6 Volts. Using the power function, the proxemic distance can be calculated given the voltage output values of the sensor.

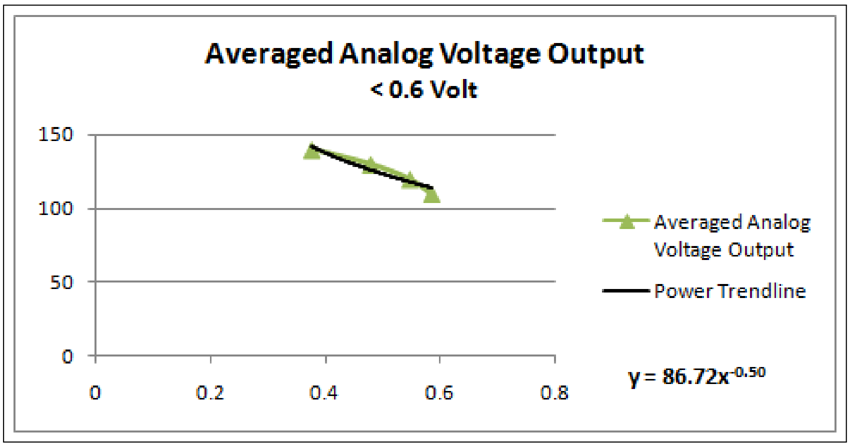


Figure 4.8: Proxemic distances plotted against voltage output for inputs less than 0.6 Volts. Using the power function, the proxemic distance can be calculated given the voltage output values of the sensor.

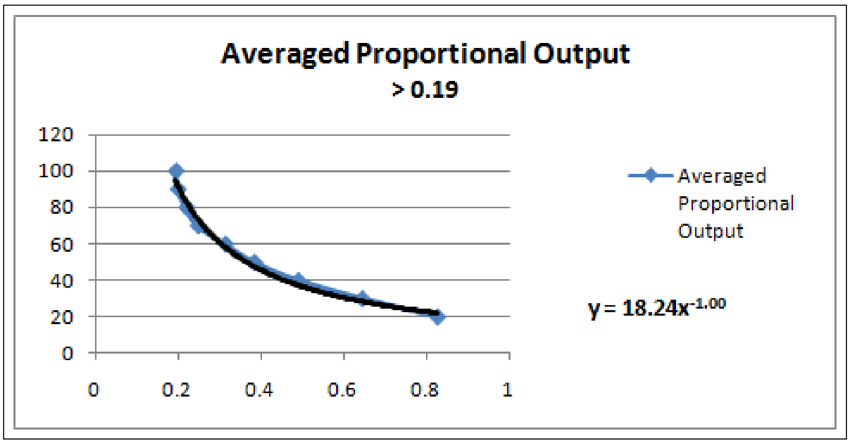


Figure 4.9: Proxemic distances plotted against normalized proportional sensor output for inputs greater than 0.19 normal value. Using the power function, the proxemic distance can be calculated given the normalized proportional output values of the sensor.

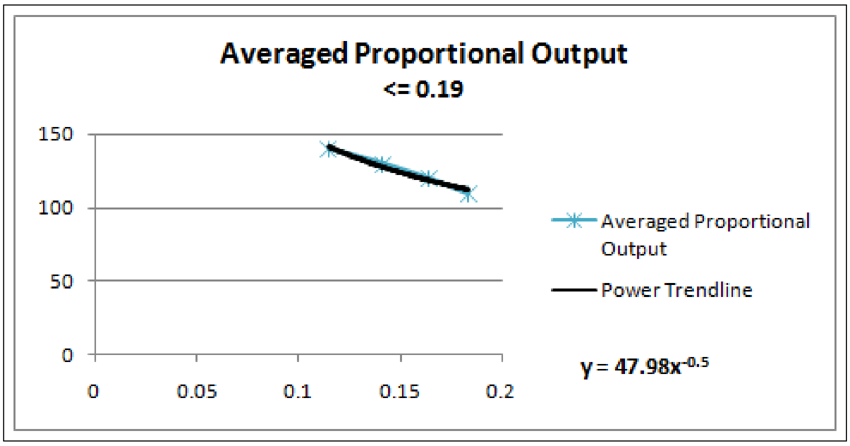


Figure 4.10: Proxemic distances plotted against normalized proportional sensor output for inputs less than or equal to 0.19 normal value. Using the power function, the proxemic distance can be calculated given the normalized proportional output values of the sensor.

Algorithmus 4.1 Power function application, where the proxemic distance can be calculated given the normalized proportional output values of the sensor.

Input: $sensor\_reading$, the normalized proportional output value from the sensor.

if $sensor\_reading > 0.19$ **then**
$proxemic\_distance = 18.24 * (sensor\_reading^{-1});$
else
  if $sensor\_reading <= 0.19 \wedge sensor\_reading > 0.1$ **then**
$proxemic\_distance = 47.98 * (sensor\_reading^{-0.5});$
  else
$proxemic\_distance = 150;$
  end if
end if

Output: $proxemic\_distance$

Figure 4.11: Laser printed brain placed over the Plinth.

Experiment Control: The Hardware

Here, we discuss different devices and hardware tools that we used during our exhibition in the first experiment together with their communication protocols that enabled us to have a smooth environment in which we could collect data from our participants.

Philips 3610 Pico-projectors

For projecting light shapes and animations onto the floor, we used Philips 3610 pico-projectors. They were arranged in a pattern so that they can cover maximum area given their projection dimensions. We implemented an Android based application to interact with the main server through *websoket.io* protocol, where the connection is initiated similar to *http* protocol, then, after an initial handshake, both the projector and the server switch to *websocket.io* protocol, which offers a robust medium for our Real-Time application to perform smoothly.

Each projector receives the radius of the hexagon they are supposed to project on to the floor. According to the projector UID within the adopted distribution pattern (see figure 4.2), the projector starts drawing only a part of the hexagon within the space it is supposed to handle. The fact that the external projectors (projector nr. 4, 5, 6, 7) had to rotate the image 90 degrees (or -90 degrees) before projecting, added a delay that could be noticed to the drawing activity. This problem was solved by measuring this delay and exclusively introducing it to the internal projectors (projector nr. 1, 2, 3) in periodic manner, so that the entire set of projectors is synchronized while drawing animations.

We faced two problems when dealing with this projector. First, the projector was over heated very quickly (less than thirty minutes), which caused the system to shut down unexpectedly sometimes. We tried to make sure that the ventilation openings in each projector is kept open, however, we could not exceed more than one hour of continuous running without a reboot.

The second challenge was because of synchronization between the seven projectors. The seven projectors should cooperate together to draw one shape (the animated hexagon), however, because of its animations, it was impossible for the seven projectors to know exactly when they are supposed to start performing such animation. Moreover, the delay that could be introduced by the network is non-deterministic, and could not be predicted each time when the projectors are to start animating.

The problem was not easily solvable because Android OS does not allow the developer to have control of the exact system clock. The only time attributes that are available to programmer are hours and minutes. Even by employing an external timing server, this problem will continue to exist, given Android OS constraints and a variable-delay network. This means that, in order to be able to draw the animations and to orchestrate these seven pico-projectors, we need an external solution, not relying on any network assumptions.

Luckily, a remote control is provided with the pico-projector, where we were able to re-program its functionality in Android. Knowing that, the seven pico-projectors are now able to detect our pre-determined remote signal and (re)start the animation accordingly.

Plinth Components

Our plinth consisted of a Gadgeteer mainboard (FEZ Spider) with connections to USB module and Wi-Fi module. In addition, we had two extenders that enable us to connect six IR sensors. The mainboard is switched on using 5V adapter. After switching on, the mainboard tries to establish a connection with a predefined SSID, hardcoded in the firmware. Guided by the broadcast packets, once the connection is established, the plinth starts sending continuously the proxemic information to the server. The components included in our Plinth are shown in appendix H.

Fisheye Camera

A fisheye camera was used to have an ultra wide-angle view of the exhibition room. Due to the low brightness level of the exhibition room, the captured videos were very noisy and needed to be preprocessed before analysis. Preprocessing and analysis of the captured videos were done in C++ using OpenGL. The exact parameters used in preprocessing steps are mentioned in the analysis section.

For night vision, the fisheye camera employs an infrared light. The impact of interference between fisheye camera signals and the Plinth IR proxemic distance sensors was neglected, since it had no obvious effect on the plinth measurements. We carried out a pilot study through which such behavior was examined for significant impacts. We compared the proxemic function output in both cases, with and without the infrared lights of the fisheye camera, and no significant differences were reported.

Experiment Control: The Software

For controlling the previously specified hardware parts and orchestrating their functionalities and roles, we implemented a complete software framework that enables us to monitor, control and record our experiment for later analysis. The architecture diagram of the developed system is presented in figure 4.12. Next, we discuss in details each entity in our architecture.

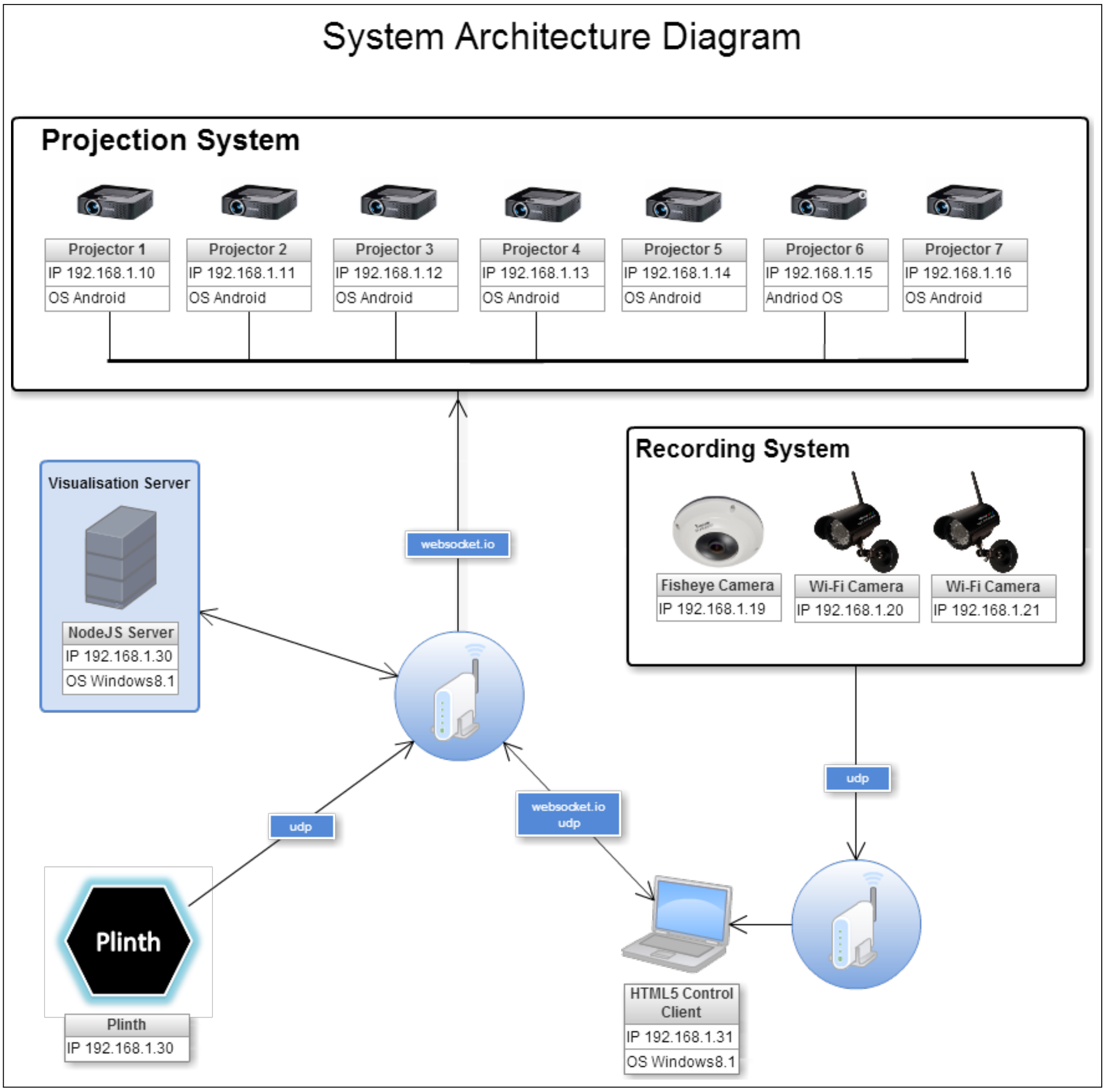


Figure 4.12: Implemented System Architecture Diagram.

Main NodeJS Server

The main server is responsible for a lot of functionalities. It offers the ability to view the interaction details in Real-Time. Also, it offers recording the entire experiment session, to be viewed and analyzed later on.

First, it starts the broadcasting service to be used by the plinth, declaring the IP of the server and the port that is accepting connections to. Second, the server continuously receives UDP packets from the plinth, with the most up-to-date proxemic information. Also, the server stores all session information once the recording button in the client-side application is pressed.

Third, according to the specified input parameters of the client-side terminal, the server sends the new information set regarding the projections to be displayed by the projectors. For exchanging messages with the projectors, we used *websocket.io* protocol.

Finally, for controlling the whole experiment (changing radius or conditions), we implemented a client-side control terminal in HTML5 and Javascript.

HTML5 Control Terminal

We implemented a control frontend to be able to monitor and records our experiment easily. Thanks to *websocket.io* protocol the control terminal was able to communicate with the NodeJS server backend quickly in no delays. Shown in figure 4.13 and 4.14, the control terminal gave us the ability to control the experiment by allowing us to enter the radii and the type of the animation that we want to project to the floor. In our experiment, we used only the inviting animation discussed above.

The recording mechanism was very helpful, as it gave us the ability to record the statuses of the IR sensors to be analyzed. Combined with the data collected from the fisheye camera, we had fruitful dataset that was almost ready to be analyzed. The control interface offered other functionalities that were not used in our experiment, like changing the animations and updating the speed of animation. The simulation tries to rebuild all the important details in the control terminal. The plinth is depicted as black hexagon. The floor projection is depicted as green hexagon. The blue lines are IR sensors with no objects detected in front of them. Orange lines are IR sensors that detect an object. The length of the orange lines is correlated with the radius of the green hexagon that depicts the floor projection, making it easy to determine whether a visitor crossed the projection line.

