Utrecht University

Department of Information and Computing Sciences

Game and Media Technology - Master Thesis

Evaluation of different interaction concepts to manipulate the viewing direction of 360-degree videos in a desktop environment

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Abstract

360-degree videos, that is, videos shot in all possible viewing directions, are a type of media that gained a lot of attention the last years. For conventional videos, several methods to interactively manipulate a video's timeline have been investigated. Yet, 360-degree videos do not only have a temporal dimension but also a spatial one, because people can explore the content in all directions surrounding them. Hardly any research has been done so far for how 360-degree videos can be manipulated and interacted with in effective and intuitive ways – neither for the temporal dimension, nor the spatial one. In this thesis, we compare representative implementations for three different interaction concepts to explore their suitability for manipulating an observer's viewing direction. These concepts are: a gesture-based method, a method using hard buttons and a method using graphical widgets. A 360-degree video player was built for the experiment. In a user study, 20 participants performed different search tasks with each of the three interaction concepts. Results show that there was no significant difference in performance between the three concepts. However, participants preferred the gesture-based method over the other three methods. Moreover, the graphical widgets method was the least preferred among participants.

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Contents

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Abstract

360-degree videos, that is, videos shot in all possible viewing directions, are a type of media that gained a lot of attention the last years. For conventional videos, several methods to interactively manipulate a video's timeline have been investigated. Yet, 360-degree videos do not only have a temporal dimension but also a spatial one, because people can explore the content in all directions surrounding them. Hardly any research has been done so far for how 360-degree videos can be manipulated and interacted with in effective and intuitive ways – neither for the temporal dimension, nor the spatial one. In this thesis, we compare representative implementations for three different interaction concepts to explore their suitability for manipulating an observer's viewing direction. These concepts are: a gesture-based method, a method using hard buttons and a method using graphical widgets. A 360-degree video player was built for the experiment. In a user study, 20 participants performed different search tasks with each of the three interaction concepts. Results show that there was no significant difference in performance between the three concepts. However, participants preferred the gesture-based method over the other three methods. Moreover, the graphical widgets method was the least preferred among participants.

Keywords
360-degree video, interaction methods, viewing direction manipulation, search task

1 Introduction

360-degree videos are a new type of media that have become increasingly popular on major video sharing platforms such as YouTube and Facebook. 360-degree videos are recorded by omnidirectional cameras that are able to capture all viewing directions of a scene [15]. Users are able to watch 360-degree videos on their desktops, mobile phones or through head-mounted displays.

For conventional videos, lots of research exits investigating different methods to interactively manipulate a video's timeline, for example, to skim through a video and search for information. Yet, for 360-degree videos, so far hardly any research has been done related to this aspect and other effective and preferred ways to interact with such content. In addition, 360-degree videos add another dimension of interaction by allowing people also to "look around" in a scene. Whereas traditional videos only show one dedicated camera view, 360-degree videos enable users to freely explore the virtual space surrounding them. Such an interaction can be particularly difficult to control when 360-degree videos are watched on a desktop PC or laptop, and consequently on a 2D screen, because in contrast to head-mounted displays, where the viewpoint is controlled by moving one's head, here, the viewpoint is changed by rotating the actual video content. This can easily lead to disorientation, especially when rotating it in both directions, that is, left/right as well as up/down.

In this thesis, we are testing representative implementations for three different interaction concepts to explore which one of them is the most preferred and efficient for manipulating the viewing direction in 360-degree videos on desktops using the keyboard and the mouse as input devices. These are a gesture-based method, a method using hard buttons and a method using graphical widgets. By means of a comparative user study, our work aims at providing concrete knowledge on which of these concepts works best for manipulating the viewing direction in 360-degree videos on desktops. That is, we address the following research problems:

RP1 - What is the most efficient interaction method to manipulate the viewing direction in 360-degree videos when viewed on desktops?

RP2 - What is the most preferred interaction method to manipulate the viewing direction in 360-degree videos when viewed on desktops?

As a first step towards answering these questions, we evaluate one representative implementation for each of the three interaction concepts stated above with respect to common use cases, which will be introduced via tasks in Section 3

The remainder of this paper is structured as follows: Section 2 discusses the related work. Section 3 describes the evaluated interaction methods, experiment design and provides the motivation for these design choices. Section 4 and 5 discuss the results. Section 6 closes with a conclusion and directions for future work.

