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Panoramic Video Techniques for Improving Presence in Virtual Environments

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Abstract

Photo-realistic techniques that use sequences of images captured from a real environment can be used to create virtual environments (VEs). Unlike 3D modelling techniques, the required human work and computation are independent of the amounts of detail and complexity that exist in the scene, and in addition they provide great visual realism. In this study we created virtual environments using three different photo-realistic techniques: panoramic video, regular video, and a slide show of panoramic still images. While panoramic video offered continuous movement and the ability to interactively change the view, it was the most expensive and time consuming to produce among the three techniques. To assess whether the extra effort needed to create panoramic video is warranted, we analysed how effectively each of these techniques supported a sense of presence in participants. We analysed participants' subjective sense of presence in the context of a navigation task where they travelled along a route in a VE and tried to learn the relative locations of the landmarks on the route. Participants' sense of presence was highest in the panoramic video condition. This suggests that the effort in creating panoramic video might be warranted whenever high presence is desired.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Virtual Reality—Presence, User Studies and Evaluation, Interaction

1. Introduction

Conventionally, virtual environments (VEs) are created by literally building a 3D model of every object in the scene. Thus, creating a realistic VE can involve a lot of detailed manual modelling work and requires costly high-end rendering hardware to support real-time animation of multiple moving objects [PC08]. However, in most cases, users only want to interact with a small number of foreground objects. Instead of using a VE with synthetic objects, the environment could also be created with images captured from a real environment. The most important benefit of the image-based approach is that the required amount of human work and computation are independent of the amounts of detail and complexity that exist in the scene. This approach also provides a photo-realistic view of the environment without requiring special hardware systems or manual modelling work. Image based techniques basically use sequences of images or videos from a real site in different ways to form the realistic background scene of a VE or to simulate a type of interaction with the VE such as looking around, walking, or flying in it.

VEs can be evaluated in different ways depending on the purpose for which they were created. In the current study, we focussed on measures of presence and navigation, which are commonly used due to their potential relevance for applications and overall user experience (for reviews on presence, see, e.g., [IDRFA00, IJs04]). While the presence measures are presented here in detail, the navigation aspect is described in detail in [Dal11].

In this paper we describe the creation of VEs using three different common image based techniques: panoramic video, regular video, and panoramic slide shows. While these techniques have been tested before in isolation, the current study provides a direct technical and perceptual comparison of these three techniques. To this end, we compared participants' subjective sense of presence achieved during navigation in each of these VEs. Finally we draw conclusions about how panoramic views and video can improve the sense of presence experienced by participants.

1.1. Photo-realistic Techniques for Creating Virtual Environments

A very recent and useful example of image-based VEs for navigation is Google Street View [Map10]. Google's approach is to capture panoramic images at specific distances along the streets being studied. Using Google Street View tools, travelling along streets occurs by stepping from one panoramic position to the next. At each position, users can smoothly change their view direction up to 360 degrees horizontally and 290 degrees vertically. Miller et al. [MHC*92] used a similar approach to create a Virtual Museum. At selected points in the museum, a 360-degree panning movie was rendered to let the user look around. Chen [Che95] captured panoramic images at all the intersection points on a grid map of an environment. Then, he composed a VE in which walking was accomplished by "hopping" to different panoramic points on the grid. In all these examples, using still images and moving in discontinuous consecutive hops results in a lack of realism for the user. When neither objects nor the observer needs to move, however, these panorama-based VE's can work very well. If there are moving objects, or to have a smooth navigation experience, the sequence of images can be replaced by video as was done in the current study.

Moving the camera while capturing panoramic images creates panoramic video at different frame rates. Neumann, Pintaric, and Rizzo [PNR00] recorded panoramic videos in an outdoor mall with the camera in a static position and in different lighting situations as well as on a truck moving at speeds between 0-40 mph. Similarly Sato, Kanbara, Yokoya, and Ikeda [SKYI04], acquired movies of outdoor scenes with a multi camera system mounted on a car moving at a constant speed. In other research, Tang, Wong, and Heng [TWH02] proposed a software system called "The Immersive Cockpit" which stitched together multiple video streams captured from ordinary CCD cameras installed in working sites, and recreated a panoramic immersive view at the remote site. Ono et al. [OOK*05] captured panoramic videos for their driving view simulation system by using a vehicle whose roof was equipped with nine video cameras and ran along a targeted road. Peri and Nayar [PN97] proposed a real time software system called omniVideo that can generate multiple perspective and panoramic video streams from an omnidirectional video stream. Kimber, Foote, and Lertsithichai [KF01] proposed a virtual reality system called FlyAbout, which used spatially indexed panoramic video for navigation simulation. Panoramic videos were captured from continuous paths by moving an ominidirectional camera along those paths.

