Fachhochschule
Salzburg University
of Applied Sciences

Believable Characters in Virtual Reality

Bachelor Thesis 2

Author: Jaqueline Wieland
Advisor: DI Dr. BSc. Bakk. Thomas Stütz

Salzburg, Austria, 02.05.2017

Affidavit

I herewith declare on oath that I wrote the present thesis without the help of third persons and without using any other sources and means listed herein; I further declare that I observed the guidelines for scientific work in the quotation of all unprinted sources, printed literature and phrases and concepts taken either word for word or according to meaning from the Internet and that I referenced all sources accordingly.

This thesis has not been submitted as an exam paper of identical or similar form, either in Austria or abroad and corresponds to the paper graded by the assessors.

Date *Signature*

First Name *Last Name*

Kurzfassung

Virtual Reality Geräte werden heutzutage immer fortgeschrittener und leistbarer. Vor allem der Einsatz solcher Geräte in der Videospielindustrie genießt in letzter Zeit erhöhte Aufmerksamkeit. Ein wichtiger Teil aller Arten von Applikationen, sei es ein Lernprogramm oder ein Videospiel, sind virtuelle Charaktere. Um eine genießbare und plausible Erfahrung zu ermöglichen ist die Glaubwürdigkeit dieser Charaktere ein wichtiger Faktor. In virtuelle Umgebungen spielen vor allem zwei Faktoren eine wichtige Rolle: Präsenz und Co-Präsenz. Präsenz stellt ein Gefühl des „dort seins" dar und Co-Präsenz ein Gefühl von „zusammen dort sein". Der letzte Faktor ist nur in einer virtuellen Umgebung möglich die eine soziale Komponente besitzt. Diese Arbeit untersucht den Einfluss von sozialen nonverbalem Verhaltensweisen auf das Gefühl von Präsenz und Co-Präsenz. Aus diesem Grund wurde im Umfang dieser Arbeit ein Blickverhaltenssystem entwickelt. Außerdem wurden auch eine einfache Kollisionsvermeidung und verschiedene Gesichtsausdrücke realisiert. Diese Arbeit handelt darum wie diese Features implementiert wurden und um ihren Einfluss zu überprüfen wurde eine User Studie durchgeführt. In dieser Studie mussten die Teilnehmer zwei verschiedene Szenen testen. Die Charaktere in diesen Szenen unterschieden sich vor allem in nonverbalem Verhaltensweisen. Nach dem Testen jeder Szene mussten die Tester einen Fragebogen ausfüllen und an einem Interview teilnehmen. Zum Schluss dieser Arbeit werden die Ergebnisse dieser User Studie präsentiert und interpretiert. Außerdem werden neue und zukünftige Möglichkeiten im Bereich glaubwürdige Charaktere diskutiert.

Schlagwörter: Virtuelle Realität, Präsenz, Co-Präsenz, Glaubwürdige Akteure, Blickverhalten, Kollisionsvermeidung, Gesichtsausdrücke

Abstract

Virtual reality devices are becoming more and more advanced and affordable in recent times. Especially the usage of those devices in the game industry are recently getting more attention. An important part of all kinds of applications, be it a tutoring application or game, are virtual characters. To ensure an enjoyable and plausible experience the believability of those characters plays a important role. Two factors that have a direct influence on that are verbal and non-verbal social behaviours. Two terms are important when talking about immersive virtual environments, presence and co-presence. Presence represents the feeling of ”being there” and co-presence the sense of ”being there together”. Co-presence can only occur if the virtual environment has a social component. This thesis investigates the influence non-verbal social cues on the sense of presence and co-presence in virtual environments. For that reason a system to enable gaze behaviour for virtual agents was implemented. Besides that, also facial expressions and a simple collision avoidance were realized. This thesis takes a closer look at how those feature were implemented. To evaluate the influence of that implementation a user study was carried out where participants had to test two scenes with different non-verbal agent behaviour. After the test they then had fill out a questionnaire and take part in a final interview. Lastly, the results of that user study are presented and interpreted and future possibilities are getting discussed.

Keywords: Virtual Reality, Presence, Co-Presence, Believable Agents, Gaze, Collision Avoidance, Facial Expressions

Contents

1 Introduction

Virtual reality (VR) devices are not only becoming more and more popular in recent times, they also, which is even more important, become easier access- and affordable to the common user. Based on that trend the VR game industry is booming (Egan et al. 2016). When it comes to VR experiences and games, presence and co-presence are two of the most crucial factors to ensure a enjoyable VR experience. Schroeder (2001) explains presence as the feeling for the player to be integrated into the virtual environment (VE), the feeling and sensation of actual ”being there”. Further co-presence gets explained as the feeling of ”being there together”, influenced by how believable another character seems to the player. This is mostly based on appearance and behaviour of the character and is only possible if the VE allow social encounters (Bailenson et al. 2005). Previous research has shown that realistic appearance is not even the most crucial factor to increase the feeling of co-presence. It is more important to create a balance between believable behaviour and appearance in virtual characters (Garau et al. 2003) (Bailenson et al. 2005).

Behrooz, Rich, and Sidner (2014) shows that believable, social characters increase the value of the gaming experience for users significantly. To not diminish presence or co-presence, virtual characters have to react believable and authentic to input, active or passive, the player and/or the environment provides [1]. Overall, virtual characters have to behave plausible in their given context to ensure intuitive and real interaction between the user and virtual world. This allows a higher sense of presence and co-presence during the experience (Jung et al. 2011) (Vinayagamoorthy et al. 2006) (Narang et al. 2016). Narang et al. (2016) introduces a way to implement crowd collision avoidance and gaze behaviour for virtual agents. Both features have proven to increase the believability of the virtual agents and therefore of the whole experience. Of course collision avoidance is not only important in crowd simulations but also between single virtual agents and the player. Several chapters in Prendinger and Ishizuka (2004) and Narang et al. (2016) emphasised the importance of gaze, facial expression and character movement in creating believable characters. The work of Garau et al. (2003) and Garau et al. (2001) have shown that informed gaze behaviour has a positive effect on the interaction quality with virtual characters in virtual environments and increases the liveliness and authenticity of those characters. There are several fields of application for believable characters in virtual environments, they can be used as virtual tutors (Jung et al. 2011), non-player characters in games (Jung et al. 2011), for mission training of military operations (Prendinger and Ishizuka 2004) (Vinayagamoorthy et al. 2006), as a virtual coach for sport applications (Baylor 2011) and many more.

The main focus of this thesis is the investigation and implementation of non-verbal communication cues between the player and virtual characters. First it will explain in detail what presence and co-presence mean in VEs and methods to measure them. It is important to understand the concepts of presence and co-presence in order to understand the goal of this study. Furthermore, it will be investigated why it is important to have characters emulating a believable behaviour,

1. Tom Sanocki. 2016. ”VRGDC: Interactive VR Characters” Accessed: April 29 2017. `http://www.gdcvault.com/play/1023925/Building-Interactive-VR-Characters-in`

especially in a game environment. More precisely what impact the behaviour of virtual agents have on the sense of presence and co-presence in such immersive virtual experiences. And why behaviour of the character has to be implemented in a way to also react believable on new inputs modern VR devices provide. Social believable agents are an active research field and their social cues have already been investigated in either a less immersive way, for example in desktop applications, or separately in different studies. The biggest focus point of this thesis is to create a believable gaze behaviour for virtual agents and its impact on the perceived quality of the experience for the user. To enhance the plausibility further, also simple facial expressions and a simplistic collision avoidance system get implemented. Those features and how they got implemented are explained in the following chapters.

To evaluate the implemented features and their impact on the sense of presence and co-presence, a user study will be held. During that study the participants have to test two scenes, one with and one without the implemented behaviour. In each level they have to fulfill a simple task. This task was implemented to give the player something to do while being in the VE and define a clear end of the experience. The task is intentionally held very simple to not distract the participant too much from the environment and the behaviour of the virtual agents. The nature of the task is the same in both scenes, but the solution is a little bit different to not be repetitive.

After each scene the participants have to fill out a questionnaire about their perceived presence and co-presence during the test. After all scenes have been tested and all questionnaires are filled out, the tester is asked to take part in a short interview. The interview allows it to ask more in-depth questions about the users experience in the VE. Questionnaires are a common way to evaluate the subjective feeling of presence and co-presence in VEs as used by Behrooz, Rich, and Sidner (2014), Narang et al. (2016) and Egan et al. (2016). Furthermore, this thesis explains how the questionnaire, used for this study, was put together and takes a closer look at related questionnaires which were used in previous studies. The results of the questionnaire will show which scene and therefore which behaviour invoked a higher feeling of presence and co-presence in the participant. Especially the interview should give a better insight on which parts of the behaviour were actively recognized by the player. Also if those were recognized in a positive or negative way. Lastly, this thesis will show and interpret the results of the study and give a short outlook on future possibilities in this research field.

2 Methods

The following chapters explain relevant literature terms like presence, co-presence and believable characters in more detail. After explaining those basic terms it will be shown how the implementation of gaze, collision avoidance and facial expressions was executed and why those features were chosen as non-verbal social cues. It will investigate the challenges during development and reason why the features were implemented the way they are. Furthermore, it will contain details about how the user study was done and how it was prepared. It gives an insight on who the participants of the study were and takes a look at their demographic data.

This chapter also includes the investigation of how the used questionnaire was created. For that reason similar questionnaires from previous studies were examined and analyzed.

2.1 Presence and Co-Presence

There are a lot of different definitions for presence and co-presence in VEs in the present literature. To date there is no clear definition for each of those terms, which is probably due to their very subjective nature. For this reason this chapter will investigate different approaches on how to define those terms and sets up a definition for them which will be used in the context of this thesis. Furthermore, this chapter investigates the distinction between presence and immersion, in regard to Slater et al. (1996) and Witmer and Singer (1998). Lastly, this chapter will give an overview over a few possible ways on how to measure presence and co-presence in VEs.

2.1.1 Presence

Presence is often described as the subjective feeling of "being" in a VE. The sensation of truly believing that the user is part of the virtual world. It has been proven to be hard to measure presence because it is a psychological phenomenon, a feeling, the user experiences (Schubert, Friedmann, and Regenbrecht 2001). One of the most common responses to VEs that allow a high value of presence, is the feeling of actually visiting another place. To feel like not being in the same real physical place as before. Another definition is the sensation of being in a real place instead of just perceiving pictures. Previous research has shown that it is not easy to determine all factors that play a role in the phenomenon of presence. Although two terms seem to appear regularly in the context of presence: involvement and immersion.