2 Related Work

This thesis is related to studies on how the user can interact with video content and specifically on 2D displays. Therefore, in this section we discuss video interaction methods for 2D displays that have been proposed over the years. Additionally, since we focus on 360-degree videos, it is important to explore studies on how users are able to interact with this type of videos. Particularly, on how they can manipulate the timeline and viewing direction in 360-degree videos. Moreover, considering that we are conducting a comparative study, we present some comparative studies on 360-degree video interaction and user experience.

2.1 Interaction with traditional videos

Interaction with traditional video commonly addresses manipulation of the timeline, that is, making the video pause or stop, increase or decrease playback speed, skim the content or go to a specific position, and so on. Various approaches and interface designs have been evaluated for different tasks and in different contexts.

Matejka et al. [17] propose Swift, a technique that supports real-time scrubbing of online videos by employing a small, low resolution copy of the video during scrubbing. Specifically, when users move the seeker bar, the video switches to low resolution and then switches back to full resolution the moment they release the mouse button. Moreover, they conduced a user study were participants performed different seeking tasks. Their results showed that users performed tasks faster using their proposed Swift scrubbing technique compared to common online video scrubbing technique.

Another interesting method for video browsing was proposed by Pongnumkul et al. [26]. In this study the authors present a content-aware dynamic timeline control for video browsing. In their approach, the authors use an elastic slider and present important video scenes based on a key clip hierarchy. The important video scenes are presented at a convenient speed as the users skim through a video.

A lot of methods for interacting with mobile video content have been studied and proposed over the years. In these studies, users are able to interact using their hands since most of the mobile devices that have been developed the past few years consist of touchscreens. Hürst et al. [9] introduce the idea of the mobile zoom slider for video navigation on mobile devices. The mobile zoom slider allows users to skim through a video on different granularity levels. The zoom slider can be enabled by tapping at any position of the screen and can be controlled by horizontal dragging. Additionally, when the users tap at the top of the screen, the seeker bar uses the finest resolution of the scale for scrolling, while when they tap at the bottom it uses the coarsest scale. Furthermore, to evaluate their interface, the authors conducted a user study where the participants performed simple navigation tasks.

Hürst and Merkle [10] present a video browser for PDAs that is designed for one-handed interaction. The interface allows users to scroll through a list of thumbnails that represent the video content by applying different gestures. Users are able to perform these gestures with their right thumb on the right side of the touch screen while they hold the device in landscape orientation. To evaluate and verify the usability of their interface, the authors conducted a user study where they asked participants to perform certain browsing tasks.

Wu et al. [29] present a video browser for mobile devices, which is controlled by titling and rotating the device. Thus, the users can interact with the video by using a single hand. The users can fastforward and rewind videos by titling the device. The speed of these functions is determined by the tilting angle. The greater the angle the faster users can seek through a video. Furthermore, by shaking the device either to the left or the right, users can activate frame-by-frame fast forwarding or rewinding. Additionally, the authors conducted a user study where they showed that users are able to quickly adapt to this interaction technique.

In this subsection we discussed various approaches and interfaces for interacting with traditional videos on 2D screens such as mobile devices and desktops. These studies were pioneer in the field of video interaction and timeline manipulation. We notice that various techniques for interacting with videos exist but that they can be classified into certain categories, such as approaches using hard buttons from the keyboard, and graphical widgets or gestures, which are both operated with a mouse. In our research, we verify the potential of each of these categories for the manipulation of the viewing direction via representative implementations.

2.2 360-degree Video Interaction: Manipulation of the timeline and viewing direction

360-degree videos are recorded by omnidirectional cameras that are able to capture all viewing directions of a scene [15]. These videos are different from traditional ones with respect to interaction insofar as they can also be explored on different screens, such as immersive virtual reality displays, and allow people to not just manipulate the time line but also the viewing direction. This makes the interaction much more difficult, and very few research has been done in this context so far.

Neng and Chambel [19] present a video player for the visualization and navigation of 360-degree hypervideos or omnidirectional videos. Users are able to see a part of the whole video content and they can drag the viewport horizontally to explore the virtual space. Additionally, the user interface of the video player provides two orientation options. The first option is a circle that resembles a pie chart where the only piece of the pie indicates the user's viewing direction. The second option is a minimap that displays a smaller version of the whole 360-degree video content and contains a rectangle that indicates the user's viewing direction. Furthermore, the user interface has small indicators on the side area of the video and on the minimap, to visualize hotspots and hyperlinks that are not in the field of view. Furthermore, the users are able to click on a thumbnail and navigate to the specific time and viewing angle.

