

Presence-Enhancing Real Walking User Interface for First-Person Video Games

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Abstract

For most first-person video games it is important that players have a high level of feeling presence in the displayed game environment. Virtual reality (VR) technologies have enormous potential to enhance gameplay since players can experience the game immersively from the perspective of the player's virtual character. However, the VR technology itself, such as tracking devices and cabling, has until recently restricted the ability of users to really walk over long distances.

In this paper we introduce a VR-based user interface for presence-enhancing gameplay with which players can explore the game environment in the most natural way, i. e., by real walking. While the player walks through the virtual game environment, we guide him/her on a physical path which is different from the virtual path and fits into the VR laboratory space. In order to further increase the VR experience, we introduce the concept of *transitional environments*. Such a transitional environment is a virtual replica of the laboratory environment, where the VR experience starts and which enables a gradual transition to the game environment. We have quantified how much humans can unknowingly be redirected and whether or not a gradual transition to a first-person game via a transitional environment increases the user's sense of presence.

CR Categories: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities;

Keywords: Virtual reality, walking interface, presence

1 Introduction

In recent years video games have become more and more popular for entertainment as well as serious gaming such as advergaming or educational games. In the context of video games, first-person refers to a graphical perspective rendered from the viewpoint of the player's character [Jenkins 2004]. Video games often utilize sophisticated rendering technology as well as multimodal interaction

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and information such as surround-sound audio feedback and haptic peripherals, which support vibration or force feedback. Usually, mouse, keyboard, joystick or game controller are used as interface devices. In video game terminology, the term *gameplay* is used to describe the overall experience of playing the game excluding factors like graphics and sound. It has been claimed that one way to enhance gameplay is to immerse users within the virtual world, so that they have a high sense of presence in the environment [Murray 1997].

Since the beginning of the early 90's developments in technology and software of the VR and games industry are strongly related and mutually affect each other [Murray 1997]. Since VR systems are able to present the game world from the viewpoint of the gamer's character, they have great potential as an enabling technology for immersive gameplay. With immersive VR technologies natural 3D user interfaces and navigation by real walking can be implemented easily. For example, players can immerse in the game environment by wearing head-mounted displays (HMDs) while tracking systems provide information about the position/orientation of the user and the input devices. Although VR research has gone through a long history of refinement, there are still only few commercially available games which make use of VR. Usually, before players can use VR technology they need to be instructed and trained with the control and input devices, for instance, they need to understand how 3D hand-based input devices are used for virtual walking metaphors. Furthermore, *real walking* has been shown to be a more natural locomotion technique than any other navigation metaphor, including virtual flying or navigation based on walk-like gestures [Usoh et al. 1999a].

An obvious approach to implement real walking is to transfer user's tracked head movements to changes of the virtual camera in the VE by means of a one-to-one mapping, i. e., a one meter movement in the tracked space is mapped to a one meter movement of the virtual camera in the corresponding direction. This technique has the drawback that the users' movements are restricted by a limited range of the tracking sensors and a rather small workspace in the real world. Therefore, concepts for virtual locomotion are needed that enable walking over large distances in the virtual world while remaining within a relatively small space in the real world. Various prototypes of interface devices have been developed to prevent a displacement in the real world [Bouguila and Sato 2002; Iwata et al. 2006]. Although these hardware systems represent enormous technological achievements, they are still very expensive and will not be generally accessible in the foreseeable future.

It is known from perceptive psychology that vision often dominates proprioceptive and vestibular sensation when they disagree [Dichgans and Brandt 1978; Berthoz 2000]. When humans can use only vision to judge their motion through a virtual scene they can successfully estimate their momentary direction of self-motion but are not as well in perceiving their paths of travel [Lappe et al. 1999; Bertin et al. 2000]. Therefore, since users tend to unwittingly compensate for small inconsistencies during walking it is possible to guide them along paths in the real world which differ from the path perceived in the virtual world. For example, intentionally rotat-

ing the virtual camera to one side causes the user to unknowingly compensate by walking a circular arc in the opposite direction. This *redirected walking* enables users to explore a virtual world that is considerably larger than the tracked working space by guiding the user on a physical path which fits into the VR laboratory space [Steinicke et al. 2008; Razzaque 2005] (see Figure 1).

Within the academic work on immersive virtual reality, presence is an important metric that is used to compare systems. Whilst various definitions of presence exist, we use the definition of Sanchez-Vive and Slater, where presence leads to the participant behaving as if the virtual world represented real situations [Sanchez-Vives and Slater 2005]. According to [Slater et al. 1998b] users might feel a higher sense of presence in the VE if it is presented as persistent space that can be entered and exited, and moreover, if the transfer into the VE involves some notion of travel or detachment from the real world. In theme parks a similar concept is used successfully. For example, prior to a ride in a roller coaster passengers have to cross dungeons or fairy tale worlds to mentally prepare for the experience. Therefore, in order to improve a VR-based game experience it seems reasonable to provide users with a virtual replica of their real environment (usually the laboratory) such that they can accustom themselves to walking in an immersive VR system [Steinicke et al. 2009]. After a certain time period, the user may enter the “real” game world, for example via a virtual door. Although it seems to be a promising approach to use a gradual transition between real and game world, it has not been verified if the usage of such metaphors as introduced by such a transitional environment increases the sense of presence in a game context.