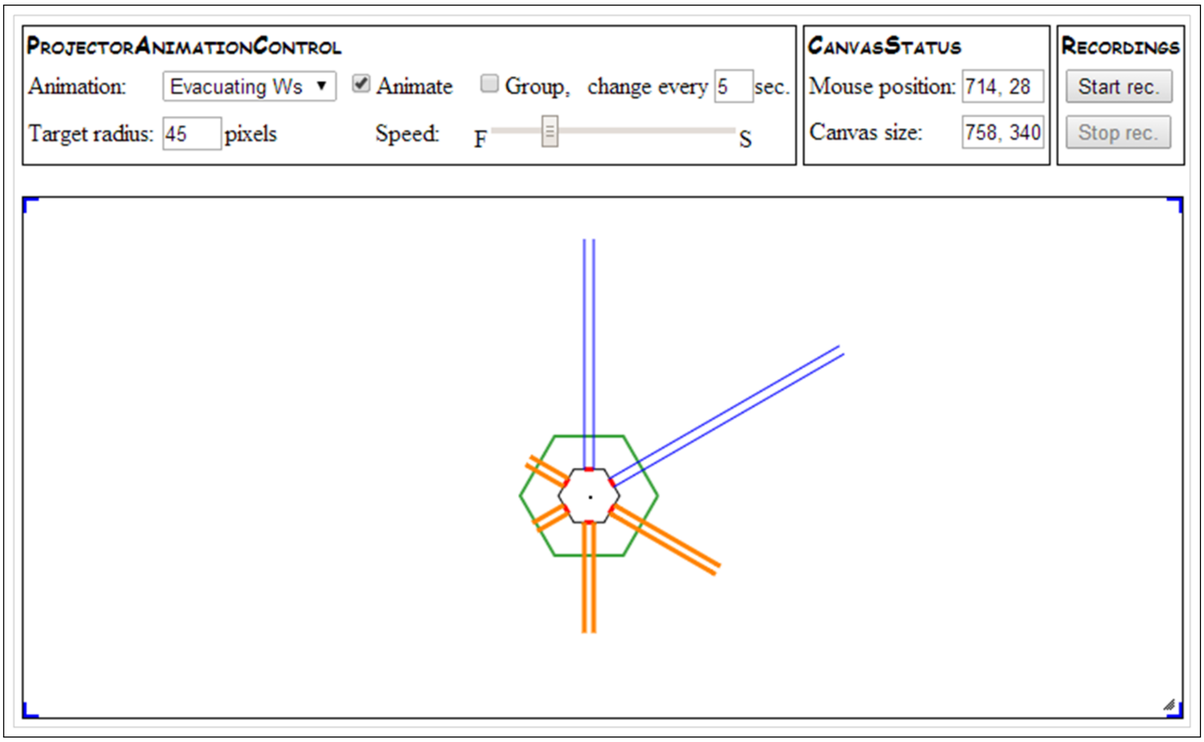


Figure 4.13: Real-Time Control Terminal. Using this interface, we had the ability to control the experiment in Real-Time, changing the radius, starting and stopping the recording.

4.2.3 Procedure

One participant entered the room at a time. Before the subject entered the exhibition room, they were asked to fill in the consent form shown in Appendix B. After the subjects came out of the room, they filled in the questionnaire containing the demographics questions about each participant, three choice questions using a seven-point Likert scale and two open ended questions. Videos are captured continuously using the fisheye camera. Also, the plinth was continuously running and monitoring the participant inside the exhibition room as she wanders around, and extracting proxemic distance information from around the exhibit.

Before a given participant entered the exhibition room, we made sure that the room is in a condition ready to welcome incoming visitors. That is, each time, we made sure that the cameras are functioning, the plinth is still providing information and the projectors are, together, projecting at the required radius. We were able to take a look at the exhibition room from our booth through two installed wireless cameras, that were able to provide us in Real-Time with live updates from the exhibition room.

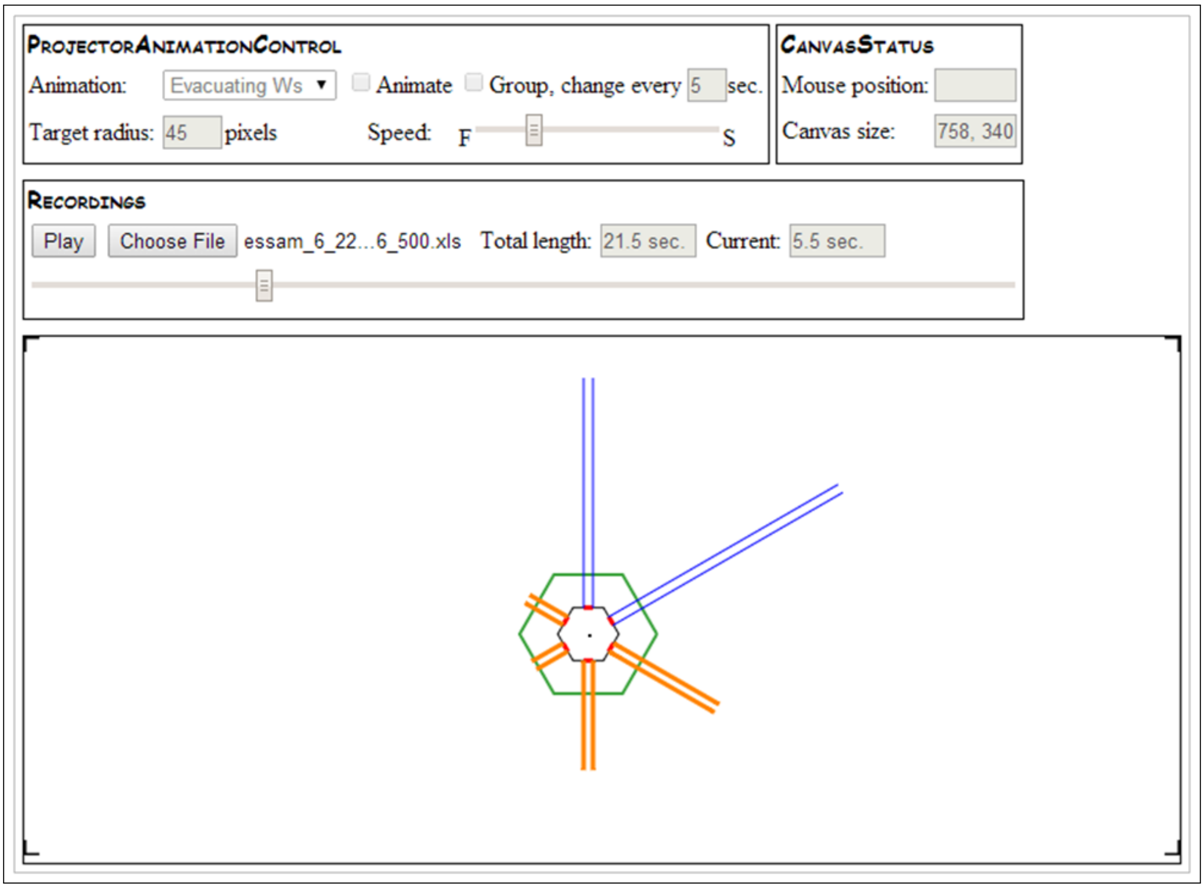


Figure 4.14: Recordings Playback Terminal. Using this interface, we could playback already recorded measurements. This makes it easier to analyze the measurements to come up with fruitful results. Also, this mechanism played a very important rule to come up with the moderation rules.

4.3 Analysis

4.3.1 Pre-Processing Steps

First of all, before carrying out any analysis step, we had to do pre-processing step. We collected data by three main sources, from which we could obtain our results:

a. Quantitative data:

   i. Fisheye camera videos.

   ii. Plinth proxemic data.

iii. Understandability and acceptance levels of our design, which were included in our questionnaires as seven-point Likert scale questions.

b. Qualitative data:

   i. Questionnaires:

      i. Asking for design recommendations to increase understandability and acceptance.

Fisheye Camera Videos

For the Fisheye camera videos, the brightness level was very low and the room was dim for the camera to have a high capturing quality that is ready to be directly analyzed. Also, the noise level in the captured clips was high. Using OpenCV, we used the following set of parameters to pre-process the captured videos. The following operations are applied in order:

1. **Median Blur**: since our videos contained a high level of noise, we used a median filter to get rid of it. Using this filter, we were able to get rid of the salt-and-pepper type noise. By employing a kernel of size 31*31, we could get rid of the noise. This step was important, since the presence of any noise in our images sequence will definitely affect our visitor detection algorithm, particularly if its pixel density is high, as in case of salt-and-pepper noise.
2. **Binary Threshold**: after the previous operation, minute amount of pixels are still affected by noise. By applying a very low binary threshold to the images sequence, we could get rid of this random noise. Using a threshold of 2, we finally obtained noise free videos that are ready to be analyzed.

We used a background subtraction algorithm (Gaussian Mixture-based Background/Foreground Segmentation Algorithm), followed by a contour detection operation to detect the visitor in the exhibition room.

Since we applied the algorithm to a sequence of images representing our captured videos, we had to control the learning degree of the algorithm. That is, how long the algorithm tries to remember previous images as if they were already processed. In other words, it is a parameter that controls the memory of the algorithm. If set to a high value (less than or equal to one), then the algorithm will always forget the pixel information of an image as soon as it is processed, and vice versa.

Due to the low quality of the image and the visitor wandering directions and speed, we used a very low learning factor of 0.009 in order to make sure that the algorithm remembers previous image sequences and considers them in the constricted contour.

The analysis program runtime console together with a sample of its output is shown in Figure 4.15 and 4.16.

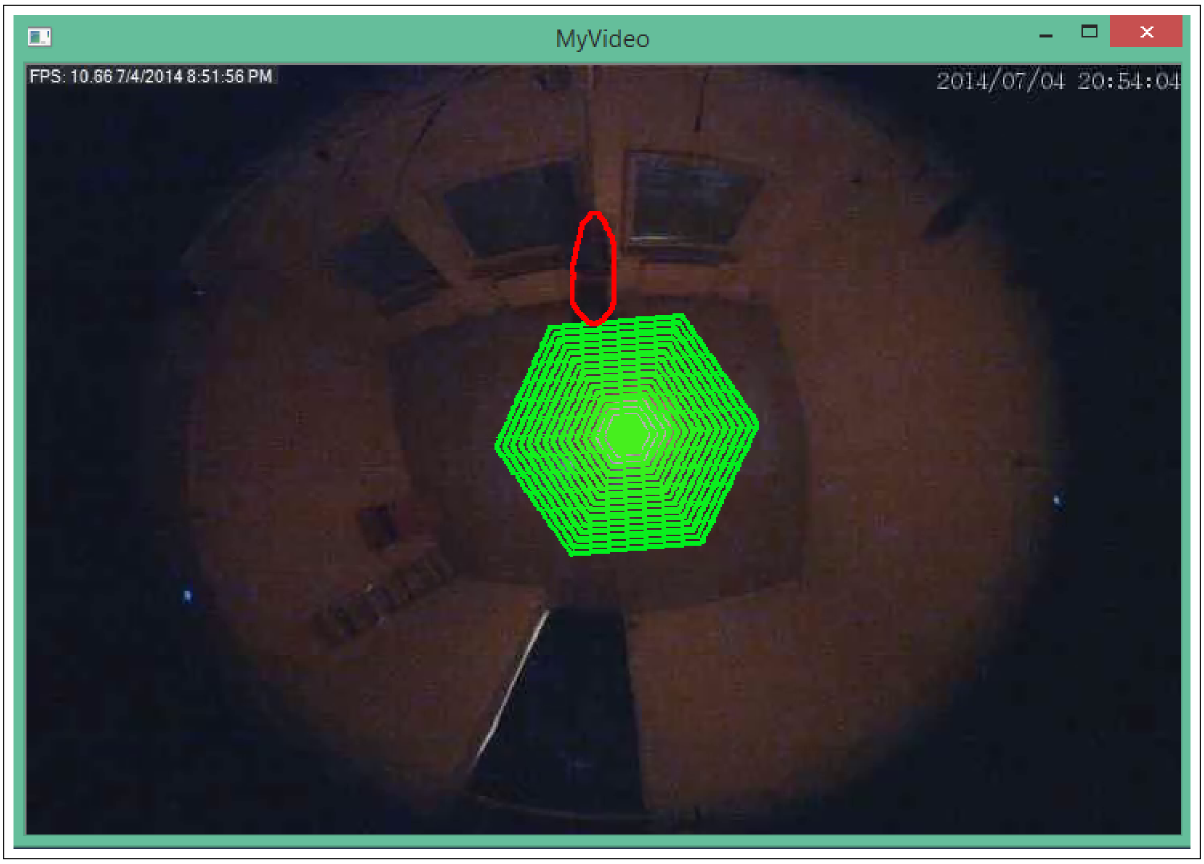


Figure 4.15: Fisheye Camera Videos - OpenCV Analysis. The bright green hexagons show the floor projection around the plinth. The visitor is surrounded by a red bold color. During the analysis we wanted to find the depth of the intersection region between these two entities. The collision depth is shown in figure 4.16.

Plinth Proxemic Data

For the plinth, six infrared sensors were not sufficient to cover 360 degrees. Given the angle covered by one sensor, fifteen degrees as stated in the datasheet, we needed more than six IR sensors. Another idea is to use ultrasonic sensors that have a relatively wider angle. However, the problem with ultrasonic sensors is that, the reflection of an echo might end up behind the sending sensor, affecting the performance of other sensors included in the same plinth. At the end, this phenomenon led to the presence of blind spots in the area covered by the Plinth. A problem we tried to overcome in our second experiment.

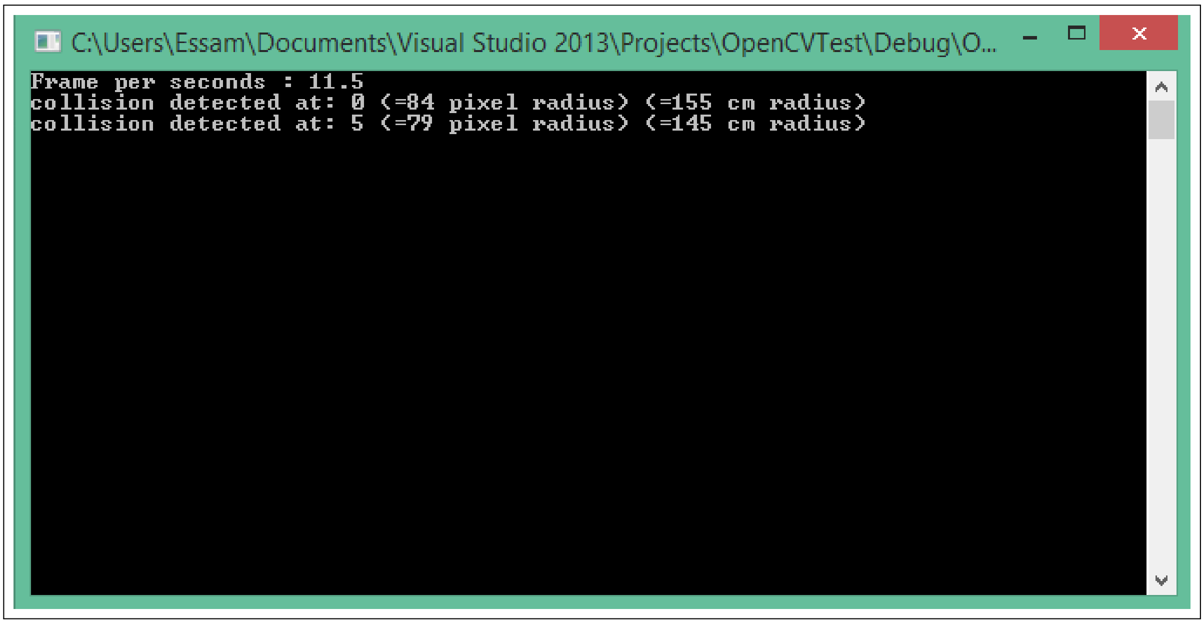


Figure 4.16: Fisheye Camera Videos - OpenCV analysis output. The collision depth as detected between the area of the hexagonal projection and the visitor shown in figure 4.15.