The distinction between the terms immersion and presence is not always clear and causes confusion from time to time, as seen in Slater (1999). In opposite to Witmer and Singer (1998), which describes immersion as an subjective sensation, this thesis goes with the definition of immersion proposed by Slater et al. (1996). It explains immersion as the sum of objective, measurable factors like field of view or resolution of the used hardware. The purpose of this hardware is to enable and support the possibility of an immersive environment by shutting the real world out. However this thesis agrees with the concept Witmer and Singer (1998) described under the term of immersion. Amongst other things this paper describes immersion as the feeling of being fully part of the VE and not acting remotely within a digital environment. The user has the feeling of truly being captivate by the VE, forgetting about the real world. To prevent any confusion, this phenomena will be referred to as *"subjective immersion"* in the context of this thesis. The objective interpretation of immersion by Slater et al. (1996) will be referred to as *"system-immersion"*. This is also proposed in Slater (1999).

Presence gets influenced by system-immersion, however it is often reported that even less immersing environments or devices, like traditional desktop games or augmented reality (AR) applications, can still cause a high level of presence. It also has to be noted that realistic visuals are not a prerequisite to allow a high sense of presence. Even abstract or fantasy environments are not an issue. However, research has shown that it is generally easier to achieve a higher level of presence with a full immersing device like a Head-Mounted-Display (HMD) (Schroeder 2001).

Amongst others, Witmer and Singer (1998) takes a closer look at the other term that often occurs in combination with presence: involvement. It gets defined as the amount of focus the user spends on the events and happenings in the VE. Involvement is affected by a various of influences, for example how comfortable the HMD fits or how good in-game events attract the users attention.

2.1.2 Co-Presence

Strongly related to presence is another sensation that can be experienced in VEs: co-presence. Both feelings are strongly related and influence each other. Co-presence can be described as the feeling of ”being there together”, while presence only covers the feeling of just ”being there”. Other terms which get often used to refer to co-presence are social presence or social richness. Roth et al. (2016) explains co-presence as the feeling of rather being and interacting with another person than just a computer interface. To allow the occurrence of co-presence the VE has to provide some sort of social component. Such VEs are usually referred to as shared VEs. It should be noted that social interaction can take place between humans, represented as avatars in the VE, or between humans and virtual agents. This thesis concentrates on the emerging of co-presence through the social interactions between human players and virtual agents.

Especially modern VR hardware, like the HTC Vive or Oculus Rift, allows the user to interact in many different ways and experience interaction via various senses. They usually allow interaction through audio, text, gestures and spatial movement in the 3D environment. Co-presence is highly depended on presence. There can not be a feeling of ”being somewhere together” if the user does not feel like ”being there” in the first place. On the other hand, it is very well possible to sense a feeling of presence without co-presence, for example if the VE does not contain any social component (Schroeder 2001).

2.1.3 Measuring Presence and Co-Presence

There are two different ways of measuring presence, subjective and objective ones. Subjective measure methods are for example questionnaires and interviews. Objective measure methods on the other hand rely on the measuring of how well or fast a task is performed, also referred to as task performance. However, it has to be noted that task performance does not necessarily increases with a higher feeling of presence. Therefore is not a reliable method of evaluating presence in a VE. The reason behind that is that several studies indicate that through higher presence the users have to divide their focus between the given task and the perceived environment. That causes that not all mental strength can be focused onto the task. This would be easier in a less immersive environment Schroeder (2001).

So far no clear correlation between task performance and presence has been proofed, therefore it did not get used as an evaluation method for this study (Schuemie et al. 2001). Another objective method is to measure bio-vital functions of the user, like heart rate or blood pressure (Egan et al. 2016).

It has shown in the past that questionnaires and interviews are well suited to measure a highly subjective feelings like presence and co-presence. This method of measurement offers multiple advantages. The test person is able to describe their personal and emotional reactions in a better way. Especially an interview is helpful in such test scenarios, because it can provide a better insight into the emotional experiences the user had during the usage of the application. On the other hand due to the subjective nature of interviews and questionnaires it is also not the most reliable source of data (Schuemie et al. 2001).

2.2 Believable Characters in Virtual Environments

The following chapter explains the importance of believable characters in VEs and their field of use in applications. Furthermore, this chapter describes what defines a believable character in the first place. With more and more realistic and immersing devices the behaviour of virtual agents in such applications and games have to hold up to that level. Believable characters, able to communicate a sense of sociability and intelligence, can increase the enjoyability of a game significantly (Behrooz, Rich, and Sidner 2014). To appear plausible, they not only have to appear intelligent but also reactive to their environment and other influences. It has to be noted that those virtual agents do not actually have to be intelligent and emotional, but must appear so to the player. There is no need of a deep cognitive process as long as the agent is able to perform a plausible behaviour (Riedl and Stern 2006). This is even more important in such an immersive context as with head-mounted VR applications. Character realism and plausibility have shown to be one of the main factors to increase co-presence in VR applications (Roth et al. 2016).

An important part in making interesting and believable characters is to implement a sense of sociability for them. Research has shown that social cues help the agent to appear more believable and intelligent. This increases the level of engagement and affects the emotional state of the player, which leads to a more memorable and interesting experience (Behrooz, Rich, and Sidner 2014). The most important requirement is that the agent has to act believable in the given context and environment. It should act as the user would expect it to. On that note, it is important to mention that it has been discovered that believable behaviour has a higher impact on co-presence than visual appearance. However, the visual realism has to be balanced to the level of realism in behaviour. In other words, a very abstract character might not be able to express a realistic behaviour, while a very realistic character without an equivalent realistic behaviour could have a negative impact on the quality of the experience (Vinayagamoorthy et al. 2006).

The usage of such agents is not limited to use them as non-player characters in games. Other fields of use could be in a learning environment as a virtual tutor (Jung et al. 2011). Other ares could be for military mission training or as a motivating coach in sport applications or for virtual therapy applications (Baylor 2011) (Vinayagamoorthy et al. 2006) (Prendinger and Ishizuka 2004). Jung et al. (2011) proposes the idea to use virtual agents as the next step of development for input and output possibilities. To be used where traditional devices, like mouse and keyboard, are not possible or not practical to use. This would be the case for example in VR/AR environments. Previous research in the field of believable social agents has shown that non-verbal communication is as important as verbal communication, if not even more important. Both are active fields in research and it has shown that creating a plausible behaviour in both topics is not easy to achieve (Jung et al. 2011).

Non-verbal social cues that virtual characters can inhabit are amongst others: gaze, facial expressions, gestures and spatial movement within the environment. Itti, Dhavale, and Pighin (2003) defines gaze as the combined movement of eyes and head and stresses the importance of gaze in social interactions.

(a) Eliza (b) Henry (c) Doris

Figure 1: Agent Character Models (Software 2017)

Gaze behaviour plays an important role in increasing the believability of virtual agents. This again improves the quality of the virtual experience (Narang et al. 2016). This motion get supported by the work of Jung et al. (2011) which explains that the expression of emotions is what makes the difference between a life-like behaviour and a robotic one. Facial expressions and gaze makes it possible to express the emotional state of a virtual agent. Research has shown that the lack of facial expressions in virtual agents has a negative impact on the perceived quality of interaction, which diminishes the enjoyability of the whole application. Some research even suggests that the non-verbal part of a social interaction has a higher impact than the verbal part (Vinayagamoorthy et al. 2006).

The main concern of this thesis is the investigation of the impact of non-verbal social cues on the sense of co-presence in HMD - VR applications. For this purpose three virtual agents where used in the implemented application. This application was used in the user study that was conducted for the purpose of this thesis. Figure 1 shows the used character models of the virtual agents. The reason behind using different genders is that Baylor (2011) points out that gender also plays an important role on how human perceive their social opponent. To not falsify the user study by using only one gender, male and female characters were used.

To make them easier referable the agents were named. Figure 1 shows the used names. These agents do not differ in behaviour, the only difference is in visual appearance and used animations. All agents implement the same components to provide a gaze behaviour as explained in Chapter 2.3. All agents also share the same collision avoidance and facial expression mechanics.

2.3 Implementation

The goal of this thesis is to investigate the influence of believable characters on the sense of co-presence of perceiving users. The main focus point especially is to see what impact non-verbal social cues have on the plausibility of a character and how that affects co-presence. Furthermore, the influence on presence value will also be measured. In the context of this thesis those non-verbal social cues are gaze, collision avoidance and a simple usage of facial expressions. One requirement while implementing those features was to have the intended usage in a game environment in mind. Thus the goal was to build a system as flexible and reusable as possible. For the gaze behaviour three different ActorComponents[2] were developed. In this chapter those components get explained in further detail and how collision avoidance and facial expression where achieved.

2.3.1 Gaze Behaviour

The implemented gaze behaviour allows a non-player-character to react to objects and players in the VE through moving its head and eyes in the necessary direction. Usually human-like and more complex characters are represented through skeletal meshes in Unreal. For that reason the developed system works only on characters with skeletal meshes. The calculated values get applied to the eye and head bones of the skeletal mesh to make the character gaze into the calculated direction.

The implementation of gaze behaviour is a three component system, each of them responsible for a different part in order to create a dynamic gaze behaviour. The most important component to enable gaze is the **GazeComponent**. This component is responsible for calculating the necessary movement for eyes and head bones. The functionality of this component and how the

2. Epic Games. 2017. "UActorComponent" Accessed: April 29. `https://docs.unrealengine.com/latest/INT/API/Runtime/Engine/Components/UActorComponent/index.html`

actual movement of head and eyes works, will be explained in further detail in this chapter. Afterwards the functionality of the **TargetSensingComponent** will get explained. It encapsulates the mechanic to choose the right gaze target for the agent. The last point of this chapter is about the third component of this system, the **GazeTargetComponent**. It is responsible for marking possible gaze targets. All components are developed in C++ as ActorComponents and exposed to Blueprints.