The remainder of this paper is structured as follows. Section 2 reviews work related to our paper. In Section 3 we propose a new user interface, which allows players to travel without restriction through a geospatial game environment by means of redirected walking. Section 4 describes the experiment that we have conducted to quantify how much users can be redirected. Section 5 explains the evaluation in which we have analyzed whether a transitional environment increases the user’s sense of presence or not. Section 6 discusses the results and Section 7 concludes the paper.

2 Related Work

In 1991 Virtuality released a VR gaming system called the 1000CS, which was an immersive HMD platform with a tracked 3D joystick. During the 90’s several VR games have been proposed for different VR setups, e. g., Nintendo’s Virtual Boy. Another example of the connection between VR and gaming is DisneyQuest providing an indoor interactive theme park which contains several VR attractions [Schell 2008]. Furthermore, the recent success of input devices such as Nintendo’s Wii or Apple’s iPhone for 3D gaming underlines some common themes of the VR and gaming domain. These gaming and VR devices, exploit the human sense of proprioception, that is body state awareness, so that certain types of action can be performed using mimicry of real actions.

Indeed, it is difficult to create a high-fidelity VR experience, primarily because of technical limitations. These limitations often interfere with even basic requirements like support for omni-directional and unlimited walking. Therefore, locomotion in a large virtual world by real walking through a limited physical setup is in the focus of many research groups. As mentioned above redirected walking [Razzaque 2005] provides a promising solution to the problem of limited tracking space and the challenge of providing users with the ability to explore an IVE by walking. With this approach the user is redirected via manipulations applied to the displayed scene, causing users to unknowingly compensate scene motion by repositioning and/or reorienting themselves. Different approaches to

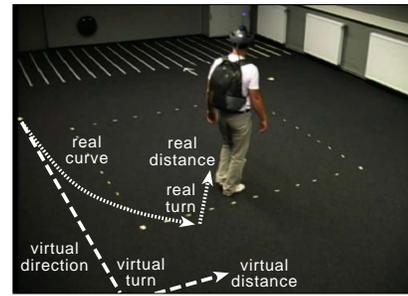


Figure 1: *Redirected walking scenario: a user walks in the real environment a different path with a different length in comparison to the perceived path in the virtual world.*

redirect a user in an IVE have been proposed. An obvious approach is to scale translational movements, for example, to cover a virtual distance that is larger than the distance walked in the physical space [Interrante et al. 2007]. With most reorientation techniques, the virtual world is imperceptibly rotated around the center of a stationary user until he/she is oriented in such a way that no physical obstacles are in front of him/her [Peck et al. 2008; Razzaque 2005; Kohli et al. 2005]. Then the user can continue to walk in the desired virtual direction. Alternatively, reorientation can also be applied while the user walks [Groenda et al. 2005; Razzaque 2005]. For instance, if the user wants to walk straight ahead for a long distance in the virtual world, small rotations of the camera redirect him/her to walk unconsciously an arc in the opposite direction in the real world. When redirecting a user, the visual sensation is consistent with motion in the IVE, but proprioceptive sensation reflects motion in the physical world. However, if the induced manipulations are small enough, the user has the impression of being able to walk in the virtual world in any direction without restrictions [Steinicke et al. 2008; Peck et al. 2008; Razzaque 2005]. Quantified analyses of how much redirection is possible in the context of game design have not been undertaken.

Walking is not only the most natural way of traveling, it is a more presence-enhancing metaphor than other navigation metaphors including “flying” or navigating by walk-like gestures [Slater et al. 1995; Usuh et al. 1999a]. There has been vigorous debate about how to best measure presence [Ellis 1997; Barfield and Hendrix 1995; Friedman et al. 2006; Meehan et al. 2002]. Due to the subjective nature of presence, it sounds reasonable to measure presence with respect to a subject’s self-reported sense of presence. For this purpose a few standard questionnaires are available [Witmer and Singer 1998; Usuh et al. 1999b; Slater et al. 1995].