1.2. Evaluation of Photo-realistic Virtual Environments

Previous research demonstrated that panoramic images and videos alone or in combination with other techniques (mostly non photo-realistic) enhance participants' engagement and their awareness of the environment (e.g. [MGvdB09] , [RSPA*05], and [NGPD90]). These findings suggest that panoramic images and videos could have the potential to provide a high sense of presence although so far there is little research in this domain. Moreover, it is still largely unknown which features of the panoramic image or panoramic video techniques contribute to what degree to the observer's sense of presence. While many earlier research projects compare photo-realistic environments with non-photorealistic environments, the literature still lacks studies that can comprehensively compare environments created using different photo-realistic techniques. In this study we have contributed to this research area by comparing three different photo-realistic techniques regarding their capability to support sense of presence in VE users.

1.3. Sense of Presence in Photo-realistic Virtual Environments

Presence has always been a concern in the development of virtual environments. There have been several attempts to provide a scientific and practical definition for it using different perspectives and theories. Ijsselsteijn, de Ridder, Freemen and Avons [IDRFA00] distinguished between physical presence, which is the sense of being physically located in a virtual space, and social presence, defined as the feeling of being together (see also [IJs04]). Most often the VE literature conceptualizes physical presence through non-mediation: people are usually considered present in an immersive VR when they report a sensation of being in the virtual world rather than operating it from outside [SvdSKvdM01]. A well-known perspective on the nature of presence, which is the basis for several techniques for measuring presence, distinguishes between subjective presence as a person's judgment of being physically present in a remote environment, and objective presence, as the possibility of effectively completing a task in a virtual environment [Sch95]. Another commonly used definition is the degree to which a person feels suspension of disbelief in what he or she is experiencing [SvdSKvdM01]. Slater and Wilbur [SW97] only applied the term presence to subjective phenomena. In this perspective, presence is defined as the subjective sensation of being in a VE.

The extent to which a VE provides a sense of presence for its users is a common evaluation criterion. Present measurement techniques can be categorized by the type of data recorded: **Subjective measurements** rely on participants' introspective judgements of their sense of presence. Presence has been subjectively assessed using post-test rating scales (like the Continuous Presence Assessment method [IDRFA00]), or measuring breaks in presence [SS00]. Post-test rating scales or subjective questionnaires are the most convenient and commonly used method for measuring presence. These subjective ratings are argued to be the primary method of measuring presence because presence is essentially a subjective sensation. Witmer and Singer's PQ [WS98], the Igroup presence questionnaire [SFR99] and the ITC sense of presence inventory [LFKD01] are among the most well known presence questionnaires formed on the basis of different theoretical views on the concept of presence. **Objective measurements** assess participants' sense of presence based on participants' behaviours, or performance in specific tasks. The most well known objective measurements of presence are behavioural measurements (e.g. reflexive responses) [She96], dual task measurements (e.g. measuring reaction time to a secondary task) [WS98, BW93] and the adjustable distraction method (i.e. measuring minimum amount of an external stimulus required to break presence) [NK10].

Different measures are appropriate for different purposes. Objective measurements, however, are difficult to implement and easily misinterpreted. Well known presence rating scales such as Igroup Presence Questionnaire [SFR99] have been shown to be fairly consistent. Hence, we decided to use a questionnaire-based subjective measure of presence in the current study. We realize that others may wish to take other approaches depending on their spoecific purpose.