Moderation Rules

Having two ways of collecting our data was very helpful and fruitful. However, we noticed that there is a difference between data collected for the same visitor between the plinth and the fisheye camera analysis. Here, we discuss the reasons for such discrepancies and reliability issues of our experiment.

- We had to take care that the sensors are not centralized (not at the exact center of the plinth, which means there will be a constant offset), giving a constant offset away from the center.
- Blind spots of the plinth should be considered as well. So, in case of a reported collision by the video analysis that is not found in the plinth data, the video analysis should over rule.
- The scale of the fish-eye camera. We had to take care that, if a visitor is standing in an upright position, she will be displayed by the camera as a line. This means, if she bends towards the plinth enough, she would be displayed as a point (her head only will show up). Accordingly she will not be detected by OpenCV analysis as approaching the plinth. Luckily, the plinth can detect such behavior, even if the visitor is at a blind spot, his proxemic distance (away from the plinth) could be estimated.

- Using hands, which is above the plinth sensors to be captured, we used the OpenCV analysis steps to estimate such proxemic distance.
- Shadow, of tall visitors, covered the floor projection. This occlusion by the shadow happened because our distribution pattern of the projectors was mainly around the plinth.
- Shadow, of tall visitors, covered the floor projection. This occlusion by the shadow happened because our distribution pattern of the projectors was mainly around the plinth.
- We had to take care of any abrupt noise at the center of the plinth, as seen by the camera, as it may register a motion at the center of the plinth while the visitor is still away (false positive).

4.3.2 Quantitative Analysis

Distance Measurement

In this Section, we discuss the analysis of the proxemic distances that we could finally agree on after considering the previously mentioned moderation roles. This is the first of two quantitative analysis steps. The second step considers the analysis of the understanding and respect levels.

Our objective is to find out whether there is any difference between the four conditions (C0, C1, C2 and C3). To do that, we should first run a number of descriptive statistical tests to understand the nature of our dataset. After that, we can decide what type of significance test we can conduct to check our objective. Finally, the significance test will suggest the probability that the observed changes (if any) occurred by chance (less than %5). The data was analyzed using IBM SPSSS. Output graphs are included in appendix C.

Recalling the study design of our experiment:

- Independent variables: radius of the floor projection.
- Dependent variables: Actual distance approached by the visitor, visitors recommendations.
- Number of conditions: four conditions, where the radius of the projection changes:
  1. C0 = no projections at all,
  2. C1 = 30 cm, approximately equals 1 foot,
  3. C2 = 45 cm, approximately equals 1.5 feet and

4. C3 = 95 cm, approximately equals 3 feet.

Descriptive Analysis

We try to describe the main traits for the visitor proxemic data we collected. The full report of descriptive statistics is included in appendix C. Here, we discuss some of these important traits.

“The distances between visitors and the exhibit increased from condition 0 (M = 27.2, SD = 3.9), to condition 1 (M = 45, SD = 11.1), to condition 2 (M = 55.56, SD = 6.82) to condition 3 (M = 76.67, SD = 27.61), in that order.”

We noticed a relative gradual increase in the standard deviation values across conditions; which means that the recorded values, denoting the minimum distance kept between the visitor and exhibit, were relatively scattered in case of bigger radius conditions; namely in conditions 1 and condition 3. This means that those visitors could not agree on a common value.

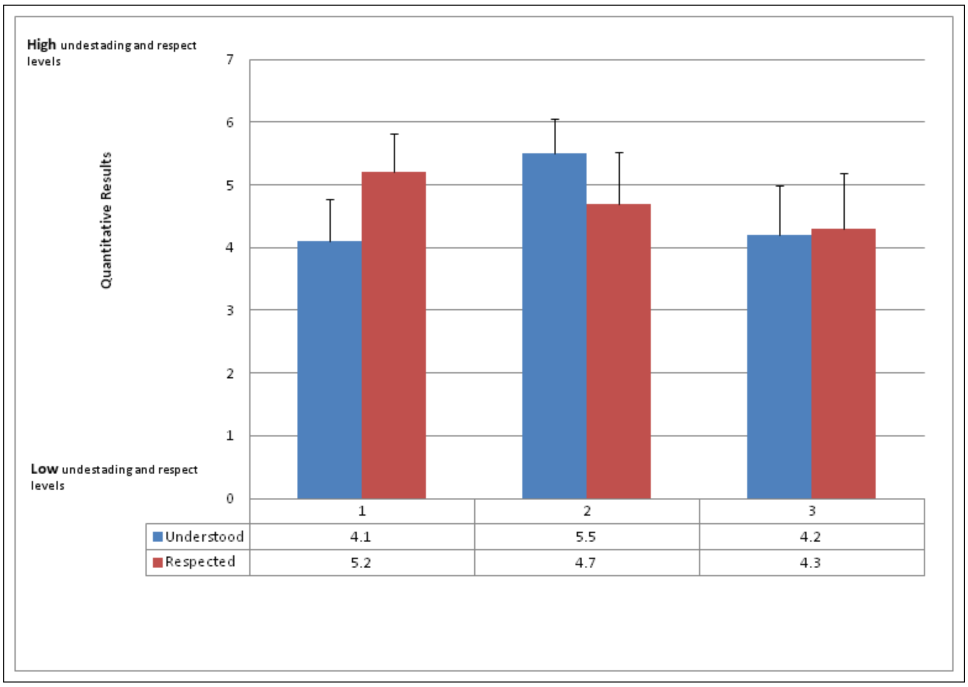


Figure 4.17: Quantitative results per condition. The visitors answered our questions regarding whether they understood and respected the floor projection round the exhibit. The standard error is visualized by the error bars.

Taking a look at the understanding levels of those visitors, we can get an insight about this kind of behavior. In figure 4.17, the understandability and respect levels are shown for the conditions 1, 2 and 3. Notice the low understanding levels of both condition 1 and 3 visitors relative to condition 2.

This means that, participants in condition 1 and condition 3 could not fully understand that the floor projections tried to act as a barrier hoping to convince the visitors to keep away. Accordingly, they reflected such low understanding level by a non-deterministic behavior (rooted at other psychological dimensions of the visitor, and our environment could not do much about it) that obviously lead to a bigger overall difference and eventually to a high standard deviation values.

The previously mentioned argument can also be seen by inspecting the descriptive results skeptically, for example, the range values of the corresponding condition groups agrees with the previous finding.

Significance Test

First, we will try to use a one-way ANOVA test to compare the means of our independent groups. A one-way ANOVA is a parametric test, where we check for statistical significant differences between the means of our condition groups. A one-way ANOVA cannot determine which of the condition groups are different, it can only report whether a significant difference or found. This means that the one-way ANOVA test should be followed-up by a post hoc test to determine which of these group combinations are different.

As for the basic requirements by one-way ANOVA; that is to have only one independent variable and one dependent variable; which are covered by this experiment. However, before doing that we should check whether the assumptions hold for carrying out this test.

One-way ANOVA assumptions:

1. The data is normally distributed: this is a robust assumption; that means some violations to this assumption can be tolerated, providing valid results.
2. Homogeneity of variances, which means that variances of the distributions for each condition group should be the same.

Testing for Normality

Since our sample size per condition is really small to be able to judge normality by looking at the Q-Q plot, or any other graphical data, we are going to use the Shapiro-Wilk test. The following results were reported:

Distances were normally distributed for the Condition 0, Condition 1, Condition 2, and Condition 3 groups, as assessed by Shapiro-Wilk's test of normality ($p > .05$)

Accordingly, with our dataset being normally distributed, we do not need any data transformations and we can continue our pursuit of the one-way ANOVA parametric test, proceeding to the homogeneity of variances test.

Testing for Homogeneity of Variances

Levene's test attempts to find out whether the population variances are equal, formally stated as:

$$\sigma_{c0}^2 = \sigma_{c1}^2 = \sigma_{c2}^2 = \sigma_{c3}^2$$

Carrying out Levene's test, we obtained the following result: The assumption of homogeneity of variances was violated, as assessed by Levene's Test of Homogeneity of Variance ($p < .001$).

As we can see, the variances of the dependent variable are not equal for all groups of the independent variable. This means that an assumption that must hold before carrying out one-way ANOVA test is violated, and we cannot interpret it anymore. Accordingly, a Welch ANOVA test was conducted, giving the following results.

Welch ANOVA test

The proxemic distance between the visitor and the exhibit was statistically significantly different between different condition groups, Welch's $F(3,15.914) = 44.133$, ($p < .001$).

Once more, all the results of the distance statistical analysis are included in appendix C. From the Welch ANOVA test it can be concluded that, not all condition group means are equal, which means at least one group mean is different to another group mean.

This means that light was able to establish a border around the exhibit, and to dictate the distance participants are allowed to keep to it.

A post hoc test is needed in order to identify which particular group means are significantly different. In our case, where homogeneity of variance assumption was violated, Games-Howell post hoc test was used. The results are presented below.

Games-Howell post hoc test

Given that the assumption of homogeneity of variances is violated, we would like to compare all possible combinations of group conditions. Games-Howell post hoc test shows confidence intervals for the differences between group means and shows whether the differences are statistically significant.

- "There was an increase in approached distances from 27 ± 3.9 in condition zero group to 45 ± 11.1 in condition one group, an increase of 17.78(95% CI, 5.68 to 29.88), which was statistically significant (p = .005 < 0.05)."
- "There was an increase in approached distances from 27 ± 3.9 in condition zero group to 55.56 ± 6.82 in condition two group, an increase of 28.3(95% CI, 20.6 to 36), which was statistically significant (p = .001 < 0.05)."
- "There was an increase in approached distances from 27 ± 3.9 in condition zero group to 76.67 ± 27.613 in condition three group, an increase of 49.4(95% CI, 19.94 to 78.95), which was statistically significant (p = .003 < 0.05)."
- "There was an increase in approached distances from 45 ± 11.1 in condition one group to 76.67 ± 27.61 in condition three group, an increase of 31.68(95% CI, 1.57 to 61.76), which was statistically significant (p = .039 < 0.05)."

Understanding and Respect Levels

To collect understanding and respect levels from our participants, we used a 7-point Likert scale. The data are analyzed for statistically significant difference across using a Kruskal-Wallis H Test.

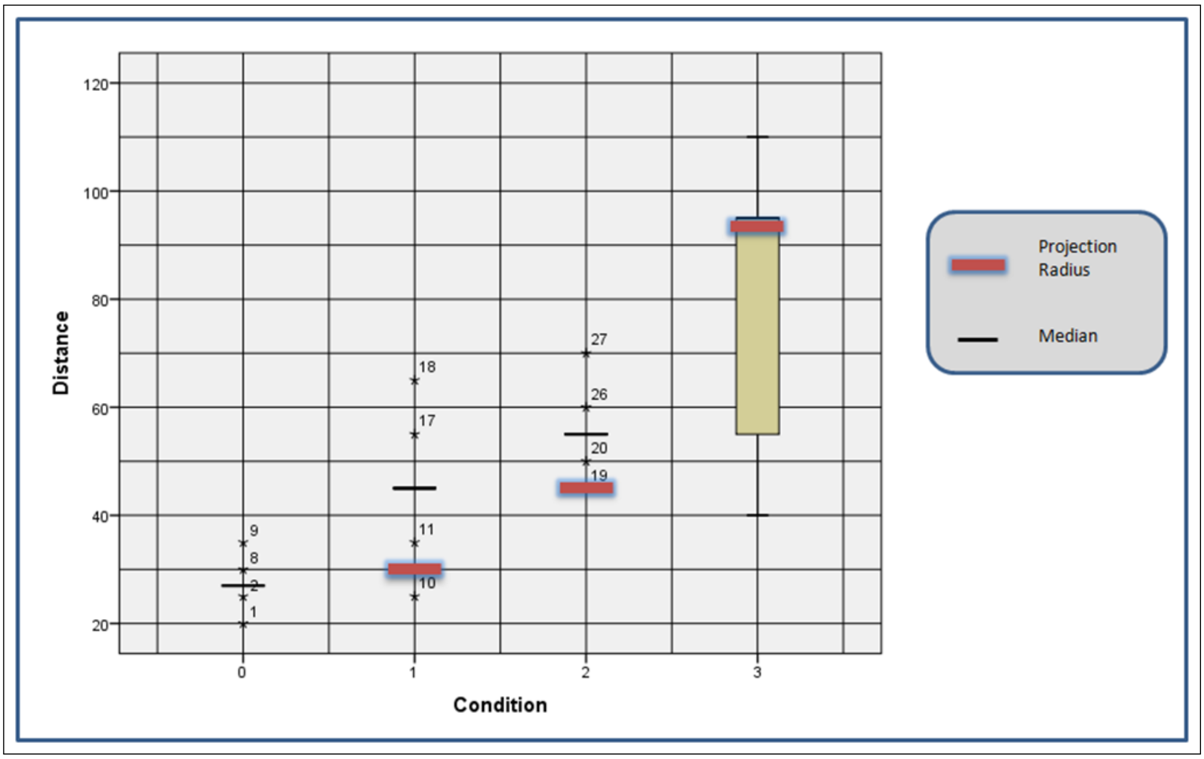


Figure 4.18: Distances approached by visitors in each condition are visualized by box plots.

For understanding levels, a Kruskal-Wallis H test was run to determine if there were differences in understanding levels between four groups of participants with different radius of floor projections: Condition 0, Condition 1, Condition 2 and Condition 3. Distributions of understanding levels were not similar for all groups, as assessed by visual inspection of a box plot found in appendix I. The mean rank of understanding level scores was not statistically significantly different between any of the four groups, $\chi^2(3) = 2.345, p = 0.31$.

For respect levels also, a Kruskal-Wallis H test was run to determine if there were differences in respect levels between four groups of participants with different radius of floor projections: Condition 0, Condition 1, Condition 2 and Condition 3. Distributions of the respect levels were not similar for all groups, as assessed by visual inspection of a box plot found in appendix I. The mean rank of respect level scores was not statistically significantly different between any of the four groups, $\chi^2(3) = 0.689, p = 0.708$.

A bar chart depicting both the understanding and respect levels for experiment 1 participant. There you can find a low level of understanding reported by condition 1 and condition 3 participants. Once again, it's because of this that we can see a relatively higher variance levels in case of these two groups.

In case of a low understanding level, it is justifiable not to find a corresponding high respect levels for the same condition. This could be due to the fact that nobody can intentionally respect something that she cannot understand.

A post hoc test is not needed in this case, since there were no significant differences across mean values for the four groups.

Quantitative Results Summary

The data was normally distributed for each group, as assessed by boxplot and Shapiro-Wilk test ($p < .05$), respectively. Homogeneity of variances was violated, as assessed by Levene's Test of Homogeneity of Variance ($p < .001$). The visitor proxemic distances were statistically significantly different between different condition groups, Welch's $F(3,15.914) = 44.133$, $p < .001$. The distances approached by the visitors increased from condition zero group (27.22 ± 3.96) to condition one group (45 ± 11.1), condition two group (55.56 ± 6.82), and condition three group (76.67 ± 27.61), in that order.