GazeComponent

The self written GazeComponent is mainly responsible for the actual gaze functionality. In opposite to the TargetSensingComponent it is not depended on a GazeTargetComponent. Any actor in the level can be set as a target. If that actor has a GazeTargetComponent, the location this component provides is used instead of the actor location. This allows to define a "look-at" point on the target. This can be used if it makes sense to look at a specific part of the object. This could be for instance to look rather at the head of a player, or other human figure, instead at the default actor location, which would be most likely somewhere around their feet. The system would still work without the usage of the GazeTargetComponent, but would most likely result in a less plausible behaviour. The GazeComponent has two modes of gaze behaviour: idle and looking towards a target.

The idle mode is used while no specific gaze target is provided. During that mode, a random set of target points are provided to perform a random gaze behaviour. It creates a more lively and realistic picture of the non-human character than starring straight all the time without any head or eye movement.

(a) Eliza Idle Targets (b) Doris Idle Targets

Figure 2: Idle Gaze Target Generation

Tests during development have shown that without that idle behaviour, users described the agents more as *"cold"* and *"robot-like"*, instead of creating the illusion of a human being. After implementing the idle behaviour, users responded more positive towards the agents. To generate a random gaze behaviour, random points in front of the character are getting calculated and used as gaze target points. Those random locations are selected randomly from within a cone shape in front of the agent. To ensure a higher distribution of location a distribution factor gets included into that calculation. In a variable interval a new target point is selected. This interval is exposed to Blueprints and the Editor and therefore can be changed to ensure a flexible

```
void UGazeComponent::LookIdle(float DeltaTime)
{
    check(OwnerSkeleton);
  check(OwnerSkeleton->SkeletalMesh);

  //Calculate random location within the specified cone
  if (IdleTargetChangeTime >= MinimalIdleTargetChangeTime || IdleTargetChangeTime == 0)
  {
    const float PointDistance = 250.0f;
    const float HConeHalfAngle = 60.0f;
    const float VConeHalfAngle = 20.0f;
    const float DistributaionFactor = 45.0f;
    bGazeHasStarted = true;
    IdleTargetChangeTime = 0;
    TargetLocation = OwnerSkeleton->GetBoneLocation(HeadBoneName) + (OwnerSkeleton->GetForwardVector() * PointDistance);
    TargetLocation += FMath::VRandCone(OwnerSkeleton->GetForwardVector(), HConeHalfAngle, VConeHalfAngle) * DistributaionFactor;
  }

  PerformGazeMovement(DeltaTime);
  ++IdleTargetChangeTime;
}
```

Listing 1: GazeComponent.cpp - Idle Behaviour

and dynamic system. At the beginning of the level the agent starts in idle mode and stays in it as long as no gaze target can be found. The second mode is to look towards a specific target, the actual gaze behaviour. This gaze target is provided externally, usually from a TargetSensing-Component. It is essentially very similar to the idle gaze mode with the difference that the target location correspondence with an actor in the 3D environment, instead of being chosen randomly.

Another important part of this mode is the **"lose interest"** mechanic. After looking at the same target for a while, the agent loses interest and either goes into idle mode or chooses another target to look at. During testing this has shown to be a important part of creating a believable behaviour. The time it takes for the agent to lose interest is variable and can be set differently for different agents. It could even be changed during runtime to enable a dynamically changeable behaviour. For example, the attention span of the agent could be less if it is tired.

Furthermore, the moment a new target is picked, the changing of the gaze target is locked for a short duration of time. Otherwise it could happen that the agent starts looking towards a target, but immediately jumps back to another one. This would result in a very unrealistic, robotic behaviour. The movement calculation of eyes and head are performed separately, to allow the exclusively execution of head and eye movement. The default setting is that the calculation of the eye movement determines if the head has to be moved as well. If the necessary movement to reach the target can not be done by only moving the eyes within a set threshold, head movement is automatically enabled. This threshold represent the boundaries within it is still comfortable for a human being to only gaze somewhere by moving the eyes alone.

The eye and head movement is further restricted by another threshold from within it has to be performed. That threshold restricts the maximum rotation the head or eyes can perform. This allows to stay within rotation boundaries which are still possible and comfortable to done by a human being. This threshold is also variable and exposed to Blueprints to allow a high level of customization and flexibility. During development it has shown that those thresholds depend to a certain level on the used model, but usually are between 120 degrees yaw and 30 degrees pitch for the head rotation and 60 degrees yaw and 10 degrees pitch for the eye rotation. The current implementation only handles the movement of eyes and head within the mentioned thresholds. This means there is currently no rotation of the upper body or the whole character implemented.

The speed of the head and eyes movement is separated from each other and also variable and exposed to Blueprints. Although it is fully adjustable, it has to be noted that the eye speed should be higher than the the head speed to allow a believable behaviour (Itti, Dhavale, and Pighin 2003). Therefore the default setting of the eye movement speed is a third higher than the head movement one. Another note regarding the movement speed of the head is that in the current implementation the speed readjusts itself depending on the delta movement the head has to perform. That means the speed increases when the head has to be rotated further to reach the target and lowers if it is smaller. Therefore the speed that can be set in Blueprints or in the Editor are only base speed values. During several test phases it has shown that this dynamic adjusting of speed for the head movement can not be calculated in a linear way and still produce proper results. Therefore a non-linear formula was used which encapsulated adjustable values to refine the results during the development process. The final used formula can be seen in Listing 2.

```
float DeltaDistance = (FMath::Abs(TargetRotation.Yaw) + FMath::Abs(
    TargetRotation.Pitch)) / 2;
float SQDeltaDistance = DeltaDistance * DeltaDistance;
float DistanceFactor = 2.2 * (SQDeltaDistance / (SQDeltaDistance + 100 *
    DeltaDistance));

float DeltaSpeed = HeadSpeed * DeltaTime * DistanceFactor;
```

Listing 2: GazeComponent.cpp - Dynamic Head Speed Formula

Because the GazeComponent always takes the current actors, head and eye location into account it can be used with nearly every animation and still produce plausible results. The final output of the GazeComponent is the next target rotation for head bone and eye bone of the used skeletal mesh. Those values can be applied in the according animation blueprint of the character.

Another important movement that is handled in the animation blueprint is the movement of eyelids and eyebrows based on the current pitch value of the pupils. If the agent looks down, the eyelids have to move down as well. The same thing applies to the eyebrows, but it is more noticeable when the agent looks up. Then the eyebrows have to get raised a bit as well. This results in a more realistic behaviour.

TargetSensingComponent

The TargetSensingComponent is one way to provide the GazeComponent with a proper target. It gathers all possible targets in the field of view of the owning agent actor and chooses the best one based on a multitude of factors. This chapter describes what possible targets are and which factors get evaluated to select a proper gaze target. To be considered a possible target for the TargetSensingComponent, the object must have a GazeTargetComponent. Furthermore, only targets within the adjustable recognition radius (default 500 Unreal units) are getting recognized. Once the target is within that radius, the component calculates if it is within the current field of view (FOV) of the character. The default horizontal FOV is 60 degrees and the default vertical FOV is 45 degrees. Nevertheless, both values can be adjusted to fit any needs. After that the component checks if the target is not obstructed by any other element in the environment. If not, it counts as a valid target.

Once all available targets are collected and saved into an array the actual calculation of target priority for each target starts. The priority value determines which target is best fitted to be the next gaze target. The priority value lies between 0 and 1, whereas 1 is the highest priority and 0 the smallest. For this purpose a set of different factors are getting weight in. Those factors are the size of the target, distance to the character, speed with which it currently moves and a base value that can be set in the GazeTargetComponent to give some objects a higher probability to get chosen as target. This could be for example, the player, especially because it is hard for a player to move very fast in a room-scale VE and therefore achieve a high priority value.

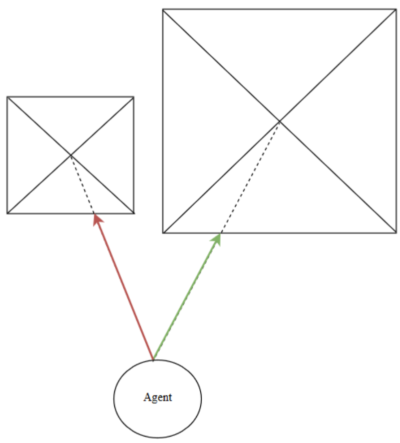


Figure 3: Surface Point Location VS. Center Point Location

To calculate the distance-factor properly not the distance to the middle point of the target gets considered, but the impact point of a ray-trace towards it. That impact point location symbolizes the surface point the character would actually look at, instead of the middle point of the target object. Especially for big objects the usage of the middle point could affect the calculation of the distance badly. Figure 3 shows the problem that occurs if the middle point location is used. If that location is used, the left object would considered closer to the agent although that is not true. To put all considered for factor for the priority calculation into perspective and to actual be able to evaluate if something is big or small or fast, further calculations take place. For example, to determine if the target object appears big or small to the owning agent, the size of the target gets mapped into a range from 0 to 1. That mapping is based on the size of the agent itself, 1 is equal to twice the size of the agent. This makes sense if we consider the fact that gaze agents can have different sizes. For example, for a mouse a crate would count as a big object, resulting in a higher priority value, whilst for a human a crate is a rather small object, resulting in a lower value. Similar calculations takes place for the other values, for distance the highest value is the maximum sight radius and speed gets weighted dynamically based on the fastest target in the list.

After all priorities are calculated the target with the highest one is set as final gaze target and via a delegate the GazeComponent gets informed that a new target has been chosen. The only exception where a target can get chosen without having the highest priority is if it intrudes the personal space of the agent. This space can be defined dynamically but is per default set to a radius of 40 units around the agent. If something comes that close to the agent, it automatically gets attention which leads to a more believable behaviour. Besides getting instant attention the agents will also try to avoid a collision with that object and tries to evade it by stepping back. For more information regarding this behaviours see Chapter 2.3.3.

GazeTargetComponent
The GazeTargetComponent is used by the TargetSensingComponent to determine if an actor can be used as target and to store extra information in it. It is also used by the GazeComponent to achieve a better gaze result than without. However, it is not necessary for its functionality. As already mentioned previously, the GazeTargetComponent can be used as look-at point for the gaze behaviour. Other information this component provides is the speed of the actor it inhabits. It provides a function that calculates the mean speed over several frames. This function is overrideable so it can be overwritten to calculate the speed however it is fitting for the current owning actor. For example, an actor that uses physics the usage of the current velocity seems like the right thing to do, instead of calculating the difference in location over the course of time.