In the past different approaches have been presented and examined in how far they increase a user’s sense of presence. Obviously, presence can be supported by exclusion of real world cues since these might interfere or be inconsistent with the presented VE. Furthermore, presence can be enhanced by incorporating a virtual representation of the user into the environment (a “virtual body”) [Slater et al. 1994; Slater et al. 1995], especially providing actual limb motion [Usuh et al. 2006]. In addition, multimodal feedback in a VE increases the sense of presence, in particular if not only haptic and tactile feedback [Insko et al. 2001] but also audio and olfactory stimuli correspond to events in the VE [Dinh et al. 1999]. Moreover, properties of the visual display have an impact on the user’s sense of presence [Vinayagamoorthy et al. 2004], such as a wide field of view [Arthur et al. 2000], realistic physical simulations [Uno and Slater 1997], stereoscopic display [IJsselstein et al. 2001], low latency [Meehan and Razzaque 2003; Barfield and Hendrix 1995] and also dynamic shadows of objects in a virtual environment con-

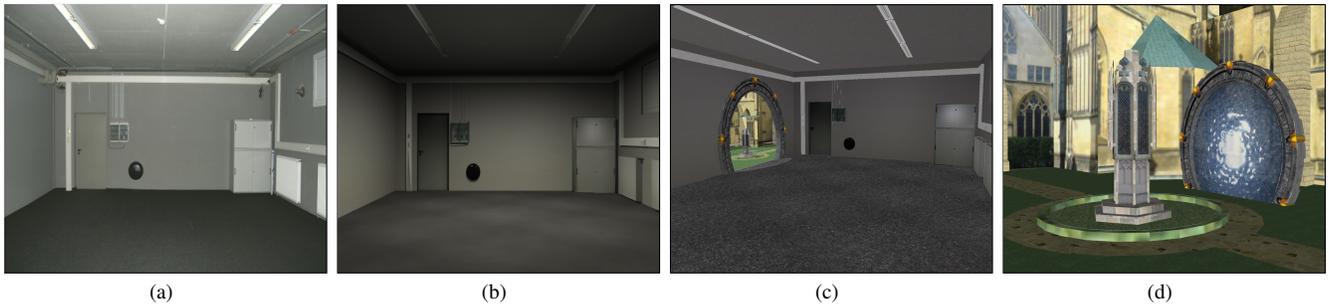


Figure 2: Images from a presence-enhancing game scenario: (a) photo of the laboratory environment, screenshots of (b) the transitional environment, (c) the transitional environment with a portal to the actual game environment, and (d) the immersive game with a portal back to the transitional environment.

tribute to a user’s sense of presence.

Apart from the intrinsic properties of the display, some work has demonstrated that the staging of the experience and introduction of users to the system can impact their subsequent sense of presence. Some projects have already used different concepts to provide a seamless transition from the real to the virtual world and in the opposite direction [Slater et al. 1998a]. Sometimes curtains in front of the laboratory are used, which block out the view to the physical surrounding [Steed et al. 2002]. Hence a conflict between the presented virtual world and the real surrounding is prevented. Slater et al. have proposed different virtual presentations in an HMD which transfer a user to another virtual world, when a HMD is put on [Slater et al. 1994]. After taking off the last virtual HMD, the user is transferred to the VE from where she was transferred before. In the games literature, the term immersion is used in a way similar to the way presence is used in the VR field. In the VR field, immersion tends to refer to a technology, whereas in the games field, immersion tends to refer to the ability of players to suspend disbelief and accepts what they perceive as reality [Laramee 2002]. The view that games necessarily require immersion has been called the immersive-fallacy by Salen & Zimmerman [Salen and Zimmerman 2004], who note that games take many forms that are not necessarily technologically immersive. Never the less, immersive VR does lend itself well to novel types of interface, and novel forms of game, so no doubt there will be more cross-over in the future.

3 Presence-Enhancing Geocaching Game

Geocaching is a high-tech treasure hunting game played throughout the world by adventure seekers equipped with GPS devices. The basic idea is to locate hidden containers, called *geocaches*¹, outdoors and then share your experiences online.

We developed an immersive version of the real-world geocaching for which we have integrated redirected walking and transitional environments.

3.1 Immersive Game Interface Setup

The physical environment within which the player moves during the game is a $10m \times 7m$ darkened laboratory room. The players wear an HMD (3DVisor Z800, $800 \times 600 @ 60$ Hz, 40° diagonal field of view (FoV)) on which the virtual game is rendered. On top of the HMD an infrared LED is fixed (see Figure 1). We tracked the position of this LED within the room with an active optical tracking system (Precise Position Tracking of World Viz), which provides sub-

millimeter precision and sub-centimeter accuracy. The update rate was 60 Hz providing real-time positional data of the active markers. For three degrees of freedom (DoF) orientation tracking we use an InertiaCube 2 (InterSense) with an update rate of 180 Hz. The InertiaCube is also fixed on top of the HMD. In the experiments we used an Intel computer (host) with dual-core processors, 4 GB of main memory and an nVidia GeForce 8800 for system control and logging purposes. Players are equipped with an HMD backpack consisting of a laptop PC with a GeForce 7700 Go graphics card (see Figure 1). A Nintendo Wii remote controller serves as input device and acoustic feedback is displayed via headphones attached to the HMD. The game is rendered using OpenGL and our own software. During the game the room is entirely darkened in order to reduce the user’s perception of the real world. All computers, including the laptop on the back of the user, are equipped with wireless LAN adapters. The entire weight of the backpack is about 8 kg which is quite heavy. However, no wires disturb the immersion and no assistant must walk beside the user to keep an eye on the wires.