Games-Howell post-hoc analysis revealed the following:

- "There was an increase in approached distances from 27 ± 3.9 in condition zero group to 45 ± 11.1 in condition one group, an increase of 17.78(95% CI, 5.68 to 29.88), which was statistically significant ($p = .005 < 0.05$)."
- "There was an increase in approached distances from 27 ± 3.9 in condition zero group to 55.56 ± 6.82 in condition two group, an increase of 28.3(95% CI, 20.6 to 36), which was statistically significant ($p = .001 < 0.05$)."
- "There was an increase in approached distances from 27 ± 3.9 in condition zero group to 76.67 ± 27.613 in condition three group, an increase of 49.4(95% CI, 19.94 to 78.95), which was statistically significant ($p = .003 < 0.05$)."
- "There was an increase in approached distances from 45 ± 11.1 in condition one group to 76.67 ± 27.61 in condition three group, an increase of 31.68(95% CI, 1.57 to 61.76), which was statistically significant ($p = .039 < 0.05$)."

As seen from the above post hoc, and after it became significant that light was able to establish a border around our exhibit, now we can see which conditions had a statistical significant difference between group means. By taking a look at the last outcome of the multiple comparisons, we can see that the difference between group means for conditions 1 and 3 was statistically significant. That is, there was a difference between the mean of the distances approached by visitors when the floor projection was at 30 cm and 95 cm away from the exhibit.

4.3.3 Qualitative Results

title After visiting our exhibition room, participants were asked to fill in a questionnaire. This questionnaire included open ended questions asking for feedback and recommendations for a design that would communicate better the instruction to keep the distance.

A summary of recommendations is included below. Full list recommendations are included in Appendix D.

C1-visitors:

- I would have understood it if the line would blink when I approach it.
- I would just draw a straight line in front of the visitor.
- A greater distance of the line to the object would better communicate that it is a distance sign.

C2-visitors:

- Use Red color.
- Use Round shaped projections.
- Stronger animations and interactivity.

C3-visitors:

- Red color.
- Interactivity,
- I expected the projection to be interactive.
- Red could serve as signal color for the border.

4.4 Discussion

4.4.1 Plinth Re-design

With six IR-sensors embedded into the sides of a hexagonal prism shaped container, the plinth is only able to cover up to 90°out of 360°. That is because each sensor covers an angle of 15°. In our earlier design we relied on the fisheye camera and on a set of moderation rules in order to find a solution to the insufficient coverage by the Plinth.

The inability to detect visitor movements made it hard to completely rely on the Plinth for detecting visitors, due to its blind spots. One way to overcome this drawback is to come up with a new design that can include a sufficient amount of IR sensors, capable of covering 360°.

Luckily, with laser cut polymers, we are able to quickly and effectively come up with solutions to solve prototyping problems. Given that our used sensors cover up to 15°angle as included in the Data sheet, we need twenty-four IR-sensors to cover 360°. This leads to our new design of the plinth (Plinth V2) as shown in figure 4.19.

Figure 4.19: Plinth new design - Plinth V2. A circular prism design with IR sensors covering 180 degrees, making it possible to detect an object wherever it is.

4.4.2 Participants' Expectations

Also, from another perspective, visitors recommended using a circle as a floor projection, to act as an instruction to keep the distance. It is more appropriate if the design of the Plinth is circular shaped instead of a hexagonal one.

By clustering comments by the participants into groups, we can find that:

1. Eight Visitors wanted to see an interactive light projection.
2. Five participants recommended a red colored design.
3. Three participants voted for a circular projection instead of a hexagonal one.
4. Three Participants encouraged the usage of animations as a mean for communication.

The mentioned statistics are visualized in figure 4.20.

Having had a set of recommended ideas that might help visitors understand and respect floor projection as being a border around an exhibit not to be crossed, we took these recommendations a step further and started working on a second experiment.

In a second experiment, we would like to see the effect of following these set of recommendations in our study in order to come up with a design that could efficiently act as a border. Moreover, we would like to see the effectiveness of such design in dictating and changing the positions of the visitors. That is, we would like to see if a floor projection succeeds in guiding the motion of visitors in a museum environment. This is what we are going to present in the next chapter.

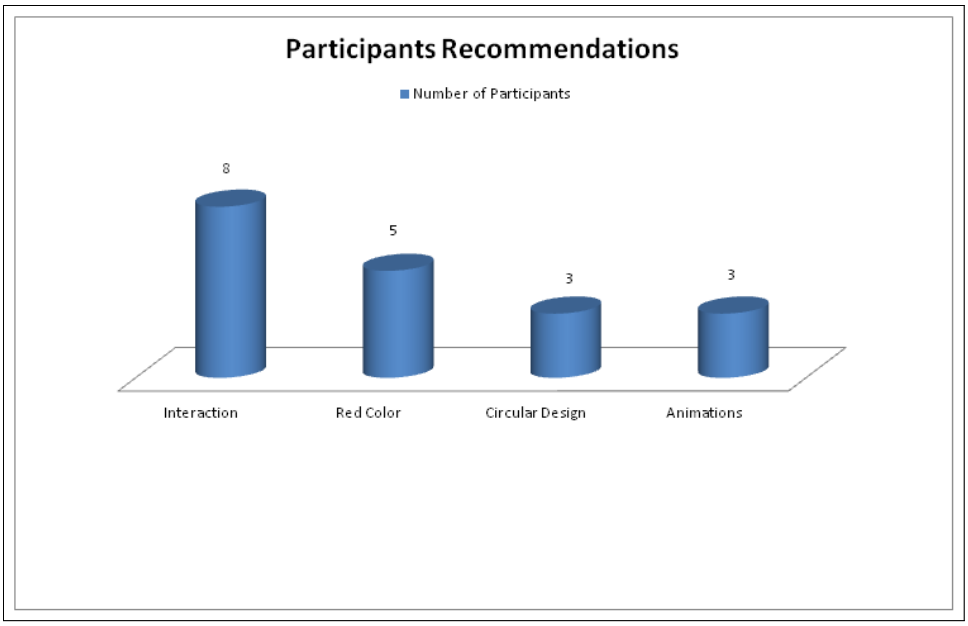


Figure 4.20: Qualitative Data Summary. Visitors were asked to fill out a questionnaire, in which they were asked about their recommendations to improve the design. Recommendations are detailed in the above section.

5 Experiment Two: Movement

5.1 Rationale

5.1.1 Research Question

In the second experiment, we focus on visitor's movement in front of an exhibit. We would like to see whether we can manipulate the distance approached by a visitor using floor projections. In essence, we try to understand and hopefully prove that light, projected on the floor in a given orientation with specific color and animations, has an effect and can be used to control and guide movements of visitors in museums.

In the next section, we present the second experiment and its study design. Then, we present the characteristics of our sample and discuss how the data we gathered from this experiment was analyzed to come up with worthwhile conclusions that we mention at the end of the chapter.

From the qualitative results that we collected in our first experiment, it became obvious that visitors would prefer a round-shaped floor projection (see appendix D). Moreover, changing the color would significantly adjust the behavior of the participants to coincide with our expectations; that is to keep the distance and not to overshoot the floor projection.

From another perspective, changing the color or including animations might seem worthless, yet they have a certain appeal. Changing color dictates that overshooting after the projected static line is not permissible. This behavior was recommended by visitors in our first experiment. Once the color of the projected line changes, a participant might ask herself why it happened, or what she is supposed to do. That's when the animations behavior comes in handy. They guide the participant to the direction to which she should start moving.

In this experiment, we would like to see whether these implicit messages are obvious enough to be understood by a sufficient number participants to a degree that is adequate to come up with a significant result, in a way that makes it unmistakable that changing color and including animations play a significant role in guiding participants and making the required behavior understandable.

As presented in our first experiment chapter, we start by explicitly and formally mentioning all details included in our second experiment, in a way that makes it reproducible and proves its correctness.

5.1.2 Hypothesis

We stated a clear and precise hypothesis that is tested through an empirical investigation. The null and alternative hypotheses are mentioned below:

H(0): "An arc, projected onto floor in front of the plinth that changes its distance to the plinth in a predetermined transitions, has no effect on manipulating proxemic distances between an exhibit and a visitor"

H(A): "An arc, projected onto floor in front of the plinth that changes its distance to the plinth in a predetermined transitions, has an effect on manipulating proxemic distances between an exhibit and a visitor"

Formally, the goal of the experiment is to refute the null hypothesis, a significance test is to be done and represented in the results section to determine whether it is reasonable to refute the null hypothesis and the likelihood of being wrong in such case.

5.1.3 Variables and Conditions

In our study, the following variable has been identified as an independent variable: the look of the arc projected around the plinth. The view of the floor projection can be controlled using two parameters, color and animation. For color, we will include red and white colors as recommended by participants in the first experiment. For animations, depending on the actual position of the participant relative to the static projected arc, three moving arcs will be shown, simulating moving waves directed to the position requested for the visitor to go to. They act as guidance for visitors, advising them where they should go.

The dependent variable is the actual distance approached by the visitor in direction of the exhibit. Through this experience, we would like to find out whether a logical relation exists between these two variables.

- Independent variable: the look of the projection; the animations and color applied to the floor projection.
- Dependent variables: Actual distance approached by the visitor, visitors recommendations.
- Number of conditions: four conditions, where color and animations of the projected arc varies:
    1. Condition 0: white color without animations.
    2. Condition 1: white color with animations.
    3. Condition 2: red color without animations.
    4. Condition 3: white and red color with animations.

Using in-between design approach, where each participant is exposed to one condition, we make sure that learning effects are isolated. The aim of the experiment is to investigate the effectiveness of floor projections in controlling/changing the position of participants.

5.2 Methodology

5.2.1 Subjects

In our experiment, forty-eight participants served as subjects. Participants had the chance to go to the university cafeteria and order a hot drink together with a cookie, after they completed the task. Eighteen participants were offered a compensation of 5,- EUR. For each participant, the task was simply to start moving from inside the room, take a look at the exhibit, and finally they can leave the room and wait in front of the door once they are satisfied exploring the exhibit. Participants were asked to sign the consents form shown in appendix K.

This scenario tried to cover what one would do inside a museum, from the moment she observes the presence of an exhibit till she is done exploring it.

As we did in the first experiment, here we included German participants only in the analysis. This is justified in Hall's contribution to the field of Anthropology [Hal66]. He showed and exemplified the effect of cultural differences on the human spatial behavior. Of course, visitors from all nationalities were allowed to participate in our experiment, however, their data was excluded during the analysis steps.

After the experiment, participants were asked to fill a questionnaire, shown in appendix J. In our experiment, we had four different conditions (C0, C1, C2 and C3) through which the look of the floor projection varies. Visitors were randomly assigned to conditions such that in each condition we had exactly twelve visitors. By doing this, we avoid any inappropriate sampling and we make sure that our samples are matching the entire population to a high degree. Also, assigning participants to conditions at random will significantly reduce the possibility of making this kind of error in our study and suppress the possibility of having any potential confounding variable between independent variable and dependent variable.

In the results section, significant tests are conducted in order to show how confident we are that our results collected from the sample population can be generalized to match the whole population.

5.2.2 Materials

Location

The experiment was performed in a Lab room with dimensions 5.4 m * 6.1 m. The room had two windows and one entrance door. The windows and shutters were closed during the experiment to make sure the perception of the floor projections is not affected by outside ambient light.

Inside the lab, we tried to construct an environment that matches to a high degree that of a museum. White boards were used to construct a 2.3 m * 2.2 m area, where the exhibit was shown. On the ceiling, a wide-angle projector was installed. The projector was chosen so that it could cover the largest possible area. 3D models of the exhibition room are presented in figures 5.1 and 5.2. In our experiment, the results were gathered using the plinth V2, as discussed in the previous chapter discussion section.

In the next section, we take a look at the exhibit used in this experiment, and discuss its design steps to exclude any blind spots and to make it easy to reliably depend on the plinth during the analysis steps.

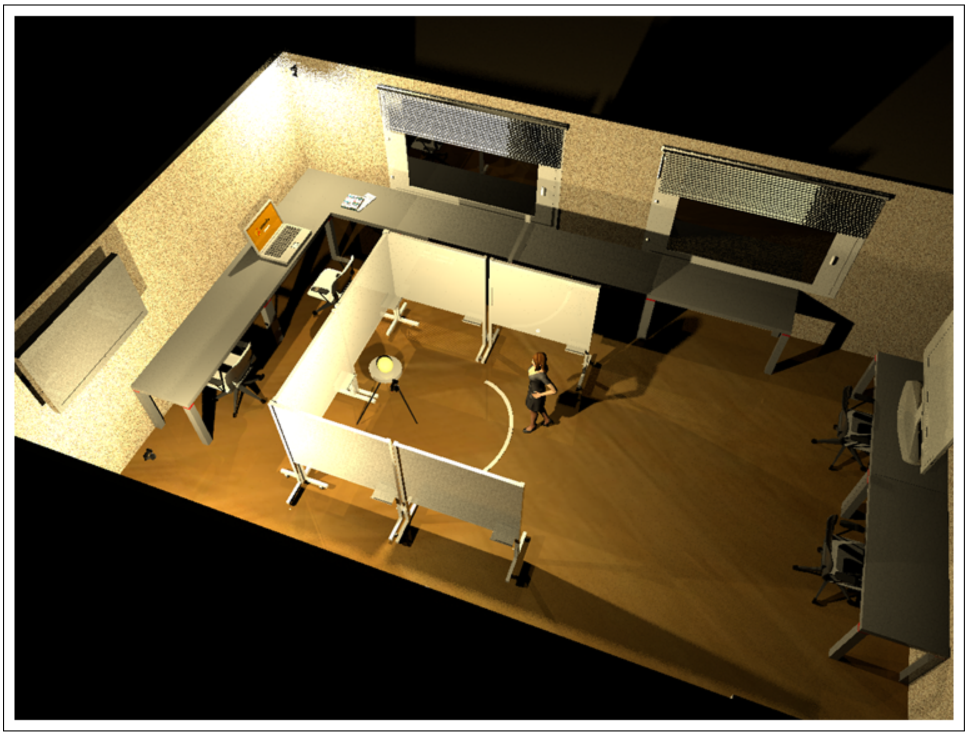


Figure 5.1: Exhibition Room 3D Model – aerial view. Visitors enter the room from the bottom-right corner, where they find the exhibit located to their left. The animations and color are condition dependent to which a visitor is randomly assigned. To the top-left corner, the Real-Time control terminal is located. Once started, the experiment proceeds automatically. The only manual interception needed is to start the recording and stop it. The recording is stopped when the visitor voluntarily leaves the room after taking sufficient time exploring the exhibit.

Exhibit

The chosen exhibit was a 3D printed brain that was used in our first exhibition. During the experiment, the exhibit was fixed on top of the plinth, so that, the plinth was able to collect proxemic distances between the visitors and the exhibit. The plinth, with the exhibit placed on top of it, is shown in figure 5.3.