2. The Problem

Different types of photorealistic techniques vary in terms of the cost and amount of effort that is required for their implementation. Depending on the level of interactivity to be provided, the difficulty involved in creating a photo-realistic virtual environment can range from very simple to very difficult and/or costly. The simplest situation involves recording a sequence of regular images (typically with a limited field of view (FOV) of less than 90 degrees) along specific paths in an environment. In this case, no interactivity in terms of view alternation or path selection is offered. In addition, the locomotion is discontinuous and hardly resembles the natural mode of transportation. Substituting the sequence of images with linear video or substituting single frame images with panoramic images can provide more realistic locomotion. Finally, the most difficult VE model to implement is one which gives the user the ability to navigate in any direction and at any desired speed with the ability to change their view at any time during the navigation. It is, however, practically impossible to capture all the possible perspectives along all the possible paths in an environment. The idea of panoramic video is that it allows for all possible view alternations from a specific viewpoint located on a specific path that is already captured. Therefore, if it is captured with sufficient granularity of directional choices, and played at interactively selected frame rates, it can ideally lead to the creation of a highly naturalistic VE. Practically though, with the current technology, creating long, high quality panoramic videos requires expensive, special cameras and takes a considerable amount of time, computer memory, and manual work. Also, a highly interactive VE requires that many sequences of panoramic video be captured.

Considering all the effort involved in creating panoramic videos, it is important to investigate if one of the simpler photo-realistic techniques such as image sequences or regular videos can efficiently substitute for panoramic video in a specific application area. To make a contribution to this research question, in this paper we describe the development and evaluation of three different VEs created by panoramic videos, panoramic image sequences, and regular video. Our VE prototypes take the form of virtual tours with restricted interactivity (e.g., constant speed and predetermined paths). They are captured from part of the Surrey Central area in suburban Vancouver, BC, Canada, using our prototype system. These virtual tours are similar in terms of being photo-realistic and having the same quality of images. However, they vary in terms of the type of locomotion technique they offer, and the implementation costs they require as follows:

Panoramic slide show: locomotion in this virtual tour involved abrupt transitions between spatially separated locations and was simulated by displaying a slide show of panoramic images captured at these locations in the environment. The traveller could navigate in the virtual tour by hopping from one position to another and at each position could look around by smoothly rotating their view in the associated panoramic image (c.f. Google Street View).

Regular video: in this virtual tour locomotion was simulated by displaying a 15 fps front facing video recorded while moving through the environment. The video was a regular video with a limited FOV of approximately 90 degrees horizontally. The resulting navigation was smooth and continuous but the view was front facing and it was not possible to change it during the locomotion.

Panoramic video: this technique was similar to the last one except that the recorded videos were panoramic with a 360-degree horizontal FOV. In this version of the virtual tour, not only was the movement continuous and smooth, but also, the viewing direction could be smoothly changed at any point during the navigation.

This study contains two main parts: (1) the implementation of the photo-realistic virtual tours; and (2) the evaluation of these virtual tours in terms of how effectively they support a sense of presence in participants.

3. Prototype System

Here, we describe the prototype system we developed for making a virtual environment using panoramic video; this can be utilized for implementing highly interactive video-based virtual environments. This system is composed of three main components: (1) the panoramic video capturing system, (2) software for creation of panoramas and the virtual environment, and (3) an interactive chair-based interface which is provided to make the interaction more natural.

3.1. Panoramic Video Capturing System

A system comprising eight regular video cameras connected to a pc was designed and implemented so that the combined FOV of the cameras covered the whole 360-degree horizontal FOV (see Figure 1(a)). Cameras were Sony model CXD3172AR, each with a 90 degrees horizontal FOV. Cameras were placed at a uniform height on the outer surface of a cylinder. The cylindrical box contained necessary electronic elements for powering the cameras and connecting them to the PC. Consecutive cameras on the cylinder had 45-degrees difference in their view direction and 22.5 degrees overlap in the view angle. This ensured that the resultant images had enough overlap to be stitched to each other. Using BNC cables, all the 8 cameras were connected to a video card that could handle multiple video inputs and was placed in a regular Windows PC. A software program worked with the video card to control the camera capture settings such as video frame rate, resolution, and compression, and managed synchronization of cameras. The PC was also placed on a cart with pneumatic tires. Two 12-volt batteries and an inverter (12v dc to 120 v ac) were also placed on the cart to power the cameras and PC during mobile video capture.

Although the cameras were individually capable of capturing video at 15 fps and 640 X 480 pixel resolution, when they worked together the optimum resolution and frame rate decreased to 422 x 316 pixel and 10 fps, respectively. This was because of the limitations in the input data bandwidth of the video card.