3.2 Transitional Environment

Before the actual game starts, the user enters a virtual replica of the real environment, i. e., a realistic 3D model of the laboratory. This is not a novel concept and has been introduced by Slater et al. [Slater et al. 1998b] After putting on the HMD, users see the 3D model of the laboratory space which is used as transitional environment (see Figure 2(a) and (b)). Since the virtual model is a one-to-one replica of the real laboratory users could walk around and touch virtual respectively real objects such as walls, doors, or cabinets. Within this *transitional environment* users can open a context menu in analogy to a menu in a game by pressing a button on the Wii remote device. Via the menu subjects can modify the game settings such as sound volume, enabling/disabling of head-up-displays etc. Furthermore, users can open a virtual portal to the actual game environment. Such a virtual portal is displayed on one wall of the laboratory space (see Figure 2(c)). Players can see the 3D game environment through the semi-transparent virtual portal. Now, when passing the virtual portal users are transferred to the game environment and can play the game. As mentioned above the virtual wall onto which the virtual portal is displayed is located in correspondence with the physical wall, which would prevent a walk-through. Therefore, we apply redirected walking techniques, in particular motion compression approaches (cf. Section 3.3), which allow users to walk through the virtual portal with no obstacle obscuring the path in the physical world [Bruder et al. 2009; Steinicke et al. 2009].

When players want to return to the virtual replica, for example to

¹ There are more than 700,000 active geocaches around the world.

change the settings of the game, they can open a virtual portal back to the transitional environment by pressing a button on the Wii remote device. Figure 2(d) illustrates such a virtual portal in the game environment. During the game players can switch between virtual game environment and virtual replica room at any time by means of *virtual portals*.

3.3 Virtual Portals

In order to transfer players from the transitional to the game environment such that they believe to be in a new environment, we need a plausible way of travel. Inspired by TV series or movies, for instance, *Stargate*, but also 3D games such as the first-person action video game *Portal* by Valve Corporation (released in 2007), we have decided to use the concepts of virtual portals. For our setup we want to provide a compelling visualization and appearance of the portals that indicate the way from the transitional environment to the virtual world and vice versa. Therefore, we visualize the portal on one of the walls of the transitional environment instead of visualizing them as floating objects within the room. As illustrated in Figure 2(c) the 3D game environment is visible through the semi-transparent portal. The portal can be placed in any location in the virtual world. By masking the area of the portal in the OpenGL stencil buffer, a different virtual world can be rendered in the fragments showing the portal. Clipping against the portal is required to prevent that objects of the world behind the portal stick out of the portal. Optionally, we blend a bumping effect to indicate that a virtual world with a different context is behind the portal (see Figure 2(d)).

As mentioned above, at the beginning of the experiment physical walls of the lab and virtual walls of the transitional environment are aligned in correspondence. Hence, a virtual portal on the wall could not be entered without additional effort. Therefore, after the user has indicated to open a portal in the transitional environment, for example by pressing a button on an input device, we apply motion compression approaches. We scaled the movements with a factor of 1.2. Thus, one meter in the physical space is mapped to 1.2 meters in the transitional world. According to Steinicke et al. [Steinicke et al. 2008] such a manipulation cannot be noticed reliably by a walking user. Hence, when subjects move to the virtual portal, they have only walked 80% of the distance in the physical world and are still far away from the laboratory wall. Now the user can pass the portal, where a physical wall has been before. Thus we are able to display a portal on the virtual wall in the transitional environment through which subjects can enter the virtual world. When subjects re-enter the transitional environment via the portal, we apply the same concept again.

When the player passes the virtual portal of the virtual replica room, she enters an urban 3D model (see Figure 2(c) and (d)). Figure 3 shows a typical view of a player in the virtual geocaching game. We use a geo-referenced 3D model of our local city in which users can walk virtually. The objective of the virtual geocaching game is to go to preassigned GPS positions by means of walking. In order to support the user to orient in the virtual city model, a virtual compass and the user's current position can be rendered on a head-up-display to indicate the user's virtual position and orientation in real-time. In order to avoid problems of collision with walls in the physical space, we have to redirect players (cf. Section 4).