The plinth was redesigned to have a circular-prism shape, as shown in figure 4.3. Since each IR sensor used in our experiment covers 15 degrees, we used twelve sensors to cover 180 degrees. This ensures that the location of the participant will be continuously monitored, given that in our experiment we only need to cover 180 degrees. With the plinth having that

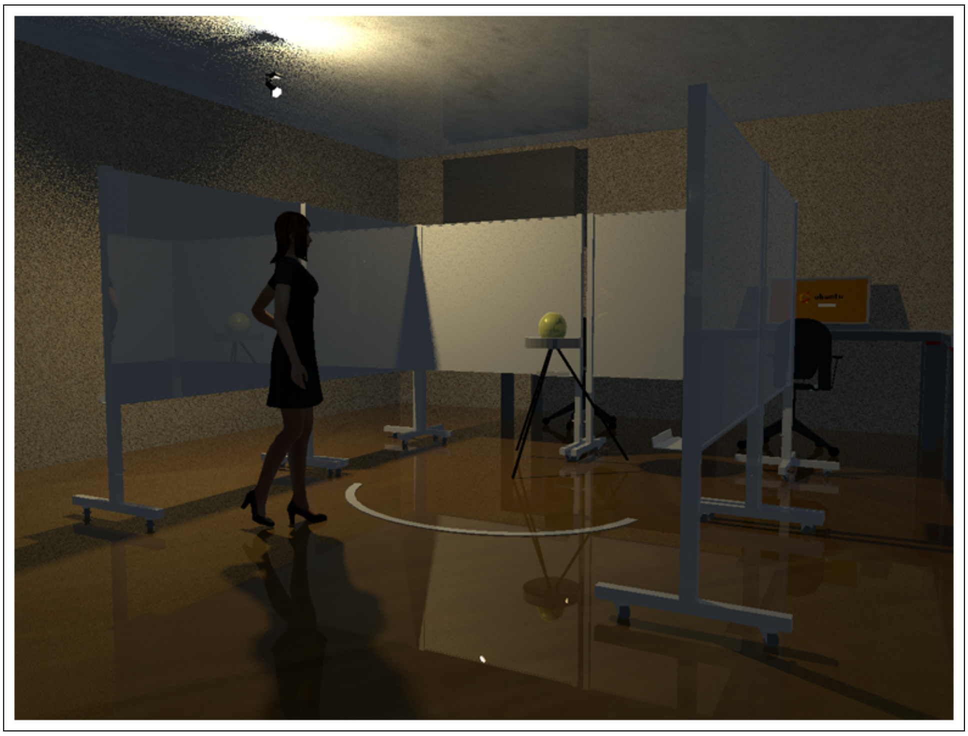


Figure 5.2: Exhibition Room 3D Model – side view. A visitor stands in front of the floor projection exploring the exhibit.

new design, now we are able to capture the distance between participants and the brain as proxemic data.

Moreover, the new circular-shaped design enables us to have circular-shaped projections. In fact, this matches with the recommendations of the participants from the first experiment. In the first experiment, having a hexagonal projection around the plinth somehow dictated the location where participants should try to stand still, if they want to. That is to stand in front of a line, not at an angle.

Having a circular-shaped projection around the plinth does not offer this assumption. The view-angle by a given participant is expected to be anywhere around the plinth. This makes sure that the level of disturbance introduced by the floor projection is reduced.

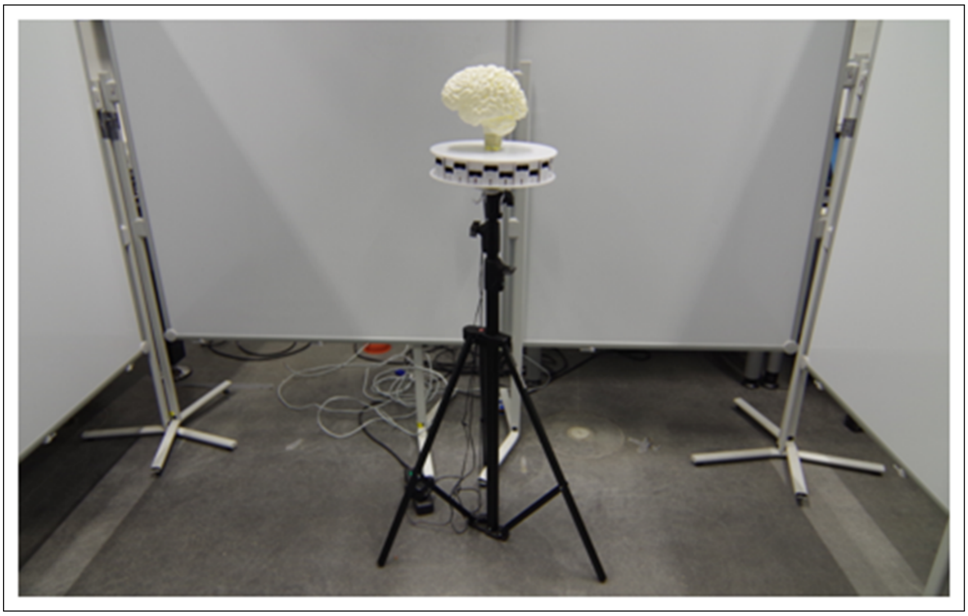


Figure 5.3: Laser printed brain placed over the plinth V2.

Experiment Control Terminal

For controlling our experiment, we implemented a simple Java program that enables us to monitor, control and record our experiment for later analysis. The architecture diagram of the developed system is presented in figure 5.4.

Being connected directly to the wide-angle projector using HDMI cable, we made sure that no network lag could be experienced. Moreover, the experiment is now controlled using one router since we don't need to access the projector via network protocols. The plinth V2 had its Wi-Fi module sending proxemic data continuously to the main Java server. The control terminal interface is shown in figure 5.5.

Procedure

One participant entered the room at a time. Before the subject entered the exhibition room, they were asked to fill in the consent form shown in appendix K. After the subjects came out of the room, they filled in the questionnaire containing the demographics questions about each participant, three choice questions and two open ended questions. The questionnaire is shown in appendix J.

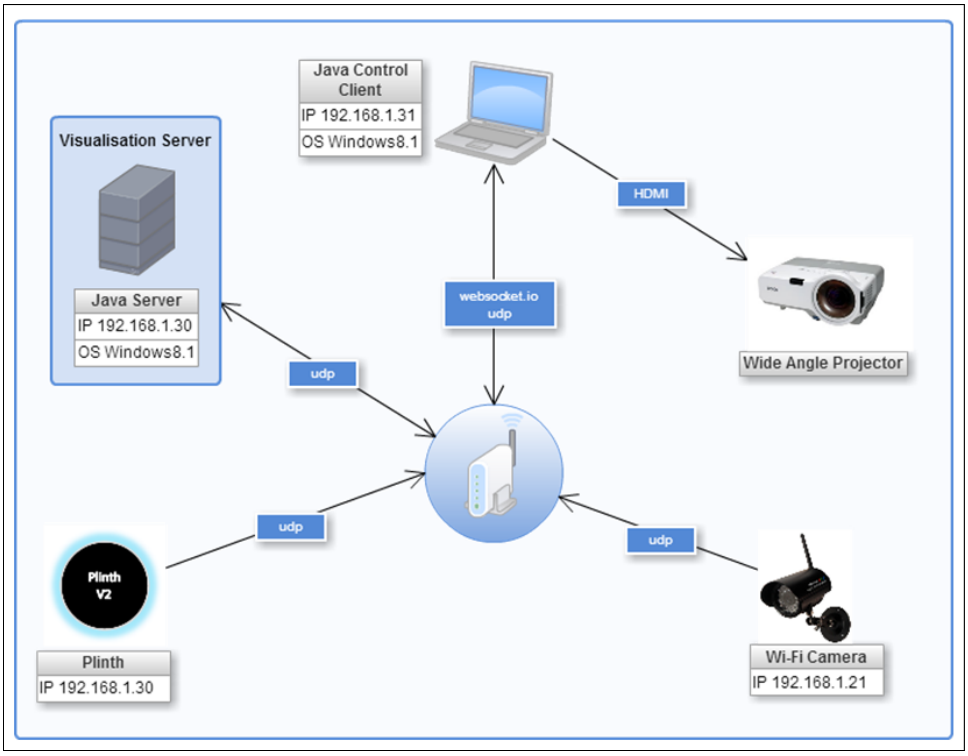


Figure 5.4: Implemented System Architecture Diagram. A Java server that is receiving messages from the plinth, calculating coordinates of the new light projection to be drawn depending on the input values, recording the messages to the client and finally sending the final graphical images to the wide-angle projector. A Wi-Fi camera is also used to make sure that the right conditions are applied to the projection floor as specified by the client terminal.

The plinth was continuously monitoring the participant inside the exhibition room as she wanders around, and extracting proxemic distance information from around the exhibit. Finally, these data are sent to the server and stored together with relevant information of the current applied condition. Before a given participant enters the lab, we made sure that it is in a condition ready to welcome incoming participants. That is, each time, we made sure that the plinth is providing information and the projector is functioning properly. We were able to take a look at the lab from the control area through an installed wireless camera that was able to provide in Real-Time live updates from the experiment location.

For all four conditions, the experiment goes through three steps. By following them, we could accurately conclude whether light projection has an effect on guiding the visitors to change their positions. The three steps are as follows:

1. Big arc projected at 150 cm on the floor away from the exhibit.

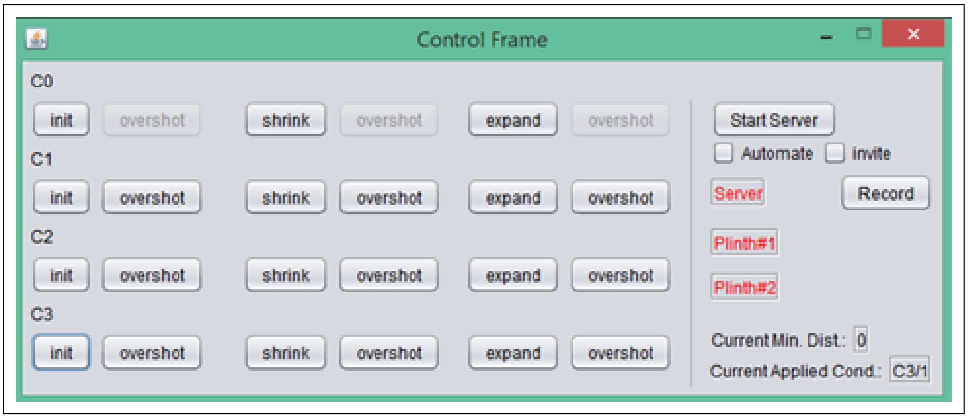


Figure 5.5: Real-Time control terminal. Using this terminal, we have the ability to control which condition is to be displayed b the projector. Also, since the sensors were not able to detect visitors more that 150 cm away from the plinth, we had to manually start/end an inviting animation, to be included only within conditions where an animation is expected. Also, using the terminal we could start/stop recording. The terminals also showed the activity of the server and the connectivity status of the plinth together with the distance to the nearest obstacle.

2. Small arc projected at 90 cm on the floor away from the exhibit.
3. Big arc projected at 150 cm on the floor away from the exhibit.

The transition from a step to the one after takes place automatically after nine seconds, unless the participant overshot the already projected static line. Depending on the applied condition, the projection will exhibit a change in the color or include a guiding animation resembling moving waves.

According to the applied condition, an arc was projected to the floor. An inviting animation was included in case of conditions 2 and 3, where three arcs start shrinking from a relatively bigger radius than the static one till they combine with the static radius. This used animation has the metaphor of sea waves that invite the visitor to come closer to the exhibit till the static arc. The exact transitions between system states is visualized for condition 3 in state diagram included in figure 5.6.

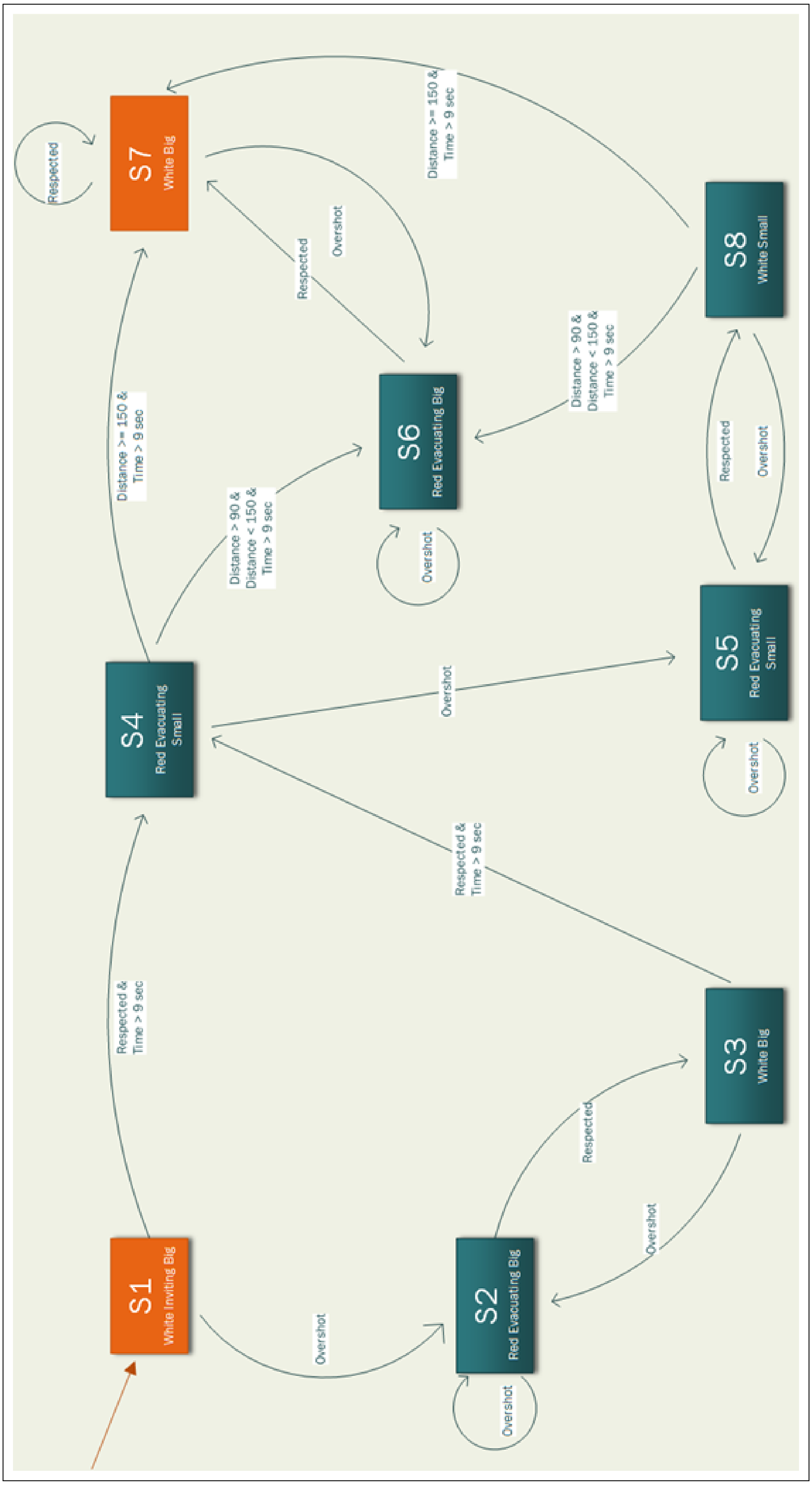


Figure 5.6: State Diagram visualizing C3 System Transitions.