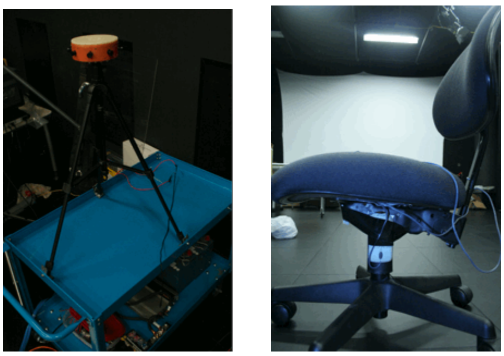

Figure 1: *(a) Panoramic video capturing system. It includes 8 cameras mounted on a trolley which carries a PC and batteries for powering the cameras and the PC. (b)Interactive chair interface for supporting body based rotations in the panoramic view; a regular office chair has beed modified by attaching an optical mouse to its rotating pivot. The mouse detects user's rotations in 360 degrees and the display system displays the corresponding part of the panoramic view.*

3.2. Software for Developing Virtual Environments from Panoramas

After the video was captured and stored in the computer a Java program performed the following operations on the video files in order to prepare them for the stitching process:

- Video streams were split into still frames,
- Frames were grouped so that the synchronized frames of all the cameras were collected in a single directory.

Using a manually produced template panorama, the PT-Gui software program [PTG10] stitched images in each directory to each other and formed a single panoramic image for every time step. Further, panoramic still frames were sequenced and encoded into a Flash movie. The final step was to use ActionScript code to map the flash movie onto a 3D surface (i.e., similar to the inside surface of a cube, but not with clear edges). This mapping removed the intrinsic distortions found in panoramic images such as inclined horizontal edges. The ActionScript code also controlled the projection parameters such as pan, tilt and zoom.

3.3. Interactive Chair Interface

In order to provide an intuitive interaction with the virtual tour system, a rotating office chair was modified so that users could change their view in the panorama by rotating the chair while they were sitting on it (see Figure 2(b)). This is implemented by attaching an optical mouse to the central rotating pivot of the chair to detect the chair's relative direction of rotation and to match the view of the panorama with the mouse cursor position. A user could sit on this chair having a laptop placed on his/her lap on top of a laptop holder that fixed the laptop in place.

4. Research Methods and Experiment

4.1. Research question and Hypothesis

The study was designed to investigate whether a virtual tour implemented using panoramic video offers a greater sense of presence in participants compared to the virtual tours created using simpler techniques such as regular video or a panoramic slide show. In other words, this study aims to answer the following questions: (1) how does continuous movement (offered by video) vs. discrete movement (offered by a slide show) in a virtual tour affect participants' sense of presence? And (2) how does the ability to change the view direction (offered by panoramic views) during navigation in a virtual tour affect participants' sense of presence?

A VE that provides more sensory modalities is expected to increase the sense of presence [Ste92, WS98]. More sensory modalities are involved in interacting with the panoramic views, as participants have both visual and body based senses involved when changing their view. Hence, the panoramic conditions were expected to increase presence

[Ste92, WS98]. Participants are also required to devote more attentional resources to control a larger visual area and physical rotations in the panoramic conditions. Devoting more attentional resources to the VE has been shown to increase participants‘ sense of presence [BH95, RKD04, WS98]. Moreover, active user motion was involved in the interaction with the panoramic views, which has been demonstrated to increase the sense of presence [WS98]. All these facts have led us to hypothesize that panoramic views and the ability to change the viewing direction contribute to a greater sense of presence.

On the other hand video has a natural update rate (15 frames per second video) compared to the slide show (one frame per 3 seconds); slow update rates would remind participants of the artificial nature of the virtual environment [Ste92, WS98]. Also, motion of the components of the environment and the visual flow is captured in the video, which has been shown to increase presence [WS98]. Therefore the update rate and environment‘s motion offered by video might contribute to a greater sense of presence. As panoramic video had the benefits of both panoramic view and video as discussed above, we expected panoramic video to grant a higher sense of presence compared to the other two conditions; and we formed our formal hypothesis as:

> Participants‘ average subjective sense of presence is greater during navigation in the panoramic video tour than in the regular video and slide show tours.

The independent variable of the study was the type of virtual tour and the dependent variable was the subjective sense of presence perceived by the participants.

4.2. Participants

Our participants were 18 adults, nine females and nine males, with age ranging from 23 to 40 years old. They were recruited on the Surrey Campus of Simon Fraser University. Therefore, our participants were mostly undergraduate and graduate students who were interested in the study or agreed to participate in the experiment in exchange for a nominal payment.

4.3. Experimental Materials and Settings

In order to prepare an appropriate and valid experimental design to answer our research questions we had to consider several issues regarding the type of environment from which we captured our videos and the way we collected video and images.