Lastly, the GazeTargetComponent also offers the option to redirect the gaze attention to another actor or GazeTargetComponent. The redirection can either happen immediately when the owing actor gets attention or after a set time of delay. This ”redirect” feature allows it for example to redirect the attention of the players hand in VR to the player itself. This helps to handle scenarios where players wave with their hands. In this situation the hands get attention for a short time before it goes to the player itself, because he is the point of interest in this scenario.

2.3.2 Facial Expressions and Blinking

(a) Anger (b) Happiness (c) Neutral

Figure 4: Facial Expressions - Eliza Character

Facial Expressions are an important part in non-verbal communication (Prendinger and Ishizuka 2004). Therefore the implemented agents have a very simplistic emotion system which regulates facial expressions. Currently the characters are able to express anger or happiness. If they are neither happy nor angry, they inhabit a neutral expression. The expressions were implemented through morph targets in Unreal. Figure 4 shows the facial expressions for Eliza, one of the three characters used in the test study. In the current implementation there are only a few situations implemented to alter the emotion of the agent. For instance, agents get angry if something intrudes their personal space. This could be the player or another object in the 3D environment. Happiness is triggered when the player is near the agent and selected as gaze target, but not close enough to intrude the personal space of the agent. The neutral expression is used when no other expression is appropriate. Of course the current usage of facial expressions is very rudimentary and could be developed further to enable more emotions and a more varied behaviour.

Another mandatory part in making a virtual agent appear more lively and realistic is the implementation of eye blinking. The human blinking behaviour follows specific rules, which were minded during the development process. Itti, Dhavale, and Pighin (2003) have introduced a precise solution to calculate a heuristic blinking behaviour. In this implementation a slightly simpler solution was used, which still creates plausible results. A blink gets performed with a probability of:

- 10% if the last blink happened three or more seconds ago,
- 0.1% if the last blink happened two or more seconds ago,
- 0.005% if the last blink happened one or more seconds ago.

It has to be noted that at least one second has to be passed since the last blink in order to perform a new one. Each blink lasts for 150ms.

2.3.3 Collision Avoidance

Collision avoidance is essential if somebody wants to create a plausible VR experience. When the player tries to move himself or his hands through the virtual agent, it has to react. The most plausible reaction is to avoid a collision with the player, if possible. Most of the desktop games nowadays do that already, and of course it is important to do it in VR games as well. The test application for this thesis implements a rather crude solution to perform the collision avoidance. As previously mentioned, the TargetSensingComponent recognizes if an object intrudes the personal space of the agent. If that happens the agent decides to move backwards. To actual avoid any obstacles the already by Unreal provided algorithm of the CharacterMovementComponent[3] is used. This implementation is not optimal but still plausible enough to see the impact of it on the sense of presence and co-presence during the test study.

2.4 Software and Assets

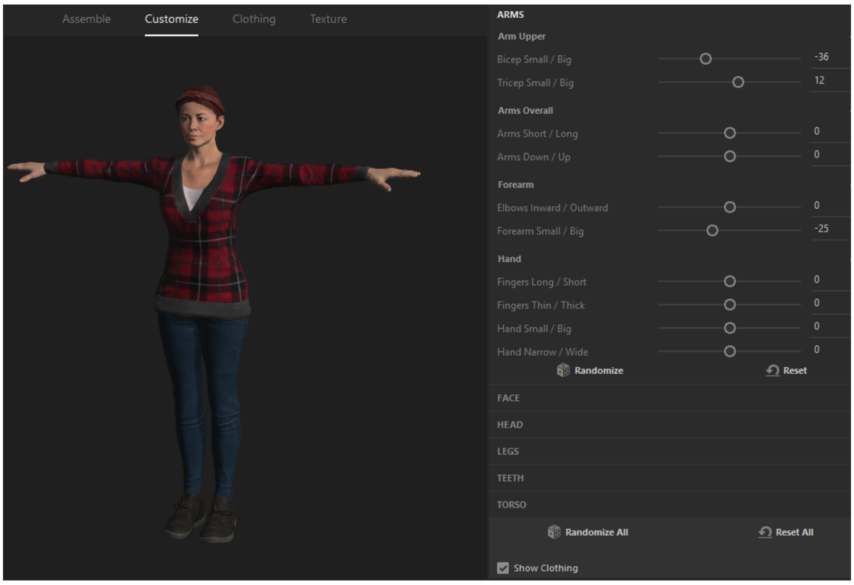


Figure 5: Character Creation with Adobe Fuse CC (Adobe Systems Software 2015)

To implement the test application and the previously mentioned features, the usage of a game engine made sense and was practical. Especially if the main usage of those features is concerned to be in game environments. For those reasons Epic's Unreal Engine 4, Version 4.15 was chosen as game engine and Microsoft's Visual Studio Enterprise 2015 as programming environment. The used programming language was C++. To edit and cut any used sound files the free version of Audacity[4] was used. Especially to convert some stereo track sound files to mono sounds.

3. Epic Games. 2017. "UCharacterMovementComponent" Accessed: April 29. `https://docs.unrealengine.com/latest/INT/API/Runtime/Engine/GameFramework/UCharacterMovementComponent/`

4. Audacity Team. 2017. "Audacity" Accessed: 01 May. `http://www.audacityteam.org/`

Human character models, to represent the virtual agents in the test application and allow for social interactions were acquired through Adobe Fuse CC (Adobe Systems Software 2015). With Fuse it was possible to create realistic 3D character models without any previous modelling knowledge. In order to create a character model it was just necessary to select separate body parts, hair, clothing and textures. The finished model was exported to the web-platform Mixamo[5]. There it got automatically rigged. Furthermore, Mixamo allows to choose between hundreds of pre-made animations, each of them with the possibility to get fitted to the uploaded and rigged character. Those animations, as well as the rigged character models, could get downloaded in a .fbx file format. Those files then were easily imported into Unreal.

To be able to create a believable 3D environment in Unreal, 3D models for level design were also necessary. Such as city buildings, trees and most important, for the test scenario, a bus station. Those models were acquired through several sources, like the Unreal Asset Store and several websites offering royalty free assets. All used assets are licensed in a way that allows it to use them for free in non-commercial applications.

2.5 Social Presence Questionnaire

To evaluate the impact of the implemented agent behaviour the test user had to fill out a questionnaire made specifically for this purpose. The main focus point of the items used in the questionnaire is to evaluate the experienced feeling of presence and co-presence during the test process. The reason it contains items regarding presence as well, and not only co-presence, is due to the connection those two values share, as explained in Chapter 2.1.2. Therefore it is important to measure both values in order to get a meaningful result.

2.5.1 Related Work

This chapter is about the resources that were used in order to develop a questionnaire made for the implemented agent behaviour. The inquired items regarding co-presence were highly inspired by the work of De Kort, IJsselsteijn, and Poels (2007) and Behrooz, Rich, and Sidner (2014). De Kort, IJsselsteijn, and Poels (2007) assumes that in games, social interaction is often more significant for the player than interaction with game objects. In their paper they mainly elaborate about the social interaction between humans in a game environment. Nevertheless, the questionnaire they have created should also be applicable to social interaction between human and non-human characters, like the implemented virtual agents and the player. Their questionnaire is divided into three areas: Psychological Involvement - Empathy, Psychical Involvement - Negative Feelings and Behavioural Involvement. According to their research an occurrence of negative feelings also presupposes a certain level of presence in order to be able to perceive those negative feelings in the first place.

5. Adobe. 2017. "Mixamo" Accessed: April 29. `https://www.mixamo.com/`

Items regarding presence were overtaken from the igroup presence questionnaire (IPQ) (Igroup 2017). The questionnaire put together by the igroup consists, amongst others, of several items of the Slater and Usoh (1993) and Witmer and Singer (1998) questionnaire (Schuemie et al. 2001). Similar to the previous questionnaires this one is categorized as well into four topics: General Presence, Spatial Presence, Involvement and Realism. All 14 items were overtaken into the questionnaire used for this thesis to ensure a meaningful result. Another reason for using the IPQ was that with that questionnaire already a big user study with over 500 participants was done.

2.5.2 Questionnaire - Items

Item	Anchor
Name	–
Age	–
Gender	–
How often do you play video games?	Daily - Never
Do you have any previous experience with VR (HTC Vive, Oculus Rift, PSVR or GearVR)?	Yes, a lot - No

Table 1: Demographic Items

The questionnaire was provided in English and German. Overall it consists of 22 items. The first part of the questionnaire inquires about demographic data, like previous experiences and age. Those items are shown in Table 1. The next 14 items are concerned to inquire about the feeling of presence during the usage of the application. Those items were overtaken from the IPQ and are provided in Table 3. The last 8 items ask about the sense of co-presence during the experience. What those items are is shown in Table 2.