5.3 Analysis

5.3.1 Pre-Processing Steps

First of all, before carrying out any analysis step, we had to do pre-processing steps. We collected data by three main sources, from which we could obtain our results:

- Quantitative data
  1. Plinth proxemic data.
  2. Measuring understandability and acceptance of the design, through a 7-point Likert scale questions.
- Qualitative data
  1. Questionnaires:
     a) Asking for design recommendations to increase understandability and acceptance.

In order to understand and justify the visitors' behavior, it is a good idea to go through the questionnaire. We asked the participants whether they understood what is behind the floor projections, and we asked them to give as feedback on future improvements that can lead to better levels of understanding. To prepare the data for analysis we had all the data from the questionnaire, which we collected during our experiment, entered in an Excel sheet. This makes it easier for analysis, especially when we want to use IBM SPSS for later analysis.

5.3.2 Quantitative Results

Visitors Response Time

In this Section, we discuss the analysis of the proxemic distances that we collected. Thanks to the plinth V2, we could reliably obtain fine grained set of information about the visitors' distances relative to the exhibit during the second experiment. This is the first of two quantitative analysis steps. The second step considers the analysis of the understanding and respect levels, as we did in our first experiment.

Our objective is to find out whether there is any difference between the four conditions (C0, C1, C2 and C3). Recall that our conditions included:

1. Condition 0: white color without animations.
2. Condition 1: white color with animations.
3. Condition 2: red color without animations.
4. Condition 3: white and red color with animations.

For each condition, the experiment goes through three steps, performing a transition of states explained in figure 5.6. The three steps are as follows:

1. Big arc projected at 150 cm on the floor away from the exhibit.
2. Small arc projected at 90 cm on the floor away from the exhibit.
3. Big arc projected at 150 cm on the floor away from the exhibit.

The transition from a step to the one after takes place automatically after *nine* seconds, unless the participant overshot the already projected static line. Depending on the applied condition, the projection will exhibit a change in the color or include a guiding animation resembling moving waves. The dataset we collected from the plinth included distance measurements. Analyzing this kind of data for a fruitful conclusion can be tricky. Given our hypothesis, what we wanted to find out is a significant difference between participants' reactions between the four conditions. We need to identify a measurable dimension that we can exploit, given the plinth and its twelve distance measuring sensors.

During our pre-analysis discussions we found that measuring the time that a participant takes in order to perform a system-requested action (SRA) shows the level of understanding. A system-requested action is an action that is explicitly asked for, either by performing animations or changing the color and radius or all of them combined, by the projection system. For example, when the radius automatically changes from a big radius to smaller one, the action requested by the system is to approach in direction of the exhibit, and is called a system-requested action.

An SRA can have one of two values, approach action or evacuate action. The plinth can detect whether a given SRA was successfully executed by a visitor. In case of an approach action, a successful execution means reading a value of 95 cm or less. For an evacuate action, a successful execution means reading a value of 150 cm. Once any of these two cases is detected, a state of SRA honored (SRAH) is reached.

In our analysis, we measured the time it takes between an SRA and an SRAH to determine, even from one dimension, the understanding levels of floor projections by our participants in each of the four conditions.

Time to Approach (TTA) is time difference between situations a) and b), identified as follows:

a. The time when the projection switches from big radius to small radius, given that the participant respected the bigger radius for the 9 seconds time interval.

b. The time at which the plinth first detects the visitor at the 90 cm radius or less.

Time to Evacuate (TTE) is time difference between situations a) and b), identified as follows:

a. The time when the projection switches from small radius to big radius, given that the participant respected the smaller radius for the 9 seconds time interval.

b. The time at which the plinth first detects the visitor at the 150 cm radius.

Applying the analysis we get the results depicted in figure 5.7. For each condition we determined the mean TTA and TTE values. Also the standard error in each case is calculated and visualized by error bars.

We notice an obvious decrease in the response times between TTAs and their corresponding TTEs for all four conditions (TTEs < TTAs). This phenomenon can be justified by thinking of one experiment as a collection of two sub-experiments, where one participant is asked to participate by (1) approaching the exhibit, followed by another one where she is (2) expected to go back. A learning effect can propagate in this case between these activities, interpreting a global faster TTEs for all four conditions compared to corresponding TTAs.

Also, we notice that the response times (both TTAs and TTEs) in case of condition 3 (that is, using animations and color changes) is smaller compared to other conditions. This means that, condition 3 participants found it easier to understand the floor projections and react accordingly, an important finding that we investigate explicitly and statistically in the next section.

Significance Test

We will use a one-way ANOVA test to compare the means of TTAs. Then it should be followed-up by a post hoc test to determine which of these group combinations are significantly different.

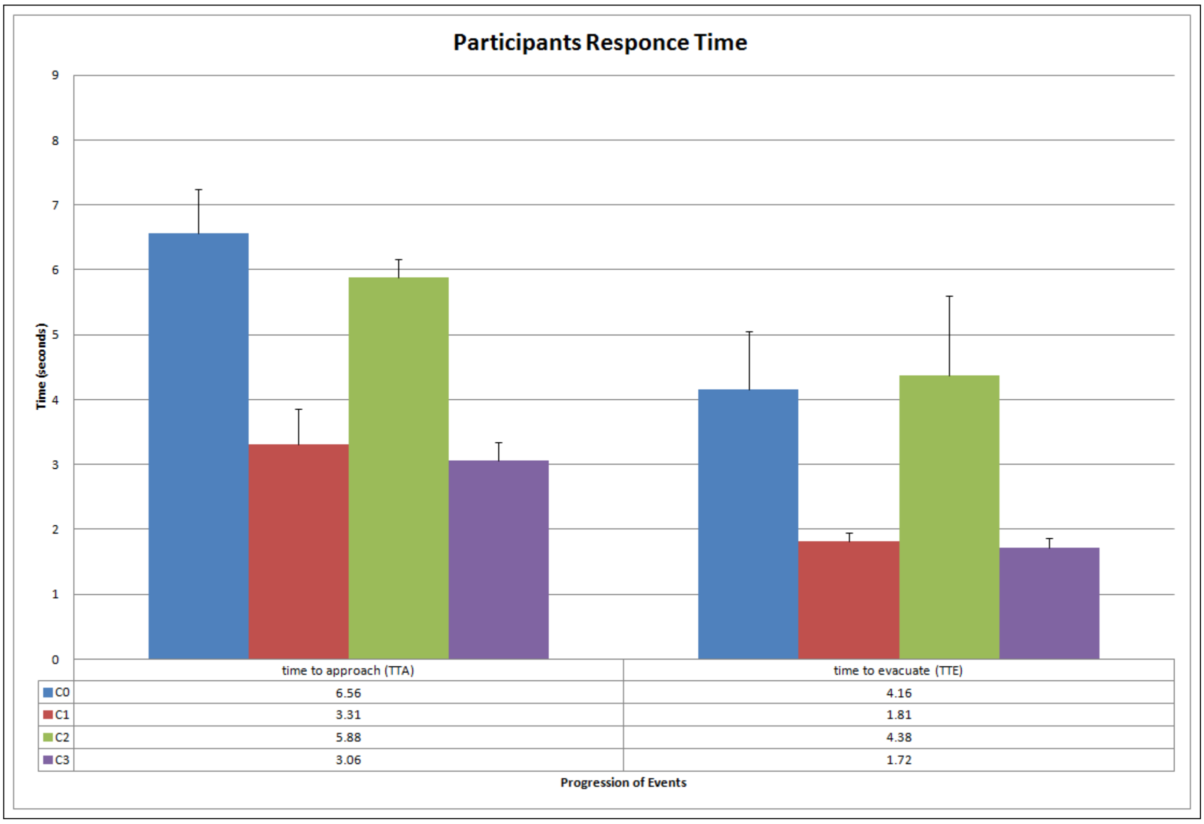


Figure 5.7: Participants response time per condition. Condition 3 has relatively lower values for both TTA and TTE.

As for the basic requirements by one-way ANOVA; that is to have only one independent variable and one dependent variable; which are covered by this experiment. However, before doing that we should check whether the assumptions hold for carrying out this test.

One-way ANOVA assumptions:

1. The data is normally distributed: this is a robust assumption; that means some violations to this assumption can be tolerated, providing valid results.
2. Homogeneity of variances, which means that variances of the distributions for each condition group should be the same.

Testing for Normality

Since our sample size per condition is really small to be able to judge normality by looking at the Q-Q plot, or any other graphical data, we are going to use the Shapiro-Wilk test. The following results were reported:

TTAs were normally distributed for the Condition 0, Condition 1, Condition 2, and Condition 3 groups, as assessed by Shapiro-Wilk's test of normality ($p > .05$)

Accordingly, with our dataset being normally distributed, we do not need any data transformations and we can continue our pursuit of the one-way ANOVA parametric test, proceeding to the homogeneity of variances test.

Testing for Homogeneity of Variances

Levene's test attempts to find out whether the population variances are equal, formally stated as:

$$\sigma_{c0}^2 = \sigma_{c1}^2 = \sigma_{c2}^2 = \sigma_{c3}^2$$

Carrying out Levene's test, we obtained the following result: The assumption of homogeneity of variances was violated, as assessed by Levene's Test of Homogeneity of Variance ($p = .004$).

As we can see, the variances of the dependent variable are not equal for all groups of the independent variable. This means that an assumption that must hold before carrying out one-way ANOVA test is violated, and we cannot interpret it anymore. Accordingly, a Welch ANOVA test was conducted, giving the following results.

Welch ANOVA test

TTAs were statistically significantly different between different condition groups, Welch's $F(3,13.943) = 18.486$, ($p < .001$).

Once more, all the results of the TTA statistical analysis are included in appendix P. From the Welch ANOVA test it can be concluded that, not all condition group means are equal, which means at least one group mean is different to another group mean.

This means that light was able to establish a border around the exhibit, and to dictate the distance participants are allowed to keep to it.

A post hoc test is needed in order to identify which particular group means are significantly different. In our case, where homogeneity of variance assumption was violated, Games-Howell post hoc test was used. The results are presented below.

Games-Howell post hoc test

Given that the assumption of homogeneity of variances is violated, we would like to compare all possible combinations of group conditions. Games-Howell post hoc test shows confidence intervals for the differences between group means and shows whether the differences are statistically significant.

- "There was a decrease in the time to approach (TTA) from 6.5 ± 1.9 in condition zero group to 3.3 ± 1.5 in condition one group, decrease of 3.25(95% CI, 0.719 to 5.781), which was statistically significant ($p = .011 < 0.05$)."
- "There was a decrease in the time to approach (TTA) from 6.5 ± 1.9 in condition zero group to 3.06 ± 0.78 in condition three group, a decrease of 3.5(95% CI, 1.235 to 5.765), which was statistically significant ($p = .004 < 0.05$)."
- "There was an increase in the time to approach (TTA) from 3.3 ± 1.5 in condition one group to 5.83 ± 0.73 in condition two group, an increase of 2.52(95% CI, 0.648 to 4.393), which was statistically significant ($p = .009 < 0.05$)."
- "There was a decrease in the time to approach (TTA) from to 5.83 ± 0.73 in condition two group to 3.06 ± 0.78 in condition three group, a decrease of 2.77(95% CI, 1.55 to 3.99), which was statistically significant ($p = .001 < 0.05$)."

Understanding and Respect Levels

To collect understanding and respect levels from our participants, we used a 7-point Likert scale. The data are analyzed for statistically significant difference across using a Kruskal-Wallis H Test. This was followed by a post hoc test to see exactly which groups had statistically significant difference between their means.

Understanding non-parametric test report

A Kruskal-Wallis H test was run to determine if there were differences in the understanding levels between four groups of participants with different floor projections: the "c0: white color", "c1: white animations", "c2: red color" and "c3: white and red animations" groups.

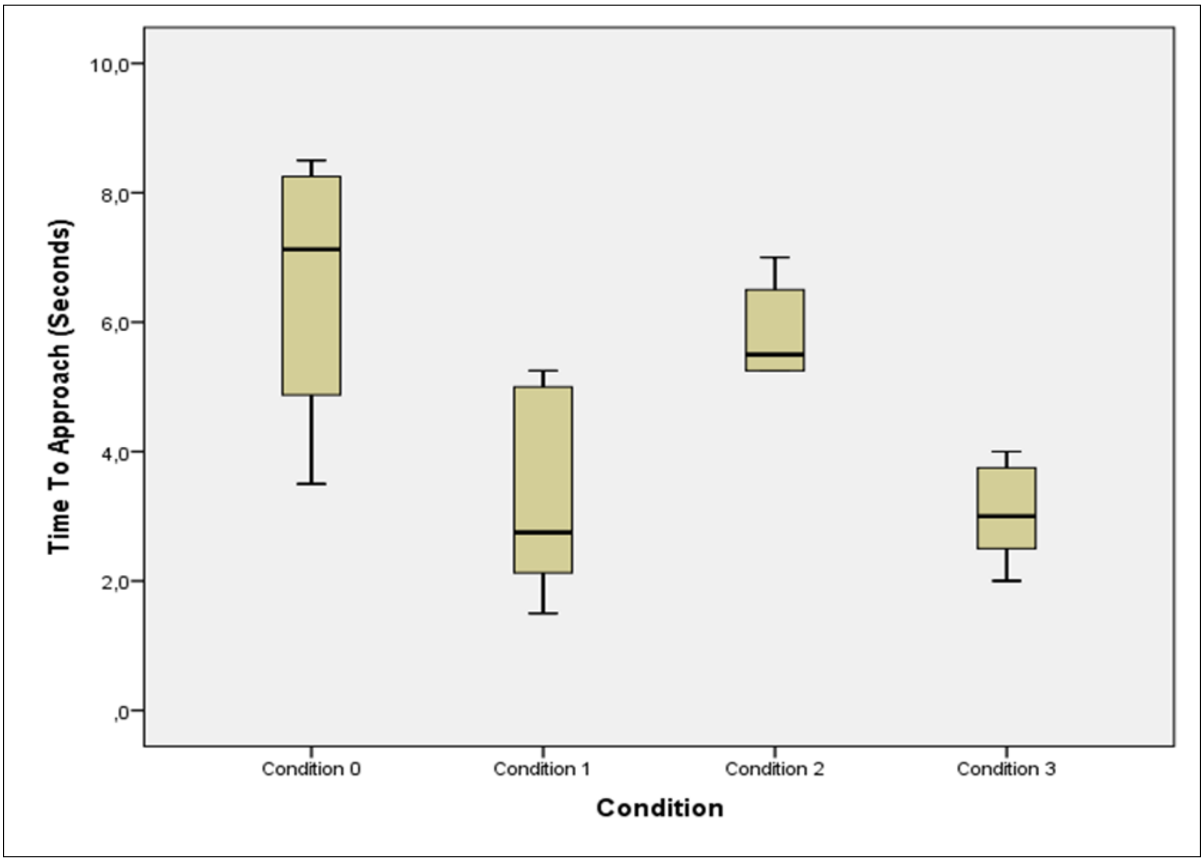


Figure 5.8: Box plots visualizing Time To Approach for each condition.