4 Psychophysical Walking Experiment

The objective of this experiment is to support omni-directional and unlimited walking for first-person games, in particular games with a geospatial context. As mentioned in Section 1 we need to redirect players in the laboratory environment on a circular arc (while they



Figure 3: The view of a player in the virtual geocaching game. The application was also used for the psychophysical experiment and the evaluation of transitional environments.

believe to walk straight) in order to keep them in the tracked space. In order to ensure that players do not observe that they get manipulated, we have performed a psychophysical experiment in which subjects had to *discriminate* the walk direction, i. e., subjects had to judge whether the walked curve is bent to the left or to the right. The visual stimulus we used in our experiment was generated by the geocaching game (see Figure 3).

9 male and 3 female (age 19-50, σ : 25.54) subjects participated in the study. Most subjects are students or members of the departments (computer science, mathematics, psychology, geoinformatics, and physics). All have normal or corrected to normal vision; 8 wear glasses or contact lenses. 2 have no game experience, 4 have some, and 6 have much game experience.

4.1 Material and Methods of Discrimination Experiment

In contrast to [Steinicke et al. 2008] we use the method of constant stimuli in a *two-alternative forced-choice* (2AFC) task rather than simple yes/no-judgements which potentially involve bias. In the method of constant stimuli, the applied gains are not related from one trial to the next, but presented randomly and uniformly distributed. The subject chooses between one of two possible responses, e. g. “Was the physical path curved to the left or to the right”; responses like “I can’t tell.” were not allowed. In this version, when the subject cannot detect the signal, he/she must guess, and will be correct on average in 50% of the trials. The gain at which the subject responds “left” in 50% of the trials is taken as the *point of subjective equality* (PSE), at which the subject perceives the physical and the virtual movement as identical. As the gain decreases or increases from this value the ability of the subject to detect the difference between physical and virtual movement increases.

We define the *detection threshold* (DTs) for gains larger than the PSE to be the value of the gain at which the subject has 75% probability of choosing the “right” answer correctly and the detection threshold for gains smaller than the PSE to be the value of the gain at which the subject chooses the “left” response in only 25% of trials (since the correct response “right” was then chosen in 75% of the trials).

In this experiment we analyze sensitivity to *curvature gains* which enforce the user to walk a curve in order to stay on a straight path. A curvature gain $g_{C[w]}$ applied to a virtual direction of walk w denotes the resulting bend of the path in the real world. For example, when the user moves straight ahead, a curvature gain that causes

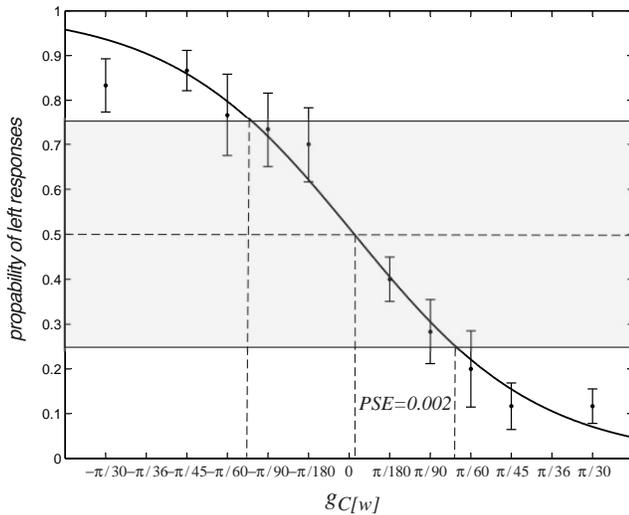


Figure 4: Pooled results of the discrimination of path curvature. The x-axis shows the applied curvature gain which bends the walked path either to the left ($g_{C[w]} < 0$) or to the right ($g_{C[w]} > 0$), the y-axis shows the proportion of subjects' "left" responses.

reasonably small iterative camera rotations to one side forces the user to walk along a curve in the opposite direction in order to stay on a straight path in the virtual world. This curve is determined by a circular arc with radius r , and $g_C := \frac{1}{r}$. In case no curvature is applied it is $r = \infty \Rightarrow g_C = 0$, whereas if the curvature causes the user to rotate by 90° clockwise after $\frac{\pi}{2}$ meters the user has covered a quarter circle with radius $r = 1 \Rightarrow g_C = 1$.

On the same level as the subject's eye we added a green dot to the scene, which turned red when the subjects had walked 7m towards it. While the subjects walked, we rotated the scene to either side with a velocity linked to the subject's movement velocity. The scene rotated by 5, 10, 15, 20 and 30 degrees after 5m walking distance. This corresponds to a curvature radius of approximately 57.3, 28.65, 19.10, 14.32 and 9.55m respectively. Hence, the curvature gains were given by $g_{C[w]} = \{\pm \frac{\pi}{30}, \pm \frac{\pi}{45}, \pm \frac{\pi}{60}, \pm \frac{\pi}{90}, \pm \frac{\pi}{180}\}$. We presented the gains each 8 times in a randomized order.