Item	Anchor
I sympathized with the others.	Fully Agree - Fully Disagree
I had an emotional reaction towards the others.	Fully Agree - Fully Disagree
I tended to ignore the others.	Fully Agree - Fully Disagree
What I did affected the others.	Fully Agree - Fully Disagree
I paid attention to the others.	Fully Agree - Fully Disagree
The others paid attention to me.	Fully Agree - Fully Disagree
I felt like I was interacting with something more than a mere program.	Fully Agree - Fully Disagree
I had the feeling of “being there together”.	Fully Agree - Fully Disagree

Table 2: Co-Presence Items

Item	Anchor
In the computer generated world, I had a sense of ”being there”.	Very Much - Not at all
Somehow I felt that the virtual world surrounded me.	Fully Agree - Fully Disagree
I felt like I was just perceiving pictures.	Fully Agree - Fully Disagree
I did not feel present in the virtual space.	Felt present - Did not feel present at all
I had a sense of acting in the virtual space, rather than operating something from outside.	Fully Agree - Fully Disagree
I felt present in the virtual space.	Fully Agree - Fully Disagree
How aware were you of the real world surrounding while navigating in the virtual world?	Not aware at all - Extremely aware
I was not aware of my real environment.	Fully Agree - Fully Disagree
I still paid attention to the real environment.	Fully Agree - Fully Disagree
I was completely captivated by the virtual world.	Fully Agree - Fully Disagree
How real did the virtual world seem to you?	Not real at all - Very real
How much did your experience in the virtual environment seem consistent with your real-world experience?	Very consistent - Not consistent at all
The virtual world seemed more realistic than the real world.	Fully Agree - Fully Disagree
How real did the virtual world seem to you?	Indistinguishable from the real world - About as real as an imagined world

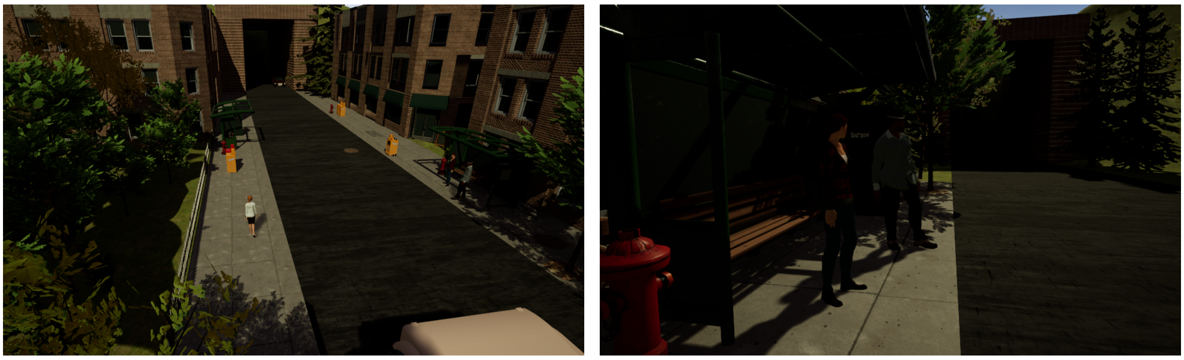
Table 3: Presence Items (Igroup 2017)

2.6 User Study

To investigate if the usage of the implemented features has any impact on the sense of presence and/or co-presence a small user study was done. Several participants had to test the implemented VR experience with the HMD Vive from HTC and two motion-controllers. The application is used as a first person view application. After each scene the participant had to fill out a questionnaire, asking about presence and co-presence. When all scenes and questionnaires were done, the tester was asked to take part in a short final interview. This chapter explains how the test was prepared, set up and executed.

2.6.1 Test Scene

Three levels were prepared for the user study. The first one was used as starting space, where testers had enough time to adjust the HMD to their needs. Besides that, participants could try out the controls used during the experience, for example the how locomotion and grabbing items works. The used locomotion mechanic is a teleport functionality. While pressing the thumpstick on the motion-controller the users were able to preview where they want to teleport, and when releasing it the teleport was performed. This function was adopted from the VR template of the Unreal engine.



(a) Level Overview 1 (b) Level Overview 2

Figure 6: Test Scene for the User Study

Another movement possibility with the HTC Vive is to move in room-scale, meaning that if players moves in the real world they also move the same amount in-game. This is of course restricted by real life boundaries like walls or furniture. Therefore a locomotion mechanic was necessary. To interact with the scene itself the Vive motion-controller were represented as hands in-game. These hand models were adopted from the VR template of Unreal as well. By pressing the trigger button on the backside of the controller the users were able to close the hands in order to grab and throw objects in the scene.

The other two scenes were the test scenes itself, both equal in composition. The only differences between the two levels was how the agents behaved, one with the implementation earlier mentioned and the other one without. Those levels were used to evaluate the impact of the implemented behaviour onto presence and co-presence. The scenes were kept small and simple to not distract the player too much from the agent behaviour and the task they had to fulfill.

The setting of the test levels was a realistic city environment. To restrict the viewable area of the test environment the city got surrounded by hills, trees and two tunnels. This helped to let the tester concentrate on the important part of the test level where the agents were placed as well as saving performance for rendering too much environment. The focus points were two bus stations as shown in Figure 6a. At both stations agents were placed. They should make the impression of waiting for the bus and also make the level more lively. For that reason several different agents were used, to let the environment appear less empty and more believable.

The bus stations were used for the functionality of the task the player had to perform. This task itself will get explained in more detail in Chapter 2.6.3. Those two stations were placed opposite of each other, separated by a street. On this street cars and buses randomly passed by. Those vehicles also served as gaze targets for the agents. The cars and buses stopped and started honking if the player or another character was in their way. This small behaviour should

(a) Interactable Can Objects

(b) Buses for Player Task

Figure 7: Interactable Objects in the VE

increase the believability of the environment as well. Other interactable objects in the scene were small cans. The testers could grab and throw them around. If they came too close to the agents they would look at it and eventually try to evade them to not get hit. If the can did hit them, the angry facial expression was triggered.

Sound is an important part in head-mounted virtual experiences. Therefore a stereo sound system was used. The ambient city sound was placed in the 3D space to create a better feeling of being in an actual 3D place rather than just watching pictures in a HMD. The ambient sound consisted of several sound effects like the rustling of the wind and bird twittering.

Besides the ambient sound, also the human characters emitted a breathing sound, only hearable if one was close enough to the character. The cars and buses had different driving sounds and the bus had extra sound effects for stopping at a bus station and opening its doors. The goal was that every object in the VE creates a plausible sound to help creating the illusion of a believable real place.

2.6.2 Participants

The test study was done with 10 participants. Their knowledge and experience with VR systems varied from none to nearly daily usage. The participants consisted of 2 female tester and 8 male tester. The mean age over all tester was 29.5 years. 60% of the participants had previous VR experience and 40% never used any VR device before that study. 80% of the testers are playing video games regularly, from daily to at least once a week. 20% are either gaming only once a month or never. Table 4 summarizes the demographic data of the participants and shows the mean values regarding game and VR experience. Table 5 shows the collected experience data in percentage.

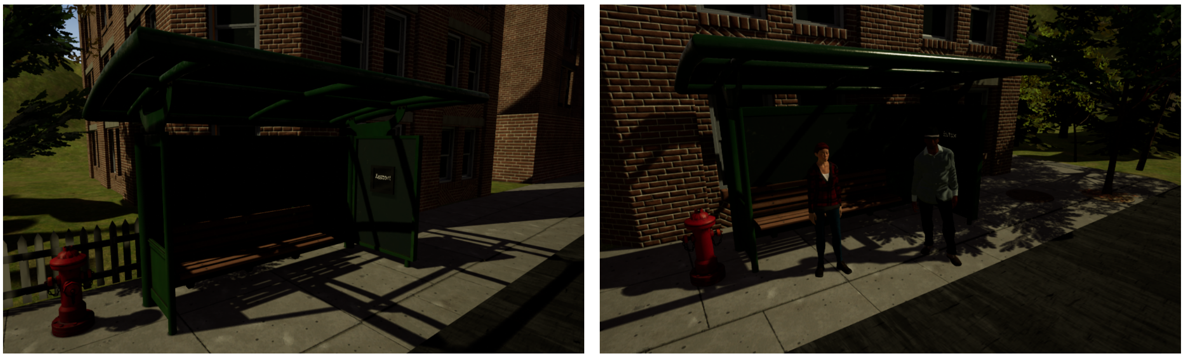
Mean Age	Female	Male	Mean Game Experience (0 to 3)	Mean VR Experience (0 to 2)
29.5	2	8	2.3	0.7

Table 4: Demographic Participant Data

Previous VR Experience	No VR Experience	Occasional Game (2 to 3)	No Gamer (0 to 1)
60%	40%	80%	20%

Table 5: Participant Experience Data in Percentage

2.6.3 Test Process

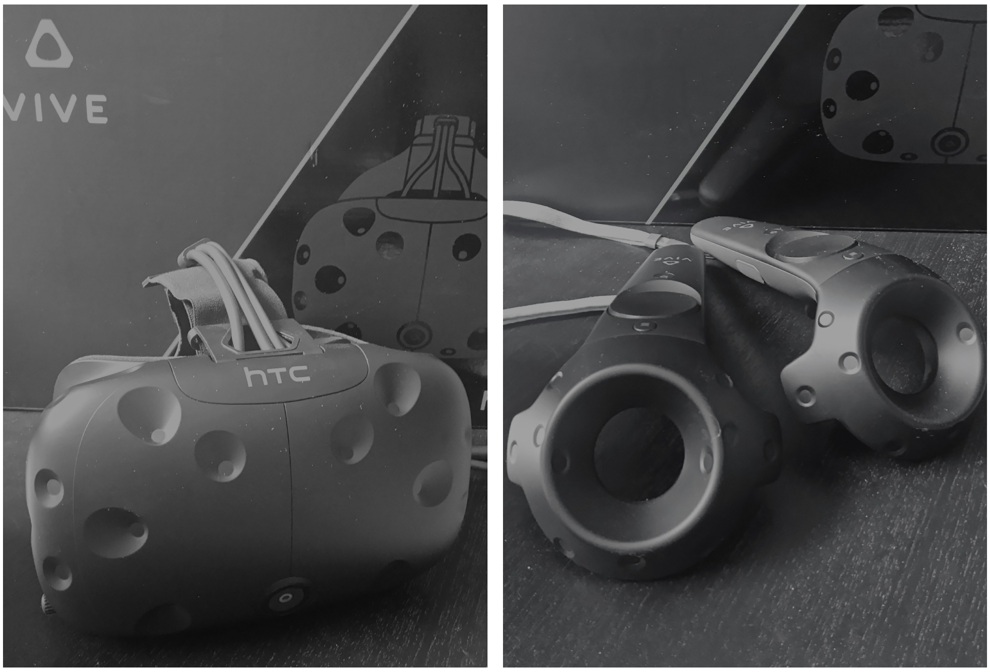


(a) Bus Station (b) Bus Station with Agents

Figure 8: Bus Station for Player Task

The user study was done in a supervised lab environment. During the whole test process the participants were observed by the test leader and could ask questions if they needed help. Before the test itself, each participant had to fill out and sign a consent form. Then each participant was introduced to the HTC Vive, the used HMD device as shown in Figure 9. After that, the application got started and the player was initially placed in the start level. In that level they had time to adjust the device to their personal needs, like adjusting the tightness of the HMD straps to their head or change the distance between the lenses.