Distributions of understanding levels were not similar for all groups, as assessed by visual inspection of a box plot. The distributions of understanding levels were statistically significantly different between groups, $\chi^2(3) = 28.048, p < .001$.

Understanding levels post hoc test report

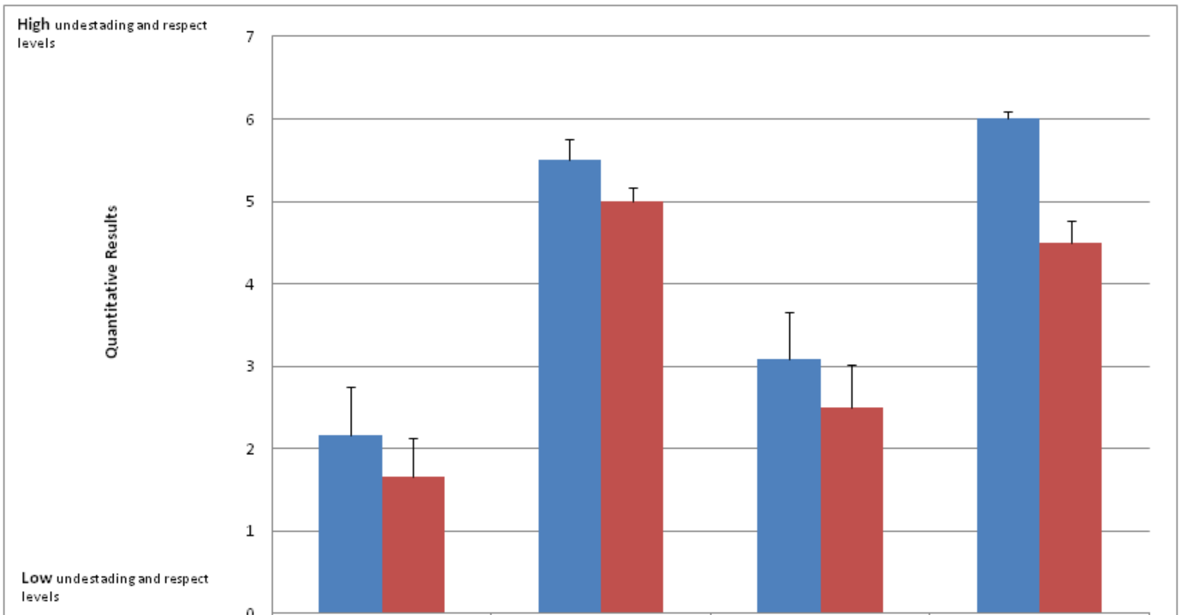
Pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .008$ level. Values are mean ranks unless otherwise stated. This post hoc analysis revealed statistically significant differences in acceptance levels between condition 0 group (12.58) and condition 1 group (32.50) ($p < .001$), and condition 0 group (12.58) and condition 3 group (36.38) ($p < .001$), and condition 2 group (16.54) and condition 1 group (32.50) ($p = .003$), and condition 2 group (16.54) and condition 3 group (36.38) ($p < .001$) but not between any other group combination.

Respect non-parametric test report

A Kruskal-Wallis H test was run to determine if there were differences in the respect levels to the floor projection between four groups of participants with different floor projections: the "c0: white color", "c1: white animations", "c2: red color" and "c3: white and red animations" groups. Distributions of respect levels were not similar for all groups, as assessed by visual inspection of a box plot. The distributions of respect levels were statistically significantly different between groups, $\chi^2(3) = 17.432, p = .001$.

Respect levels post hoc test

Pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the p < .008 level. Values are mean ranks unless otherwise stated. This post hoc analysis revealed statistically significant differences in the respect levels between condition 0 group (13.46) and condition 3 group (30.29) (p = .003), and condition 0 group (13.46) and condition 1 group (34.42) (p < .001), but not between any other group combination.



	c0	c1	c2	c3
Understood	2.2	5.5	3.1	6.0
Respected	1.7	5.0	2.5	4.5

Figure 5.9: Quantitative Results, Understanding and Respect Levels. The visitors answered our questions regarding whether they understood and respected the floor projection round the exhibit. The standard error is visualized by the error bars.

Quantitative Results Summary

By analyzing the plinth data recorded during the experiment, and by interpreting the time that visitors take in order to respond to a demanded reaction as a measure of understanding for the displayed floor projections, we found that condition three participants had the lowest responding times for both approaching the exhibit and evacuating away from it. That means, they could easily understand the presented floor projection and react accordingly. This kind of analysis does not show only the understanding levels of a given floor projection, but also shows the reaction time of the participants.

From the non-parametric tests performed in the previous section and the post hoc tests that followed, it became clear that users favored the animations and found it easy for establishing a communication medium that they can be understood. This behavior could be seen from the bar plot of the understanding and respect levels, shown in figure 5.9. For conditions number 1 and 3, where animations were added to the floor projection, participants found it easy to understand the message of keeping distance.

Moreover, with the inclusion of color changes to animations, understanding levels of the participants of condition 3 increased as shown in figure 5.9. This means that, visitors could associate the change in the color with a change in the attitude of the surrounding environment. And it becomes up to the animation to help the visitors interpret this sudden change in the mood of the environment.

The data was normally distributed for each group, as assessed by boxplot and Shapiro-Wilk test ($p < .05$), respectively. Homogeneity of variances was violated, as assessed by Levene's Test of Homogeneity of Variance ($p = .004$). The time to approach (TTA) was significantly different between different condition groups, Welch's $F(3,13.943) = 18.486$, $p < .001$.

Games-Howell post-hoc analysis revealed the following:

- "There was a decrease in the time to approach (TTA) from 6.5 ± 1.9 in condition zero group to 3.3 ± 1.5 in condition one group, decrease of 3.25(95% CI, 0.719 to 5.781), which was statistically significant ($p = .011 < 0.05$)."
- "There was a decrease in the time to approach (TTA) from 6.5 ± 1.9 in condition zero group to 3.06 ± 0.78 in condition three group, a decrease of 3.5(95% CI, 1.235 to 5.765), which was statistically significant ($p = .004 < 0.05$)."

- “There was an increase in the time to approach (TTA) from 3.3 ± 1.5 in condition one group to 5.83 ± 0.73 in condition two group, an increase of 2.52(95% CI, 0.648 to 4.393), which was statistically significant (p = .009 < 0.05).”
- “There was a decrease in the time to approach (TTA) from to 5.83 ± 0.73 in condition two group to 3.06 ± 0.78 in condition three group, a decrease of 2.77(95% CI, 1.55 to 3.99), which was statistically significant (p = .001 < 0.05).”

5.3.3 Qualitative Results

After visiting our exhibition room, participants were asked to fill in a questionnaire. This questionnaire included open ended questions asking for feedback and recommendations for a design that would communicate better the instruction to keep the distance.

A summary of recommendations is included below. Full list recommendations are included in appendix L.

C0-visitors:

- Justification: it was not clear to me that the projection indicated some distance to the object.
- Recommendation: if a critical distance to the object is reached may be a label in the floor would be more useful.
- Justification: it is not really clear what to do.

C1-visitors:

- Justification: try to interact and check accuracy of the device.
- Justification: have not seen the bold line while backing up.
- Recommendation: a short textual sign would be helpful because it is not entirely clear that the projection is meant to be an instruction rather than being a part of the installation.
- Recommendation: may be a little bit slower so it is not distracting and does not make people pay too much attention to it and start experimenting what would happen if I ignore it.

C2-visitors:

- Justification: it was clear that the red projection was a sign to move away but if the object is to far away to have a proper look at it I would ignore it.
- Justification: the red color represents in most cases a warning symbol so therefore I had the feeling not to cross the red line.

- Recommendation: if the goal is to keep people away there should not be any visuals unless the persons comes too close since it could be very distractive and even encourage the person to come too close.
- Recommendation: it would have been a bit clearer if the red lights would have changed colors (less red, more white) as I went back.

C3-visitors:

- Justification: because of red light, but I wanted to test what happens if I cross the border.
- Justification: in a scenario of an exhibition it is clear that there is a distance you must respect.
- Recommendation: the design was very intuitive and clear.
- Recommendation: if you are close to the object the floor projection is out of view not directly visible.
- Recommendation: pretty clear, the red one is annoying, guess it was intended.

After investigating the answers provided by participants, they recommended projecting text onto the floor with the exact behavior that should be followed by the visitor. The feedback provided by five participants was about including written requests to be presented in front of the visitor, projected onto the floor.

Other participants voted for the inclusion of images to be displayed on the floor just in front of the visitor. Also, one participant voted for the inclusion of an audio signal. A bar chart with these statistics is shown in figure 5.10.

5.4 Discussion

After the non-parametric analysis of the understanding and respect levels, it became clear that light projection can play an influential rule in human-spatial behavior. When served with animations and color changes, visitors could easily understand the message communicated by light projections.

From a visitor's perspective, in our experiments we relied on eyesight as the sense to detect abrupt changes in the surrounding environment. Such changes may be in the form of animations or color changes. This should trigger a change in the actions of the visitor. That is, eyesight was expected to induce a reverse action after noticing the changes, and to consider the light projections as a physical barrier.

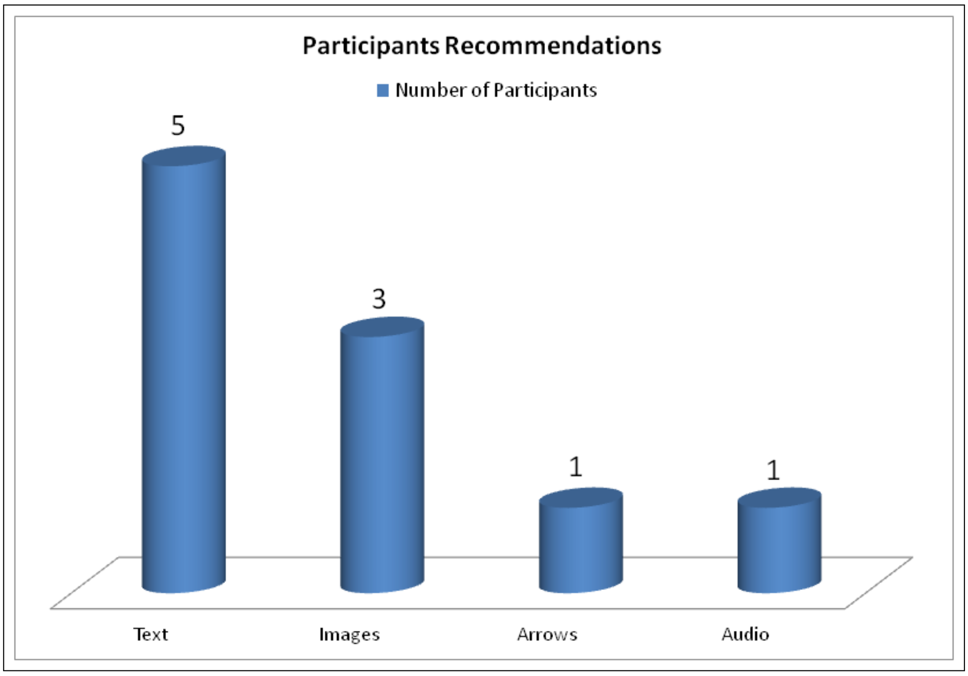


Figure 5.10: Qualitative Data Summary. Visitors recommended the usage of textual signals on the floor, other recommended images such as road signs. One participant suggested using audio signals to alarm the visitors of his/her unexpected position.

Figure 5.9 shows that it is highly effective to use animations together with color changes in order to make the visitors understand that they are supposed to keep the distance. When we look at respect levels, white animations had the highest respect rates. This means using only white wave animations without any color changes succeeded to convince the visitors to keep the distance. Accordingly, in our case, it is a crucial point to take the respect level into account as well. These respect levels are to be taken seriously since in our set up there is no physical barrier, and we need to make sure that a light projection is respected and treated as a barrier. One needs to consider such respect levels also when museum curators are very anxious about the exhibit state.

An important conclusion, that goes some way towards paving the way for us to understand the potential applicability of this idea in a museum, is the usage of eyesight for notifying visitors about our message. In an explorative environment, like museums, it's arguably much practical to rely on visual signals to induce significant inclinations in ones behavior. Normally, museums can expect a number of hearing impaired visitors more than that of visually impaired ones. This means, relying on audio signal only to alert visitors that something is going wrong is not enough. That is, as far as innovation is concerned, using eyesight is more reliable to guide visitors in a museum environment from a market perspective.

Also in our experiment, a lot of participants (11 participants) overshot the projected line aiming for the exhibit, even if they understood that they were supposed to keep the distance. In the questionnaire, they justified their action by being curious. Although that is not an excluded action from a real museum environment given the circumstances, it would be risky to have this situation happening in a real environment. From this angle, a variable animation behavior is recommended. This variable could be the speed, the color or the brightness of the animation. Nevertheless, it is not advised to use only light projections in case of shaky exhibits that are already in an alarming situation. Also, in museums where high number of children and visitors with impairments are expected, it is recommended not to use floor projections.

6 Conclusion

In 1966, Edward T. Hall founded Proxemic as a research field that defines theories governing our usage of space [Hal66]. He approached this topic from many perspectives and disciplines, trying to establish a rigorous foundation that we used in this thesis.

Researchers applied Hall's proxemic theory in HCI. Greenberg et al. introduced five dimensions for proxemic interactions [MG12]. We extended the research done by Greenberg et al. by investigating two proxemics dimensions in the context of interactive exhibitions.

In this thesis, we investigate the effectiveness of light projections in dictating proxemic interaction in a museum environment. We focus on distances and movements between exhibits and visitors.

We used experiments as our scientific method, in an attempt to find out whether floor projections affect proxemic interactions between visitors and exhibits in a museum environment. We investigated this potential effect from two proxemic dimensions: *distance* and *movement*. We performed two experiments to try to approve or refute our hypothesis. Each experiment focused on one of these dimensions.

In a first experiment, we focused on distance as our proxemic dimension, where the independent variable in this model was the radius of floor projection around the exhibit. The dependent variable was the actual distance approached by the visitor in direction of the exhibit. We wanted to detect whether such projections are understood and respected by the visitors. We measured the distances that visitors keep to an exhibit. In the experiment, we had four conditions (C0: no floor projection, C1: 35 cm, C2: 45 cm and C3: 90 cm), that were used in an in-between design approach, isolating learning effects.

The quantitative results showed that, proxemic distance between the visitor and the exhibit was statistically significantly different between condition groups. This means that light was able to establish a border around the exhibit, and to dictate the distance participants are allowed to keep to it. Also, we analyzed the data collected from the questionnaire about the understanding and the respect levels visitors had to the floor projection. The mean rank of understanding level scores was not statistically significantly different between any of the four groups. Also, the mean rank of respect level scores was not statistically significantly different between any of the four groups.

Qualitative results showed that visitors favored an interactive and colorful floor projection in a circular design. These suggestions guided us to the second study design.

In the second experiment, we focused on visitor's movement in front of an exhibit. We would like to see whether we can manipulate the distance approached by a visitor using floor projections. The look of an arc projected around the exhibit, this means its animations and color, was identified as our independent variable. The dependent variable was the actual distance approached by the visitor in direction of the exhibit. Four conditions were identified (C0: white color w/o animations, C1: white color w/ animations, C2: red color w/o animations and C3: white and red color w/ animations), and they were also used in an in-between design approach to isolate learning effects.