- **Environments** We selected three regular residential environments from the area close to the SFU Surrey campus. The three environments were similar in terms of their general environmental look, the shape of the traversed routes, the number of turns in the routes, and the angles of each turn.
- **Video and Image Materials** Using the camera system described in Section 3.1, we captured videos of about five minutes length from each of the environments by pushing the cart containing cameras down the selected routes at a speed of about 2-3 m/s for the straight paths and 1-1.5 m/s for the turns. Virtual tours using all the three different locomotion techniques, panoramic video, regular video and slide show, were created for every environment. For the panoramic slide show, video frames were sampled at 3-second intervals producing 1 panoramic image at about every 6-9 meters distance during the straight paths and about every 3-4.5 metres during the turns. The tighter sampling for turns allowed participants in the panoramic slide-show condition to know there is a turn, as there is no optic flow indicating it. For regular video, 90 degrees (horizontally) of the straight-ahead view of the panoramic video was cut rather than using the video stream from the single forward-facing camera. This ensured the consistency of the image quality in all the conditions as the stitching traces appeared in regular video too. For all conditions the vertical FOV was about 100 degrees.
- **Experimental Settings** Using black drapes to block external light or distractions an immersive dark cubical space was built as the platform for the experiments. In this small cubical space participants sat on the interactive chair and with a laptop and a laptop holder on their laps. They watched the videos on the laptop screen and changed their view angle in the panoramic videos or the slide shows by rotating their chair.

4.4. Experimental Design

We designed a within-participant experiment so that all the participants were exposed to all three experimental conditions. For handling the possibility of one condition affecting or carrying over to another, we used a completely counterbalanced design approach. Therefore, each of the six possible orders of the three conditions was tested with three participants. Different environments were also randomly assigned to different locomotion techniques, so that, different participants could experience a specific locomotion technique in different environments.

For all conditions navigation was partially passive in that users could not control the speed of navigation, choose their path, or make stops. Also, it was only possible to go forwards, not backwards. Basically, for video conditions participants watched the video of moving forward and for slide show condition they watched the transition of panoramic images moving forward. Each image was displayed to the participant for three seconds. For panoramic video and panoramic slide-show conditions, participants could freely change their view and look around while watching the forward moving video or slide show. We explained this situation to our participants by using the wheelchair passenger metaphor: they imagined sitting in a wheelchair being pushed down the streets at a fixed speed. During this wheelchair ride they could look around in panoramic conditions. In this way we kept the amount of time participants spent in each condition equal so as not to let the time confound the effects of our independent variables on the results.

The other metaphor we explored was that of a "tour", where our participants were carried as passengers around the virtual environment and thus were given a tour of a remote site. They were asked to learn the landmarks they visited in the environment and their relative locations. The full results of this exploration go beyond the scope of this paper and are reported separately [Dal11].

4.5. Tasks

After completing each virtual tour, participants answered a questionnaire assessing their subjective sense of presence on a scale of 0 to 10. A subset of questions from the Igroup Presence Questionnaire [SFR99] was selected that was relevant to our virtual tour experience and could be answered in a reasonable amount of time compared to the length of our experimental session. Consequently, our presence questionnaire contained questions about the reality of participants‘ experience, its consistency with the real world experience, feeling of being surrounded by the virtual environment, and the sensation of being in that environment. Table 1 shows the questions used for our presence questionnaire.

Table 1 - Presence Questionaire

Q1	In the virtual tour I had a sense of being there. (agree=10, disagree=0)
Q2	Somehow I felt that the virtual world surrounded me. (agree=10, disagree=0)
Q3	I had a sense of acting in the virtual space rather than operating something from outside. (agree=10, disagree=0)
Q4	How well did your experience in the virtual space seem consistent with your real world experience? (10=quite consistent, 0=inconsistent,)
Q5	How real did the virtual world seem to you? (10=quite real, 0=unreal)
Q6	How aware were you of the real world surrounding while navigating in the virtual world (e.g. sounds, room temperature, other people)? (10=unaware, 0=quite aware)

After completing the tasks for each virtual tour, participants proceeded to the next virtual tour. At the end of the experimental session participants answered a questionnaire about their general immersion ability. They also provided comments about how difficult the landmark learning tasks were or other details of the experiment. Questions about participants‘ immersion ability were selected from Igroup presence questionnaire [SFR99].