The rotation of the virtual camera started after subjects had walked the 2m start-up phase. After subjects walked a total distance of 7m in the virtual world, the screen turned white and the question of the discrimination task appeared. The subject's task was to decide whether the physical path was curved to the left or to the right by pressing the corresponding "left" or "right" button on the Wii controller. Then the subject was guided to a new starting position.

4.2 Results of Discrimination Experiment

Figure 4 shows the mean probability for the response that the physical path was curved to the left against the curvature gains $g_{C[w]}$. Error bars indicate the standard error. The PSE for the pooled data is $\frac{\pi}{1423} = 0.002$. At this PSE the subjects have in fact walked a circular arc with a radius of 453.14m, and rotated by less than one degree after 5m. For individual subjects the PSE varied between $-\frac{\pi}{162.51} = -0.019$ and $\frac{\pi}{60.90} = 0.052$ (8 subjects with PSE above or equal, 3 less than 0.0022). The detection thresholds are given by the stimulus intensity at which subjects correctly detect the bending of the path 75% of the time. Detection thresholds were $g_{C[w]} = \pm 0.045$, i. e., $g_{C[w]} = -\frac{\pi}{69.23}$ for leftward bended paths and $g_{C[w]} = +\frac{\pi}{69.23}$ for rightward bended paths. At these threshold val-

ues, subjects walked physically a circular arc with a radius of approximately 22.03m. Within this range of these detection thresholds subjects cannot estimate reliably if they walk straight or a curve.

In summary, if the laboratory space covers an area of approximately 40m \times 40m, it becomes possible to guide the user on a circular arc in the physical world, while the user walks straight without restriction in the VE. Hence, a physical environment within an amusement park can be constructed where several gamers can walk unlimitedly in any directions as long as they are redirected according to the results mentioned above.

5 Evaluation of Transitional Environment

Now that we are able to allow players to walk through an arbitrary environment we wanted to verify whether or not a gradual transition to the virtual game environment further increase the user's sense of presence. Therefore, we have performed an evaluation based on the subject's self-reported sense of presence according to the SUS presence questionnaire.

7 male and 3 female subjects (age 23-53, σ : 32.6) participated. 3 subjects had no game experience, 4 subjects had some, and 3 subjects had much game experience. Four of the subjects had experience with walking in VR environments using HMD setups. Subjects were allowed to take breaks at any time. Some subjects obtained class credit for their participation. The total time per subject including pre-questionnaire, instructions, training, experiment, breaks, and debriefing took 2 hour and was performed within two days.

Half of the subjects have performed the experiment first with and then without transitional environment, whereas the others have performed the experiment in reversed order.

5.1 Material and Methods for Evaluation of Transitional Environments

In order to verify if a transitional environment increases the subject's sense of presence we have conducted the experiment with two conditions. With the first condition (RW) subjects started in the virtual city model when they turned on the HMD, so they started the virtual geocaching game directly from the real world. With the second condition (TW) subjects were transferred to the virtual city model via a transitional world. Hence, after having been equipped with the HMD, subjects saw a realistic model of the laboratory space used as transitional environment and could enter the virtual city model after opening and passing a virtual portal. In contrast to the situation in the virtual city model subjects could talk with the experimenter while they were walking through the transitional environment. We allowed this communication to indicate that they are still not in the virtual world. Since the virtual model is a 1-to-1 copy of the real laboratory users could walk around and touch virtual respectively real objects such as walls, doors, or cabinets. After approximately 5 minutes we told subjects that they had to press a particular button on the Wii remote device in order to open a portal to the virtual world. The portal was displayed on one wall of the laboratory space (see Figure 2(c)).

After walking through the portal (as described in Section 3.3) subjects were transferred to the virtual city model and the portal closed behind them. When a subject pressed the home button on the Wii remote device another portal to the virtual replica room appeared and the subject could walk through this portal back to the virtual laboratory (see Figure 2(c)). Sounds related to the virtual city model (ambient city noise) were turned off in the virtual replica and subjects could talk to the experimenter again. The virtual world was

the same in both conditions no matter whether subjects entered directly or after they moved through the transitional environment first. We ensured that subjects stayed the same timespan (10 minutes) in the immersive virtual environment for both conditions.

5.2 Results for Evaluation of Transitional Environments

5.2.1 Subjective Presence

In order to analyze if the gradual transition to the virtual world increases the subject's sense of presence we evaluated the subjects' self reports. We used the Slater-Usuh-Steed (SUS) presence questionnaire, which has been developed over a number of years in several experiments at the University College London [Usuh et al. 1999b]. The questions are based on variations of three themes, i. e., sense of being in the VE, the extent to which the VE becomes the dominant reality, and the extent to which the VE is remembered as a place. Subjects had to rate each of six questions on a 1-to-7 Likert scale (where 1 means no presence, and 7 means high presence). In the following s_{cond} refers to a user's self-reported sense of presence under condition $cond$, with $cond = TW$ for the condition with and $cond = RW$ for the condition without transitional environment.