By analyzing the distance measurements we found that, visitors had much faster response time in case of condition 3 (that is, using animations and color changes) compared to other conditions. This means that, condition 3 participants found it easier to understand the floor projections and react accordingly.

Also, we analyzed the data collected from the questionnaire about the understanding and the respect levels visitors had to the floor projection. Analysis revealed that visitors found it easier to understand our intention to keep the distance in case of changing the color of the projected line. Also by animating the projected line, it became more understandable and had higher levels of respect. The combination of an interactive color change and animations that react according to the visitor's proxemic distance to the exhibit had the highest levels of understanding and respect.

Our work adds to the research body of proxemic interaction. Having conducted two experiments, it became clear how visitors are affected by floor projections and how this effect can be used to dictate their proxemic dimensions, namely distances and movement.

7 Future Work

While our work used only distance measuring techniques, this chapter we will propose a new solution that encapsulates a model-driven approach and try to capture the visitor's emotions as well. It is worth mentioning that, the model described below is usable in case of a single visitor or a group of separate visitors, where group dynamics are isolated.

Our proposal consists of two related steps. A model should be used, capturing both (1) the initial motion speed with which the participant approaches the exhibit, (2) the emotions expressed by the visitor and (3) producing a guidance action. It is no surprise that the actions taken by this model will be driven by our participants' recommendations from the previous experiments. First of all, a floor projection will be employed, hopefully carrying understandable information to the visitor.

According to the votes of our visitors, these *guidance actions* will include, but are not limited to:

1. Animations (for example, wave animations which we used in our study).
2. Color changes (white, red, blue, or green).
3. Textual statements projected onto the floor.
4. Using signs (for example, road signs).
5. Using Audio.
6. The speed of applying a given animation.

These guidance actions can also be mixed as we mentioned. For example, using stop sign as shown in figure 7.1 includes both textual and visual requests for one to keep distance.

For the training process, the first of two required inputs is the initial approaching speed. This became clearly relevant during our second experiment, thanks to the inviting animation we used during that initial step. Emotions are driven by Motion, where analyzing human accelerations can have fruitful results into predicting specific emotions [Kob07]. That takes us to the second module, which is responsible for emotions capture.

Figure 7.1: Traffic sign as a design candidate asking visitors to keep distance.

For this training step, face monitoring cameras aided by an EEG is recommended. Of course there is a limit to how much EEG can tell us about participants' emotions, however, it should be sufficient enough to distinguish between signals erupting as a results of feeling confusion and satisfaction. Given this aid, our face monitoring camera will be able to effectively detect the feelings of the visitor later on.

A guidance descriptor is also used as an input. This is simply a description of the allowed distance up to which approaching is permitted. Finally, guidance actions will be provided as an input during the training process. The model which is used in the training step is visualized in figure 7.2. After the training process, parameters used by the Visitor Personality Mapper (VPM) are now ready to function and to be put under test. During the test process, we will make use of the model visually described in figure 7.3.

It is incomplete, indeed, to solely consider distance measuring techniques to guide visitors in an environment where emotions and feelings influence decision making. With the presented model, we are simply presenting a balance between potentially influencing variables, distances and emotions, capturing all perspectives available. It is rather important to note that, in this model emotions and distance can be interdependent variables, and should not be dealt with as if no relations existed, that is an interdependence relation should be anticipated. Tackling such problems from multiple perspectives is essential to understand its depth. We, however, are convinced that scientists and researchers will flock to exploring other dimensions of proxemic interaction, and unleash impressive contributions taking museum visiting experience to another level.

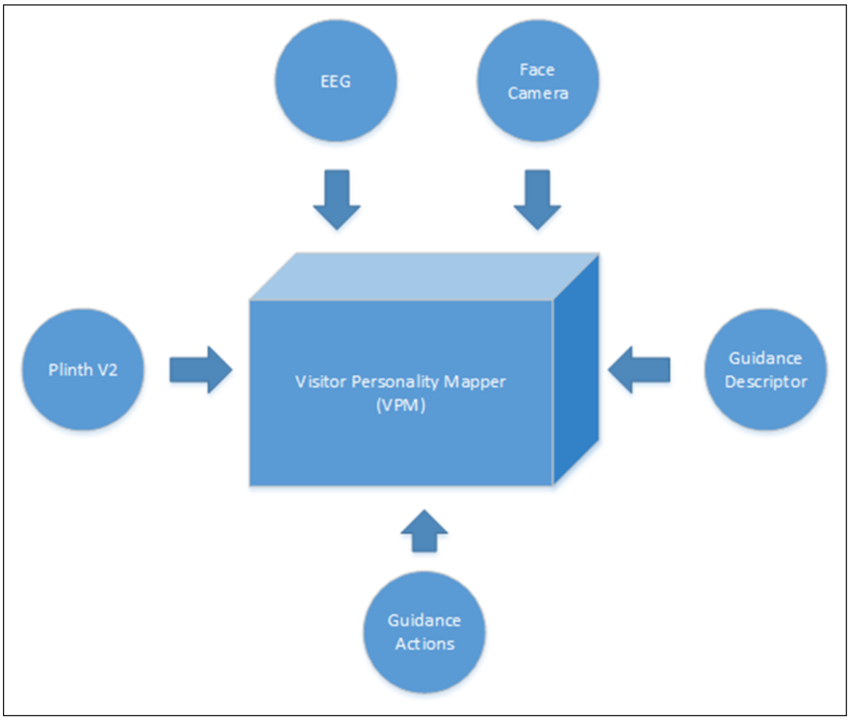


Figure 7.2: Model Training.

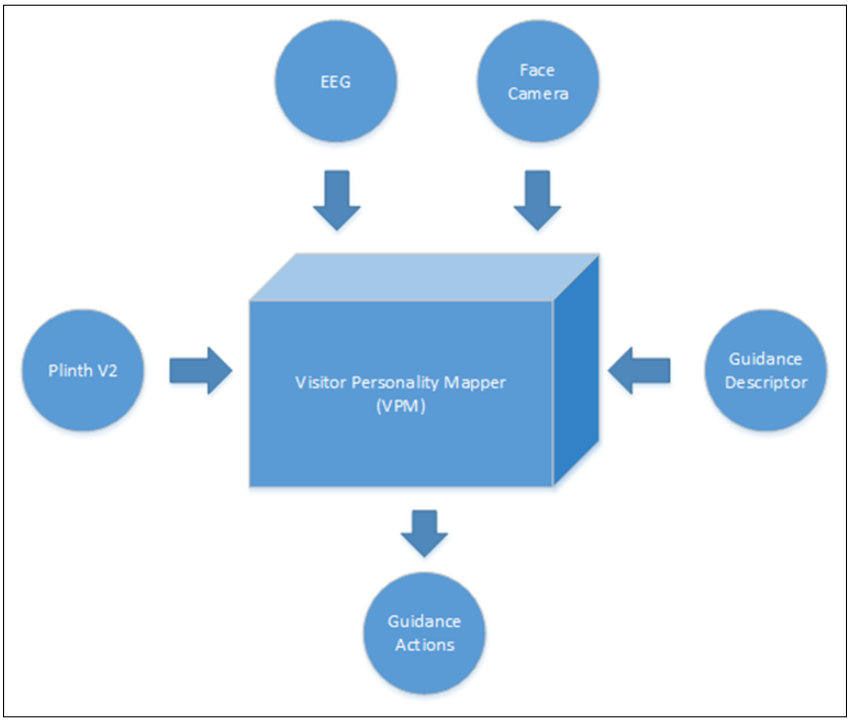


Figure 7.3: Model Testing.

Bibliography

[Aie87] J. Aiello. Human Spatial Behaviour. In D. Stokols, I. Altman, editors, *Handbook of Environmental Psychology*. John Wiley & sons, 1987. (Cited on page 18)

[ASB13] ASB Systembau Horst Babinsky GmbH. Sports flooring. ASB Glassfloor - Sports flooring with LED marking lines. [Online]. Available: http://www.asbglassfloor.com/ [2014, November 12], 2013. (Cited on pages 7 and 24)

[AZ91] L. Adams, D. Zukerman. The Effect of Lighting Conditions on Personal Space Requirements. *The Journal of General Psychology*, 118(4), 1991. (Cited on page 11)

[BMG10] T. Ballendat, N. Marquardt, S. Greenberg. Proxemic Interaction: Designing for a Proximity and Orientation-aware Environment. In *ACM International Conference on Interactive Tabletops and Surfaces*, ITS '10. ACM, New York, NY, USA, 2010. (Cited on pages 11, 18, 19 and 20)

[Bux96] W. Buxton. Living in Augmented Reality: Ubiquitous Media and Reactive Environments. In K. Finn, A. Sellen, S. Wilber, editors, *Video Mediated Communication*. Erlbaum, Hillsdale, NJ, 1996. (Cited on pages 18 and 19)

[DS13] A. Deschamps-Sonsino. Good Night Lamp. The Good Night Lamp. [Online]. Available: http://goodnightlamp.com/ [2014, November 12], 2013. (Cited on pages 23 and 24)

[Fei02] S. K. Feiner. Augmented Reality: A New Way of Seeing: Computer scientists are developning systems that can enhance and enrich a user' view of the world. *Scientific American*, 2002. (Cited on page 22)

[Fou84] M. Foucault. Des Espace Autres. *Architecture /Mouvement/ Continuité*, 1984. (Cited on page 15)

[Hal66] E. T. Hall. *The hidden dimension*. Doubleday, Garden City, NY, 1966. (Cited on pages 3, 11, 15, 16, 27, 28, 30, 66 and 87)

[HD96] S. Harrison, P. Dourish. Re-place-ing Space: The Roles of Place and Space in Collaborative Systems. In *Proceedings of the 1996 ACM Conference on Computer Supported Cooperative Work*, CSCW '96. ACM, New York, NY, USA, 1996. (Cited on page 21)

[JLK08] W. Ju, B. A. Lee, S. R. Klemmer. Range: Exploring Implicit Interaction Through Electronic Whiteboard Design. In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work*, CSCW '08. ACM, New York, NY, USA, 2008. (Cited on pages 18 and 19)

[KFBS02] R. E. Kraut, S. R. Fussell, S. E. Brennan, J. Siege. Understanding effects of proximity on collaboration: Implications for technologies to support remote collaborative work. In *In P. Hinds & S. Kiesler (Eds.), Distributed work*. MIT Press, 2002. (Cited on page 18)

[KGH85] M. Krueger, T. Gionfriddo, K. Hinichen. Videoplace - An Artificial Realtity. In *Proceedings of CHI*. 1985. (Cited on page 22)

[Kob07] Y. Kobayashi. The EMOSIGN - analyzing the emotion signature in human motion. In *Systems, Man and Cybernetics, 2007. ISIC. IEEE International Conference on*, pp. 1171–1176. 2007. doi:10.1109/ICSMC.2007.4413929. (Cited on page 89)

[Kok13] B. J. Kokes. Project Longhaul. KdN - Kokes dot Net. [Online]. Available: http://www.kokes.net/projectlonghaul/projectlonghaul.htm [2014, November 12], 2013. (Cited on pages 12 and 23)

[KS14] T. Kubitza, A. Schmidt. A First Set: Physical Components for the Creation of Interactive Exhibits. *In Online-Proceedings of TEI 2014*, 2014. (Cited on pages 7 and 21)

[Las13] Laservision. Softstop - Laservision. Softstop. [Online]. Available: http://bit.ly/1EmjX5k [2014, November 12], 2013. (Cited on pages 7 and 24)

[Lef74] H. Lefebvre. *La Production de l'espace*. Anthropos: Paris, 1974. (Cited on page 15)

[LS98] H. Leopoldseder, C. Schenck, editors. *Cyberarts 98: International Compendium Prix Ars Electronica*. Ars Electronica, Springer, 1998. (Cited on pages 7, 22 and 23)

[MDBP97] P. Maes, T. Darrell, B. Blumberg, A. Pentland. The ALIVE System: Wireless, Full-body Interaction with Autonomous Agents. *Multimedia Syst.*, 5(2), 1997. (Cited on page 22)

[MG12] N. Marquardt, S. Greenberg. Informing the Design of Proxemic Interactions. *IEEE Pervasive Computing*, 11(2), 2012. (Cited on pages 3, 7, 11, 17, 18, 20, 21 and 87)

[Nik13] Nike and Doubleyou. NiceKicks.com - The source for sneaker news, information, culture, and history. Nike FC247 MIPISTA: Lasers help create soccer field anywhere. [Online]. Available: http://bit.ly/145Hvk4 [2014, November 12], 2013. (Cited on pages 12 and 23)

[OY13] Y. Ono, H. Yoshimoto. INAHO. tangent | design and invention. [Online]. Available: http://tangent.uk.com/works/inaho/ [2014, November 12], 2013. (Cited on pages 12 and 23)

[Rek97] J. Rekimoto. Pick-and-drop: A Direct Manipulation Technique for Multiple Computer Environments. In *Proceedings of the 10th Annual ACM Symposium on User Interface Software and Technology*, UIST '97. ACM, New York, NY, USA, 1997. (Cited on pages 18 and 19)

[Rek98] J. Rekimoto. A Multiple Device Approach for Supporting Whiteboard-based Interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '98. ACM Press/Addison-Wesley Publishing Co., New York, NY, USA, 1998. (Cited on pages 18 and 19)

[SR09] S. S. Snibbe, H. S. Raffle. Social Immersive Media: Pursuing Best Practices for Multi-user Interactive Camera/Projector Exhibits. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '09. ACM, New York, NY, USA, 2009. (Cited on page 22)

[Tve01] B. Tversky. Spatial schemas in depictions. In *IN M. GATTIS (ED.), SPATIAL SCHEMAS AND ABSTRACT THOUGHT*. MIT Press, 2001. (Cited on page 16)

[Uni13] United Nations, Department of Economic and Social Affairs, Population Division (2013). World Population Prospects: The 2012 Revision, Key Findings and Advance Tables. Working Paper No. ESA/P/WP.227. *ESA*, 2013. (Cited on page 12)

[VB04] D. Vogel, R. Balakrishnan. Interactive Public Ambient Displays: Transitioning from Implicit to Explicit, Public to Personal, Interaction with Multiple Users. In *Proceedings of the 17th Annual ACM Symposium on User Interface Software and Technology*, UIST '04. ACM, New York, NY, USA, 2004. (Cited on pages 18, 19 and 20)

[Wei99] M. Weiser. The Computer for the 21st Century. *SIGMOBILE Mob. Comput. Commun. Rev.*, 3(3), 1999. (Cited on page 20)

[Yat66] F. A. Yates. *The Art of Memory*. University Of Chicago Press, 1966. (Cited on page 16)

All links were last followed on March 05, 2015.

Declaration

I hereby declare that the work presented in this thesis is entirely my own and that I did not use any other sources and references than the listed ones. I have marked all direct or indirect statements from other sources contained therein as quotations. Neither this work nor significant parts of it were part of another examination procedure. I have not published this work in whole or in part before. The electronic copy is consistent with all submitted copies.

place, date, signature