5. Results

5.1. Subjective Sense of Presence

Reported presence scores were subjected to a mixed-model analysis of variance having three levels of locomotion technique (panoramic video, regular video, slide show). The order of exposure to the different locomotion conditions, participants, and environments were entered into the model as the random effects. The main effect of locomotion technique

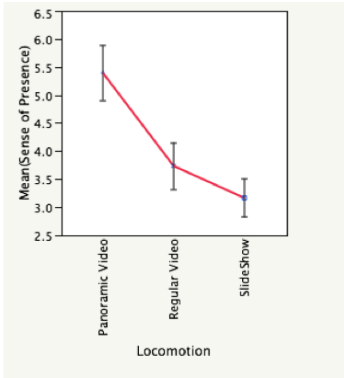

Figure 2: *Comparison of participants' mean subjective sense of presence for the three locomotion techniques. Error bars depict the standard errors of the data.*

was significant, $F(2,28.61)=11.98$, $p<.001$. Post-hoc analysis using Tukey‘s HSD criterion indicated that the mean sense of presence was higher in the panoramic video condition (M=5.4, SD=0.5) than regular video condition (M=3.7, SD=0.4), $p<.05$, and it was higher in the panoramic video condition than the slide show condition (M=3.2, SD=0.3), $p<.05$. There was no significant difference between the mean sense of presence in the regular video condition and the slide show condition, $p>.05$. The average sense of presence in different locomotion conditions is compared graphically in Figure 2.

Participants‘ answers to five out of six individual questions of the presence questionnaire demonstrate consistently higher ratings for the panoramic video condition (see figure 3). It was only when responding to the question 6 asking about how aware of the surrounding environment they were that participants rated all conditions similarly.

5.2. Participants‘ Comments

Because the navigation was passive with no possibility of stopping and going back and forth, participants had difficulty keeping track of the route, as they stated in their post experiment comments.

The only problem participants encountered with panoramic video was that when they tried to look around, in some cases, due to the lack of control over the forward

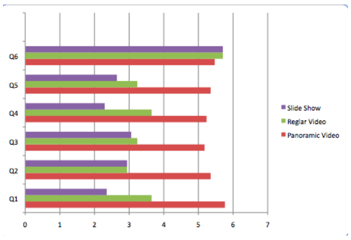

Figure 3: *Participants' ratings of individual presence questions for each locomotion condition.*

movement, they lost track of the direction they were moving in. In a few cases participants became dizzy from rotating to see what is happening around them.

6. Discussion

Our results demonstrated that panoramic video provides a significantly stronger sense of presence compared to the regular video and slide show. Therefore, it appears that the ability to interactively control the view and the smooth locomotion offered by panoramic video, as suggested by the literature, do contribute to a stronger sense of presence [BH95, RKD04, Ste92, WS98]. It also appears that the interactivity, more sensory modalities, and greater visual area available in panoramic images are as important for users to feel present in the VE, as are the higher update rate, object motion, and visual flow presented in the video. The non-significant difference in the averages of sense of presence in the slide show and regular video conditions confirms this inference. Although our participants generally had problems keeping track of their movement direction in the conditions with panoramic view (e.g. panoramic video and slide show), in the panoramic video condition, the smooth locomotion offered by video seems to have had reduced this problem to a great extent.

Witner and Singer [WS98] suggest that if a task is more difficult and needs greater attention, it increases the sense of presence. However we observed a contrary pattern in our experiment. Participants had the most difficulty learning the environment in the slide show tour, but they had the most sense of presence in the panoramic video tour. This can be because the difficulty of the task exceeded a specific level where participants lost their motivation and engagement.

7. Conclusions and Future Works

From our results it appears that for applications that benefit from their users feeling highly present in the virtual environment (e.g. games, therapy or experimental VEs), the effort and costs of creating panoramic video are warranted.

Despite participants' lack of previous experience with panoramic video, they reached a greater sense of presence in the virtual tours generated by panoramic video. In contrast, most of the participants were familiar with regular video (e.g., from watching regular movies) and slide shows (e.g., from Google street view). However, they felt significantly less present in virtual tours created using regular video or slide show techniques. This demonstrates the high compatibility of the panoramic video and its potential for future uses. This potential plus the power of panoramic video to offer sense of presence, provides a motivation for the assessment of panoramic video in more interactive levels where users can actively explore the environment.

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