Subjective evaluation of the condition without transitional environment shows that subjects had only a slight sense of presence s_{RW} . This is indicated by the average score of 3.63 ($\sigma = 0.70$) of the SUS questionnaires; no high rates, i. e., 6 or 7, were chosen by the subjects. We compare this score with the transitional world condition later. As mentioned above we were not focused on the absolute sense of presence, but on the sense of presence in comparison to situations when subjects were in the transitional environment first. Thus, we want to examine whether the scores for the SUS questionnaires for both conditions vary significantly and the low degree of presence in both conditions is dispensable.

In comparison to the first condition, subjective evaluation of the virtual geocaching with the transitional environment condition shows that subjects still had a slight, but statistically increased sense of presence s_{TW} . The virtual geocaching were identical in both conditions, but subjects had to walk through a transitional environment in the condition TW. The increase of the subject's sense of presence s_{TW} is underlined by the average score of 4.31 ($\sigma = 0.57$) of the SUS questionnaires; 3 subjects answered three questions with 6. This is an increase of the subject's sense of presence of 19%. On average each subject increases her SUS scores by 0.68 ($\sigma = 0.59$).

Figure 5 shows the results for condition RW and TW for all subjects. No subject reported a lower sense of presence when entering the transitional environment first.

5.2.2 Behavioral Presence

We have also considered the subjects' behaviors by means of videos, which we have captured during the experiment, in a post-session a few days later. Due to our redirection concepts subjects could walk unlimitedly in the VE. We reviewed their way of walking. We have measured their speed, but also considered other noticeable problems while they were walking, such as unnatural walking, walking with arms reached out, stumbling and so on. One naive observer had to view different video sequences of the experiment days after the experiment took place. This observer did not know if the shown sequence was from the experiment with condition RW or condition TW, i. e., if the shown subjects had been in the transitional environment first or if they had started in the virtual world directly. The observer had to classify the way of walking by means of considering walking speed, patterns, reliability, overall impression and relation between walk and view direction. Each aspect

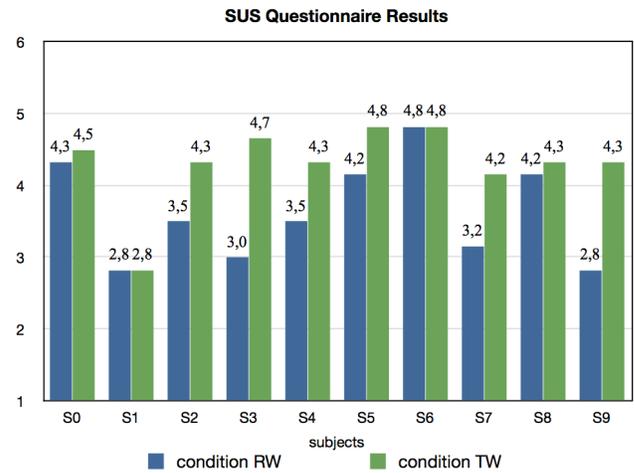


Figure 5: Results of the SUS questionnaires for individual subjects S0,...,S9 for condition RW and TW.

had to be classified according to three levels such as very slow - slow - normal, or unnatural - almost natural - natural etc. The evaluation of the ways of walking of the different subjects shows that subjects partly feel uncomfortable and insecure, while walking in the HMD environment. The viewer classified the walk speed with this condition with 1.75 on average, which corresponds to very slow to slow walking. The pattern of walking was evaluated as 2.1, where 1 corresponds to walking with caution, and 3 corresponds to safe walking. The overall impression of the walk to the viewer was 2.3 on average, which corresponds to almost natural walking. Two subjects reached out their arms almost constantly. When considering the view direction the viewer noticed that subjects looked to the direction they walk most of the time. He classified this by 2.0, where 1 corresponds to always looking at heading direction and 3 corresponds to free look-around. 4 subjects tried to talk to the experimenter during the experiment, although we told them that talking to the experimenter while they are in the VE is not possible.