The controls and movement possibilities were explained and the user had the chance to get familiar with them before the test itself started. The last point before starting the test scenes was to explain the task the participant had to perform during the test. The task is that the user has to find the correct bus station to enter the bus into the previously given direction. To do so the player can read on a sign on the bus station in which direction the bus goes. The target destination was told to the tester by the test leader at the beginning of each scene.
When one of the test levels was loaded the participants found themselves on the sidewalk next to one of the bus stations and a newsstand filled with cans. In the reactive scene usually the



(a) HTC Vive - HMD (b) HTC Vive - Motion Controller

Figure 9: HTC Vive

first agent already recognizes the presence of the players and gazes at them for a moment. To perform the given task several actions are necessary. The participant has to move to each of the bus stations, either in room-scale or via locomotion. The next step is to read the sign at each bus station to find out in what direction the related bus goes.

When the participants had found the correct station they had to wait for the bus. The waiting time is usually around 15-20 seconds. This waiting time should support further interaction between player and agents. When the bus arrived the participant was told to enter it. This is possible by pressing the buttons near the bus doors. The opening of the door is indicated by playing of the used door opening sound effect. If it was the correct bus, the screen starts to fade out and the tester was put back into the start level.

During the test the participants did not know if they were in the reactive level, with the implementation of the agent behaviour, or in other one. They also did not know the difference between them. Furthermore, the order in which the scenes got experienced was altered from one tester to another, to avoid any error in the final results by always testing one level before the other. Also were the participants not aware of the goal of the study, to test presence and co-presence. This measure should help to prevent any tampering of the final results. After each level the participant had to fill out the questionnaire introduced in Chapter 2.5. Once both test scenes and questionnaires were done, the participant was asked to take part in a short interview.

The core questions asked during that interview were:

- Could you make out any difference between the two scenes? If yes, which ones?
- Which scene felt more believable, where did you feel more involved and why?
- Did you notice any change of behaviour of the characters between both scenes? If yes, which ones?
- Did it feel like the characters would actually recognize you? If yes, why?

The interview should allow a deeper understanding what the tester felt during both scenes and which behaviour was actively recognized and if that happened in a positive or negative way. Any further feedback was highly appreciated.

3 Results

Factor	Mean Values	Mean Values in %	Standard Deviation	Deviation to Counter Scene
With Implementation				
G	4.600	76.67%	1.020	+5.00%
SP	4.460	74.33%	1.539	+4.67%
INV	4.125	68.75%	1.486	+11.67%
REAL	2.625	43.75%	1.698	+9.58%
CP	4.025	67.08%	1.508	+35.83%
Without Implementation				
G	4.300	71.67%	1.269	-5.00%
SP	4.180	69.67%	1.410	-4.67%
INV	3.425	57.08%	1.642	-11.67%
REAL	2.050	34.17%	1.642	-9.58%
CP	1.875	31.25%	1.706	-35.83%

Table 6: Questionnaire Results

The resulting values of presence and co-presence, based on the filled out questionnaires, can lie between 0 and 6. Whereas 0 represents no feeling of presence or co-presence and 6 represents the highest feeling of those. With the questionnaire five different values got measured: General Presence (G), Spatial Presence (SP), Involvement (INV), Realness (REAL) and Co-Presence (CP). The first four factors contribute to the feeling of presence and encompassed 14 items in the questionnaire. Those 14 items were used from the IPQ (Igroup 2017). The last factor represents co-presence and was covered by 8 items in the questionnaire. Some items were inverted questions (SP2, REAL1, INV3 and CP3) and the according values got inverted properly to map to the same 0 to 6 scale. By comparing the mean values of both scenes for each factor it showed that especially co-presence was influenced highly by the implemented behaviour. The co-presence value, for the scene with implementation, was 4.025 which equals a co-presence level of 67.08%. The test scene without the implemented behaviour only resulted in a co-presence value of 1.875 which equals 31.25%. So the implemented agent behaviour resulted in an increase of +35.83% in co-presence. The standard deviation for co-presence for the reactive scene was 1.508 and for the non-reactive scene 1.708.

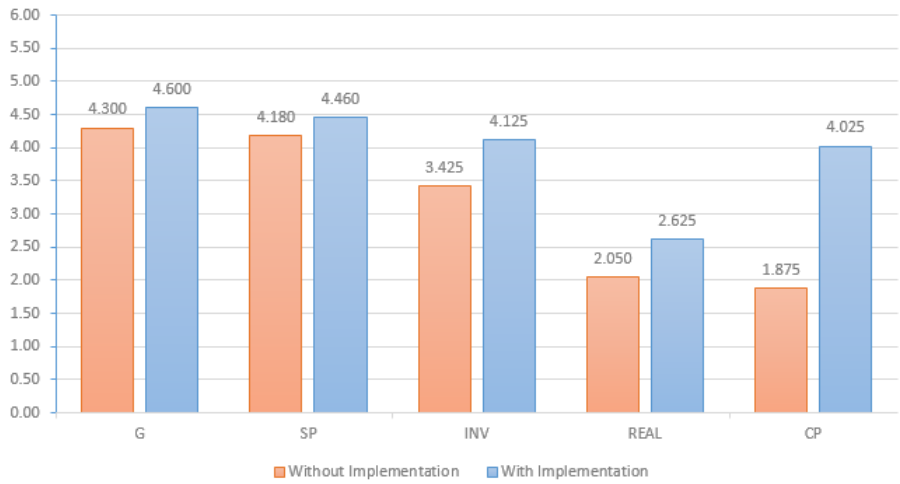


Figure 10: Factor Comparison

Figure 10 shows the resulting factors of both scenes in comparison. It shows that the implemented behaviour cues also had an impact on the factors regarding presence. However that impact is significant smaller than on co-presence. The presence areas that got affected the most were REAL with an increase of +9.58% and INV with an increase of +11.57%.

Another factor that played a role in interpreting the results is the previous VR experience of the participants. It is interesting to see how previous experience affected the perceived behaviour of the agents and the difference between scenes. The study has shown that previous VR experience has an impact on presence and co-presence. Figure 11 shows the results if previous VR experience was taken into account. Table 7 summarizes all the results for both scenes split up based on the previous VR experience. The perceived difference between scenes is for testers with previous VR experience significant higher that for testers with no previous knowledge.

Generally it can be said that all values are rated higher by users without previous experiences. The interview showed that those user were *"so overwhelmed"* by the first usage of a VR device and the experience. Some of them did not even notice any difference between the scenes and therefore did not notice the agent behaviour at all. This shows also when the co-presence values are compared in percentage. The increase of co-presence for testers with previous experience was +44.10%, the increase for those without it, was only +23.44%.

Factor	Mean Values with previous VR Experience	Mean Values in %	Deviation to Counter Scene	Mean Values without previous VR Experience	Mean Values in %	Deviation to Counter Scene
With Implementation						
G	4.167	69.44%	+5.56%	5.250	87.50%	+4.17%
SP	4.367	72.78%	+13.89%	4.600	76.67%	-9.17%
INV	3.958	65.97%	+13.19%	4.375	72.92%	+9.38%
REAL	2.083	34.72%	+12.50%	2.650	44.17%	+13.33%
CP	3.771	62.85%	+44.10%	4.406	73.44%	+23.44%
Without Implementation						
G	3.833	63.89%	-5.56%	5.000	83.33%	-4.17%
SP	3.533	58.89%	-13.89%	5.150	85.83%	+9.17%
INV	3.167	52.78%	-13.19%	3.813	63.54%	-9.38%
REAL	1.333	22.22%	-12.50%	1.850	30.83%	-13.33%
CP	1.125	18.75%	-44.10%	3.000	50.00%	-23.44%

Table 7: Results Considering VR Experience

Those questionnaire results are getting supported by the results and insights made during the interview. It revealed that the scene without the implementation felt *"boring"*, *"lonely"* and generally *"less interesting"* than the other scene. Testers reported that if the virtual characters did not react to the presence of the player they felt ignored and the agents seemed like *"lifeless robots"*.

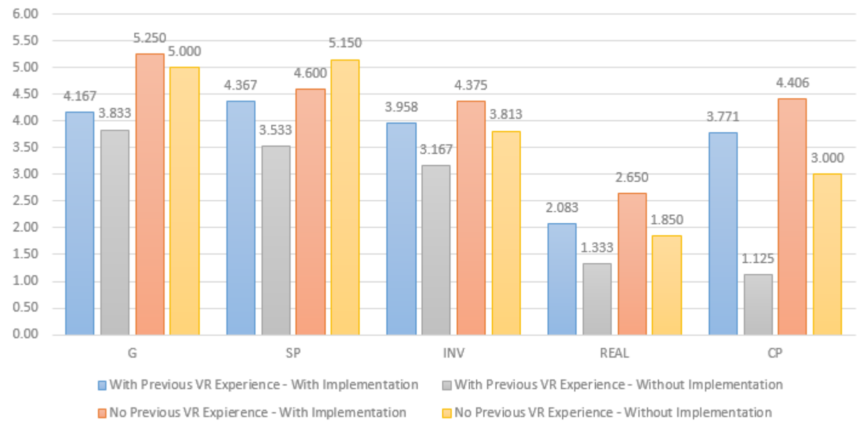


Figure 11: Experience - Factor Comparison

Figure 12 shows the results in a spider chart. All factors are represented in the chart. It shows the difference between both scenes in a more clear way. It can easily be noticed that especially the difference plays out on the sense of co-presence in the user. It also can be seen that the value for SP and G are nearly the same. Figure 13 shows the questionnaire results with the consideration of previous VR experience in spider charts. Figure 13a presents the data of participants with

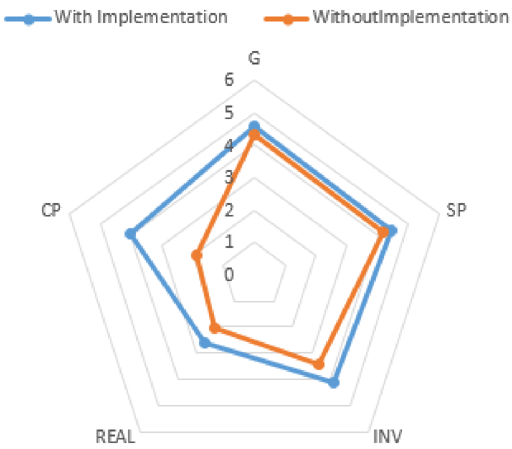
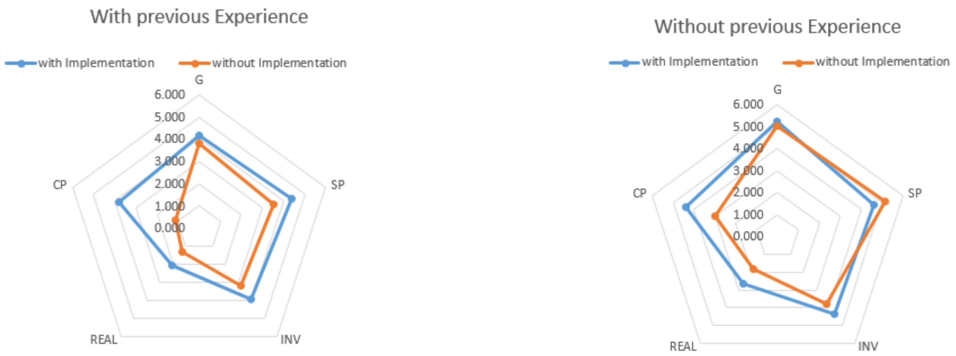


Figure 12: Spider Chart - Results



(a) Spider Chart - With VR Experience

(b) Spider Chart - Without VR Experience

Figure 13: Spider Charts considering VR Experience

previous VR experience and Figure 13b shows the results from those without. As previously mentioned, it can again be seen that the change in presence and co-presence perceived from participants with previous experience is more measurable than from those participants without.