In the same way to the results for the condition RW we reviewed the subjects' behaviors on the captured videos for the condition TW. The evaluation of the way of walking for the different subjects shows that subjects feel more comfortable and safe, while walking in the HMD environment, when they have entered via a transitional environment. The same viewer classified the walk speed in this condition with 2.1 on average, which corresponds to slow walking. The pattern of walking was evaluated as 2.3, where 1 corresponds to walking with caution, and 3 corresponds to safe walking. The overall impression of the walk to the viewer was 2.5 on average, which corresponds to an impression between almost natural walking and natural walking. When considering the view direction subjects steered less to the direction they walk in contrast to condition RW. The viewer classified this by 2.6, which corresponds to rather free look-around during walking. Hence, after approximately 5 minutes walking in the transitional environment, which subjects have entered before they use the HMD, they seem to move faster and more natural in comparison to the situation when they start the VR experience directly in an entirely virtual world. 3 subjects tried to talk to the experimenter while in the virtual geocaching game. This number has decreased although in this condition subjects were allowed to talk to the experimenter during the time when they were in the transitional environment. 6 subjects started to talk to the experimenter when they re-entered the transitional environment after the virtual geocaching. When entering the VE through the virtual portal, all subjects walked carefully and decreased speed. 4 reached

out their arms when walking through the portal. In summary, from an extraneous perspective subjects move more comfortable and safe through the VE when they have visited a transitional environment first.

6 Discussion

According to the experiment described in Section 4, if the laboratory space covers an area of approximately 40m × 40m, it becomes possible to guide the player on a circular arc in the physical world, whereas the user can walk straight in the VE unlimitedly. We add a security area within the tracking region. When the player has left this security area we redirect her with respect to the angle of the intersection of her current walk direction and the border of the tracking region either to the left or to the right such that she will return to the security area.

We have performed further questionnaires in order to determine the users' fear of colliding with physical objects. The subjects revealed their level of fear on a four point Likert-scale (0 corresponds to no fear, 4 corresponds to a high level of fear). On average the evaluation approximates 0.6 which shows that the subjects felt safe even though they were wearing an HMD and knew that they were being manipulated. Further post-questionnaires based on a comparable Likert-scale show that the subjects only had marginal positional and orientational indications due to environmental audio (0.6), visible (0.1) or haptic (1.6) cues.

The evaluation of transitional environments has shown that such a gradual transition to the game environment has the potential to increase the player's sense of presence. Subjective comments show that subjects of this experiment feel a higher sense of presence with the condition TW, i. e., when they have entered the virtual world via a transitional environment. A statistical analysis has shown that the increase of the SUS scores from 3.63 to 4.31 is statistically significant ($p = 0.05$). As mentioned above the strongest impact of the usage of a transitional world could be manifested by the subjective measurements as well as subjective comments after the experiments. For instance, one subject remarked:

"After walking through the wormhole, I really got the feeling of being transferred to another world."

This was a typical comment of the subjects. The metaphor of a virtual portal supports their notion of being transferred to another world. Some subjects noticed that acoustics were very important when they left the transitional world and entered the virtual one. In the transitional world we neglected acoustics, whereas in the virtual world ambient city noise was displayed.

The behavioral measures show that subjects move faster, more safely and naturally through the VE, when they entered via a transitional environment. According to the evaluation of the observer no subject moved more slowly or unsafely after they have walked in the transitional world. Two subjects remarked that it was definitely easier for them to orient themselves and that they had a better feeling for distance estimation in the VE. In general, subjects have remarked that estimation and performance of motions have improved after they have visited the transitional environment. This is also underlined by the increased walking speeds of the subjects for condition TW, i. e., when they have visited the transitional environment first.

We were surprised about the positive feedback about the application of virtual portals. The subjective comments have shown that subjects really preferred the usage of portals, which transferred them to the virtual world.

7 Conclusion and Future Work

In this paper we have presented a presence-enhancing user interface for immersive first-person gameplay. For this setup we have quantified how much players can be guided on a circular arc, and we have analyzed the usage of transitional environments via which player could enter a virtual world. The results of the psychophysical experiments have shown that players can be guided on circular arc with a radius of 22.03m whereas they believe themselves to be walking straight. Within the range of these detection thresholds subjects cannot estimate reliably if they walk straight or on a curve. In the evaluation of transitional environments we focused on the question whether the usage of transitional environments affects the user's sense of presence in the virtual environment or not. The self-reports of the participants show a significant increase of the subject's sense of presence. Furthermore, subjects seem to move more safely and naturally when they have accustomed themselves to the VR system setup in a familiar environment first. We have shown that transitional environments enhance the level of feeling present in the game. The benefits were shown for an example game, and we are confident that the results even hold for other first-person games.

Many factors may have a certain impact on the results of the presented experiment and further experiments need to be conducted. Moreover, in future experiments we will consider whether the usage of a transitional environment improves distance estimation or user movement in general. It has been shown that distance estimation in virtual environments which are known from the real world is better than distance estimation in unknown environments. Perhaps such skills could be transferred to the virtual world, when users enter a game environment via a virtual replica of a known environment.

To summarize the results, we suggest using redirected walking and transitional environments for immersive games since they have great potential to enhance gameplay, while portals to the virtual world can further improve the VR experience.

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