Another fact the interview has revealed was that the most noticed behaviour was the gaze behaviour. All participants noticed that the agents followed the player and the players hands. About 80% noticed that the agents also gazed at passing cars, buses and thrown cans. Only 50% noticed the facial expressions and if they did, they mostly only observed the anger expression. For example when coming too close to the agent or throwing cans at them. During the interview only around 30% reported that they saw the happiness facial expression. Only one participant, thus 10%, actively noticed the idle gaze behaviour. The reason behind this small number might be that this special behaviour is not easily spotable and adds rather passively than actively to a more believable behaviour.

One behaviour mechanic that was easier observeable was the collision avoidance regarding the player and other objects like cans. During the interview around 70% mentioned that they perceived this behaviour cue.

Overall the final interviews have shown, that the scene with the implemented agent behaviour was more realistic and believable. Although for some the gaze behaviour was perceived as *"creepy"* due to cases where the head movement was perceived as too slow. Future research and adjustments in this area have to be made.

4 Discussion and Future Possibilities

The user study for this thesis only involved 10 participants. To get more reliable and meaningful results a study with more participants would be the next step. Another important change that has to be considered is that not all agents should be continuously aware of their environment. Currently every agent always observes the environment and looks out for possible gaze targets. Some agents should be distracted, for instance by using their phones or listening to music. This behaviour would already be possible in the current implementation by increasing the value for minimum priority in the TargetSensingComponent, but did not get used in the conducted user study. That was one thing that the participants in the study pointed out as an *"odd"* behaviour. One factor that did not get measured was how long the participants needed to fulfill the task. The reason behind that is that the testers should not be concerned with finishing the task in a short time. They should have enough time to notice the agent behaviour and react to it. As mentioned in Chapter 2.1.3, task performance is not a qualified factor to evaluate presence or co-presence. Another point is that the used test setup did not include any direct player - agent interaction. This would also be a factor that could be investigated in a future user study.

It has to be noted, that some items on the questionnaire caused confusion for the participants which had to fill them out. The inverted items with then also inverted scale were sometimes not completely clear and some participants needed help while filling it out. A few anchor points caused some unclarity. This was the case with item 16 ("How real did the virtual world seem to you?") and the negative anchor ("About as real as an imagined world"). A lot of participant noted that imagined worlds can feel very real. Most of the participants also had a problem for example with item 15 "The virtual world seemed more realistic than the real world.". Their response to that question was usually *"How can be something more real than the real world?"*. That leads to the fact that the used questionnaire has to be improved before conducting further user studies.

Next steps regarding the implementation of believable characters would be to enhance the collision avoidance. In the current implementation it only tries to evade objects that are already inside the personal space of the character. A better solution would be to preemptively watch objects further away that are moving towards the agent. Not only the collision avoidance could benefit from that mechanic but also the gaze behaviour. It would improve the gaze behaviour, because humans tend to put their attention and therefore their gaze to objects that move towards them, for example thrown objects (Itti, Dhavale, and Pighin 2003). If the agents would be able to recognize those objects earlier, than the moment when they intrude their personal space, they would be able to perform a more believable reaction in this situation.

Further necessary improvements would include the recognition and reaction to sound. To ensure a plausible reaction this should include environment sounds (e.g. honking of cars, cans hitting the ground) as well as sounds the player could make (e.g. through the microphone). Which leads to another future possibility to let virtual agents embrace a more reasonable behaviour: voice recognition of the player. Although voice recognition is a wide research field on its own, already the recognition if the player says something in a high-pitched or low-pitched voice could help to determine the current emotional state of the player and could be used to let agents react in a more realistic way.

Not only the emotional state of the player is important to implemented a plausible behaviour, also the emotions of the virtual agents should be taken into account. Agents that appear intelligent and emotional are more relatable and believable for the player (Riedl and Stern 2006). Thus, a emotion and memory system for virtual agents would be a significant improvement to enhance co-presence in the long run and allow a more enjoyable experience. A more complex emotion system would afford and support more complex facial expressions. Those expressions could be used to communicate the current emotional state of the agent to the player.

Not only the behaviour itself could be improved but also on which kinds of input it reacts. Voice recognition got already mentioned, but other new input methods are currently in development for room-scale HMDs. For instance eye tracking[6] and full body tracking[7]. Those new features enable whole new areas of possibilities on what an agent could react to. For example, eye tracking could be used in communication situations to check if the player pays attention to the virtual character or to point to specific objects in the environment. The full body tracking could be used to improve gesture recognition. Generally gesture recognition would be another beneficial feature to enhance the agents behaviour. The tracked motion-controllers of current VR devices like HTC Vive or Oculus Rift would allow to implemented such a feature. One factor that has to be considered when using gesture recognition is the cultural background of the player, as some gestures could have different meanings when it comes to different cultures.

6. Ian Hamilton, UPLOADVR. 2017. ”Plug-And-Play Eye Tracking Peripheral” Accessed: April 29. `https://uploadvr.com/7invensun-eye-tracker-for-vive/`

7. Joe Durbin, UPLOADVR. 2017. ”Full Body Tracking With Vive” Accessed: April 29. `https://uploadvr.com/improved-full-body-tracking/`

5 Conclusion

The goal of this thesis was to investigate the impact of non-verbal social cues, like gaze and facial expressions, on the sense of presence and co-presence in immersive VEs. Another point of this thesis was to explain why believable characters are important in several applications and their field of use in the industry. This thesis also described what determines a believable character and the importance of non-verbal communication in player to agent interaction. Besides the implementation and study itself, this thesis also gave a brief overview on the definition of presence and co-presence and took a look at different approaches to those terms. Furthermore, the distinction between the terms presence and immersion got investigated and defined for the context of this paper. The last chapter regarding presence and co-presence investigated methods to measure those values. It showed that questionnaires and interviews are the best ways to measure such a subjective sensations like presence and co-presence. Therefore those methods got used for this user study.

To measure and evaluate the impact of non-verbal social cues on co-presence, a system for agent gaze behaviour was developed. The implementation also includes a simple collision avoidance behaviour and the implementation of a simple emotion system to provide facial expressions. This thesis explains how those mechanics were implemented and how they work. The developed behaviour was evaluated through a user study with 10 participants. Each tester had to experience two scenes, one with the implemented behaviour and one without. After each scene a questionnaire, that got prepared for exactly that study, had to be filled out by the tester. This thesis gave an overview of different presence and co-presence questionnaires and explained how the one used for this study was built up. The main topics the questionnaire did inquire with its 22 items were presence, split up into general presence, spatial presence, involvement and realness, and co-presence.
It also collected demographic data like the amount of previous experience in video games and with VR devices. That data helped interpreting the results and gave an insight how much previous VR experience matters when it comes to perceived presence and co-presence.

The thesis also provided an insight on how the user study was set up and executed. The results of the questionnaires and the following interviews showed that the implementation of non-verbal social cues has a big impact on the feeling of co-presence. Especially noticeable for testers with previous VR experience. The implemented behaviour also had a small impact on the sense of presence in the VE but it was significant smaller than on co-presence. The last chapter of the thesis discusses the results of the executed study. It shows that in order to get more meaningful and reliable data a bigger study with more participants is necessary and that the questionnaire has to be edited before conduction further studies. Nevertheless, this study gave already an interesting insight on the impact of non-verbal social cues on presence and co-presence. The last point of the thesis is about possible future ways to enhance the implemented behaviour of believable characters in immersive VEs. Lastly, it gives a short outlook on possible new input methods of HMD devices and ways to use them to improve plausible behaviour.

List of Figures

Listings

List of Tables

References

Adobe Systems Software. 2015. *Adobe Fuse CC Beta.* Version Beta. Accessed: 2017-04-29, November 30. http://www.adobe.com/at/products/fuse.html.

Bailenson, Jeremy N., Kim Swinth, Crystal Hoyt, Susan Persky, Alex Dimov, and Jim Blascovich. 2005. "The Independent and Interactive Effects of Embodied-agent Appearance and Behavior on Self-report, Cognitive, and Behavioral Markers of Copresence in Immersive Virtual Environments." *Presence: Teleoper. Virtual Environ.* (Cambridge, MA, USA) 14, no. 4 (August): 379–393. ISSN: 1054-7460. doi:10.1162/105474605774785235. http://dx.doi.org/10.1162/105474605774785235.

Baylor, Amy L. 2011. "The design of motivational agents and avatars." *Educational Technology Research and Development* 59 (2): 291–300.

Behrooz, Morteza, Charles Rich, and Candace Sidner. 2014. "On the Sociability of a Game-Playing Agent: A Software Framework and Empirical Study." In *Intelligent Virtual Agents: 14th International Conference, IVA 2014, Boston, MA, USA, August 27-29, 2014. Proceedings,* edited by Timothy Bickmore, Stacy Marsella, and Candace Sidner, 40–53. Cham: Springer International Publishing. ISBN: 978-3-319-09767-1. doi:10.1007/978-3-319-09767-1_6. http://dx.doi.org/10.1007/978-3-319-09767-1_6.

De Kort, Yvonne AW, Wijnand A IJsselsteijn, and Karolien Poels. 2007. "Digital games as social presence technology: Development of the Social Presence in Gaming Questionnaire (SPGQ)." *Proceedings of PRESENCE* 195203.

Egan, D., S. Brennan, J. Barrett, Y. Qiao, C. Timmerer, and N. Murray. 2016. "An evaluation of Heart Rate and ElectroDermal Activity as an objective QoE evaluation method for immersive virtual reality environments." In *2016 Eighth International Conference on Quality of Multimedia Experience (QoMEX),* 1–6. June. doi:10.1109/QoMEX.2016.7498964.

Garau, Maia, Mel Slater, Simon Bee, and Martina Angela Sasse. 2001. "The impact of eye gaze on communication using humanoid avatars." In *Proceedings of the SIGCHI conference on Human factors in computing systems,* 309–316. ACM.

Garau, Maia, Mel Slater, Vinoba Vinayagamoorthy, Andrea Brogni, Anthony Steed, and M. Angela Sasse. 2003. "The Impact of Avatar Realism and Eye Gaze Control on Perceived Quality of Communication in a Shared Immersive Virtual Environment." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 529–536. CHI '03. Ft. Lauderdale, Florida, USA: ACM. ISBN: 1-58113-630-7. doi:10.1145/642611.642703. http://doi.acm.org/10.1145/642611.642703.

Igroup, Project-Consortium. 2017. "igroup presence questionnaire (IPQ)." Accessed: 2017-04-29. http://www.igroup.org/pq/ipq/index.php.

Itti, Laurent, Nitin Dhavale, and FrÃ©dÃ©ric Pighin. 2003. "Realistic Avatar Eye and Head Animation Using a Neurobiological Model of Visual Attention." In *Proceedings of SPIE 48th Annual International Symposium on Optical Science and Technology.* San Diego, CA, August. doi:10.1117/12.512618. http://ict.usc.edu/pubs/Realistic%20Avatar%20Eye%20and%20Head%20Animation%20Using%20a%20Neurobiological%20Model%20of%20Visual%20Attention.pdf.

Jung, Yvonne, Arjan Kuijper, Dieter W Fellner, Michael Kipp, Jan Miksatko, Jonathan Gratch, and Daniel Thalmann. 2011. "Believable Virtual Characters in Human-Computer Dialogs." In *Eurographics (STARs),* 75–100.

Narang, Sahil, Andrew Best, Tanmay Randhavane, Ari Shapiro, and Dinesh Manocha. 2016. "PedVR: Simulating Gaze-based Interactions Between a Real User and Virtual Crowds." In *Proceedings of the 22Nd ACM Conference on Virtual Reality Software and Technology,* 91–100. VRST '16. Munich, Germany: ACM. ISBN: 978-1-4503-4491-3. doi:10.1145/2993369.2993378. http://doi.acm.org/10.1145/2993369.2993378.

Prendinger, Helmut, and Mitsuru Ishizuka, eds. 2004. *Life-like characters - tools, affective functions, and applications.* Cognitive Technologies. Springer. ISBN: 978-3-540-00867-5. http://dblp.uni-trier.de/db/series/cogtech/354000867.html.

Riedl, Mark O., and Andrew Stern. 2006. "Believable Agents and Intelligent Story Adaptation for Interactive Storytelling." In *Technologies for Interactive Digital Storytelling and Entertainment: Third International Conference, TIDSE 2006, Darmstadt, Germany, December 4-6, 2006. Proceedings,* edited by Stefan Göbel, Rainer Malkewitz, and Ido Iurgel, 1–12. Berlin, Heidelberg: Springer Berlin Heidelberg. ISBN: 978-3-540-49935-0. doi:10.1007/11944577_1. http://dx.doi.org/10.1007/11944577_1.

Roth, D., J. L. Lugrin, D. Galakhov, A. Hofmann, G. Bente, M. E. Latoschik, and A. Fuhrmann. 2016. "Avatar realism and social interaction quality in virtual reality." In *2016 IEEE Virtual Reality (VR),* 277–278. March. doi:10.1109/VR.2016.7504761.

Schroeder, R. 2001. *The Social Life of Avatars: Presence and Interaction in Shared Virtual Environments.* Computer Supported Cooperative Work. Springer London. ISBN: 9781852334611. https://books.google.at/books?id=d-7vegnIgJsC.

Schubert, Thomas, Frank Friedmann, and Holger Regenbrecht. 2001. "The experience of presence: Factor analytic insights." *Presence: Teleoperators and virtual environments* 10 (3): 266–281.

Schuemie, Martijn J., Peter Van Der Straaten, Merel Krijn, M. Sc, M. Sc, Charles A. P. G, Van Der Mast, and Ph. D. 2001. "Research on Presence in VR: a Survey." *ACM Virtual Reality Software and Technology (VRST* 4:202.

Slater, Mel. 1999. "Measuring Presence: A Response to the Witmer and Singer Presence Questionnaire." *Presence: Teleoper. Virtual Environ.* (Cambridge, MA, USA) 8, no. 5 (October): 560–565. ISSN: 1054-7460. doi:10.1162/105474699566477. http://dx.doi.org/10.1162/105474699566477.

Slater, Mel, Vasilis Linakis, Martin Usoh, Rob Kooper, and Gower Street. 1996. “Immersion, presence, and performance in virtual environments: An experiment with tri-dimensional chess.” In *ACM virtual reality software and technology (VRST),* 163:72. ACM Press New York, NY.

Slater, Mel, and Martin Usoh. 1993. “Representations Systems, Perceptual Position, and Presence in Immersive Virtual Environments.” *Presence: Teleoperators and Virtual Environments* 2 (3): 221–233. ISSN: 1054-7460. doi:10.1162/pres.1993.2.3.221.

Software, Adobe Systems. 2017. “Mixamo: Quality 3D character animation in minutes.” Accessed: 2017-04-29. https://www.mixamo.com/.

Vinayagamoorthy, V., M. Gillies, A. Steed, E. Tanguy, X. Pan, C. Loscos, and M. Slater. 2006. “Building Expression into Virtual Characters.” In *Eurographics 2006 - State of the Art Reports,* edited by Brian Wyvill and Alexander Wilkie. The Eurographics Association. doi:10.2312/egst.20061052.

Witmer, Bob G., and Michael J. Singer. 1998. “Measuring Presence in Virtual Environments: A Presence Questionnaire.” *Presence: Teleoper. Virtual Environ.* (Cambridge, MA, USA) 7, no. 3 (June): 225–240. ISSN: 1054-7460. doi:10.1162/105474698565686. http://dx.doi.org/10.1162/105474698565686.

Abbreviations

AR - Augmented Reality
HMD - Head-Mounted-Display
VE - Virtual Environment
VR - Virtual Reality

Appendix

Questionnaire

Description
The used questionnaire for this study to measure presence and co-presence in virtual environments. The questionnaire is provided in an english and german version.

File Location
`UserStudy\RawDocuments\SocialPresenceQuestionnaire_English.pdf`
`UserStudy\RawDocuments\SocialPresenceQuestionnaire_Deutsch.pdf`

Form of Consent

Description
The form of consent, each participant had to fill out before being allowed to take part in the user study. This document is only available in german.

File Location
`UserStudy\RawDocuments\Einverstndnisserklrung_FormOfConsent.pdf`

Questionnaire Results

Description
This document includes all answer values of the two questionnaires every participant had to fill out. It contains the raw data as well as the mapped values of the questionnaire. The most important part it that it shows the results of the user study and contains diagram-ms to demonstrate those results.

File Location
`UserStudy\Results\UserStudyResults.xlsx`

Filled out Documents

Description
All documents filled out by the participants of the study. This includes the signed form of consent and 2 filled out questionnaires. Overall each document consists of 20 sites.

File Location
`UserStudy\FilledOutDocuments\UserStudy_AlexanderMoser.pdf`
`UserStudy\FilledOutDocuments\UserStudy_AndreasFriedle.pdf`
`UserStudy\FilledOutDocuments\UserStudy_FlorianSchmiederer.pdf`
`UserStudy\FilledOutDocuments\UserStudy_FlorianStadlberger.pdf`
`UserStudy\FilledOutDocuments\UserStudy_JuergenEichinger.pdf`
`UserStudy\FilledOutDocuments\UserStudy_LukasRosenberger.pdf`
`UserStudy\FilledOutDocuments\UserStudy_MichaelaFliesser.pdf`
`UserStudy\FilledOutDocuments\UserStudy_NeilDoppelmayr.pdf`
`UserStudy\FilledOutDocuments\UserStudy_RobertRoeder.pdf`
`UserStudy\FilledOutDocuments\UserStudy_SusanneWieland.pdf`

Interview Notes

Description
Notes made during interviews while conducting the user study.

File Location
`UserStudy\Results\Interview_Notes_UserStudy.pdf`

Test Application Build

Description
The implemented test application, used for the test study. This includes all necessary data to start the test application, like the .exe to start up the application. The application starts in the start level. To enter the other levels, with and without the implemented behaviour press 1 (with behaviour) or 2 (without behaviour).

File Location
`Implementation\PackagedBuild\BAC2.exe` - To start the application
`Implementation\PackagedBuild\BAC2\` - Content Files
`Implementation\PackagedBuild\Engine\` - Engine Files

Test Application Project

Description
The Unreal project of the test application. This also includes the C++ files that contain the code that enables the implemented behaviours, like gaze. Furthermore is contains all blueprints,animations and models as .uasset files. The .uproject file is used to open the project in Unreal.

File Location
`Implementation\ProjectFolder\BAC2.uproject` - To start the Unreal project
`Implementation\ProjectFolder\Config\` - Engine Config Files
`Implementation\ProjectFolder\Content\` - Content Files
`Implementation\ProjectFolder\Source\` - C++ Files

Archived Websites

http://web.archive.org/web/20170415114705/http://www.igroup.org/pq/ipq/index.php
http://web.archive.org/web/20170416145835/http://www.adobe.com/at/products/fuse.html
http://web.archive.org/web/20170416150006/https://www.mixamo.com/
https://archive.is/Edlsx
https://archive.is/bTeS5
http://web.archive.org/web/20160526144551/http://scottbilas.com/files/2002/gdc_san_jose/game_objects_slides_with_notes.pdf