Some research has been done on ways to manipulate the viewing direction in 360-degree videos using a VR device. Petry and Huber [25] present a new way on how to navigate in Omnidirectional videos (ODV). In their approach they make use of an Oculus Rift and a Leap Motion controller. Specifically, the viewing direction in the video scene is realized by the head rotations. Petry and Huber [25] present a new way on how to manipulate the timeline in Omnidirectional videos (ODV). Specifically, temporal navigation is achieved by using hand mid-air gestures. For instance, the user can play a video using a push gesture, pause a video by keeping his arm stretched, and fast forward or rewind a video by moving his hand left or right.

Pai et al. [21] further present GazeSphere, a navigation system that allows hands-free interaction and smooth transition between 360-degree video environments in VR using head rotation and eye gaze tracking. Specifically, users are able to transition from one point to another by rotating their head. From their user study, the authors showed that users were able to adapt to this technique without any noticeable motion sickness. Li et al. [14] introduce an algorithm that constructs Route Tapestries from 360-degree videos similarly to slit-scan photography technique. Furthermore, the authors present Tapestry player which is a desktop-based 360-degree video player prototype that uses Route Tapestries for timeline navigation. In order to evaluate their video player, they conducted an experiment where the participants completed target finding tasks using their video player and two baseline techniques. Their results showed that participants completed tasks faster than the other two techniques and missed fewer targets.

From the studies that we discussed in this subsection, we notice that most of the research was related to methods for the manipulation of the viewing direction in 360-degree videos using VR devices. Yet, not many studies exist on methods for the manipulation of the viewing direction in 360-degree videos on 2D displays. Our research addresses this gap.

2.3 Comparative studies on 360-degree video interaction and user experience

After discussing studies on interaction with traditional and 360-degree videos, we now focus on comparative studies related to 360-degree video interaction and user experience.

Pakkanen et al. [22] explored three different Virtual Reality (VR) interaction methods for controlling 360-degree video playback in a web-based player. These methods were remote control using graphical buttons in the user interface, pointing with head orientation, and hand gesture interaction. Their findings indicated that gesture interaction was worse than the other two methods. Additionally, they concluded that either the remote control or the pointing using head orientation with a graphical user interface would be the best interaction methods for controlling 360-degree videos in VR environments. From their findings we can assume that our gesture-based method for the manipulation of the viewing direction in 360-degree videos will be the worst method. However, this study was conducted using a VR device whereas we explore different methods for the manipulation of the viewing direction in 360-degree videos on a 2D display.

Van den Broeck et al. [5] conducted a comparative study on the 360-degree video viewing user experience on mobile devices using different interaction techniques. Specifically, they used a smartphone where the users were able to navigate through video space using dynamic peephole navigation, a tablet where they used touch as input modality to explore the video content, and a head mounted display (HMD) where the users could use their full body to navigate the virtual space of the 360-degree video. Their results showed that users preferred watching 360-degree videos on a smartphone since they were more familiar with the navigation controls compared to the other techniques. Moreover, their results suggested that 360-degree videos with moving viewports offer immersive viewing experience but they are cognitively demanding and cause discomfort.

Zoric et al. [30] investigated the viewing and interaction with panoramic videos using a TV screen. Specifically, they focused on content interaction. To explore this they conducted two user studies. In the first user study, the users were able to interact with the video content by using a second touchscreen of a tablet. In the second user study, the users were able to use wide hand gestures to interact with the video content that was displayed on a large screen. In both studies the users were able to perform interactions such as zooming in and out, and navigate through the video space by tilting and panning. Their results revealed that navigation in panoramic videos should be intuitive and fast enough to cover relevant movement in the scene.

In this subsection we discussed studies that investigated users' experiences and interactions with 360-degree videos. Again, we notice that in most of these studies, researchers used VR devices to conduct them. In our thesis, we conduct a comparative study between three different interaction methods to explore which one of them is the most preferred and efficient for manipulating the viewing direction in 360-degree videos on desktops using the keyboard and the mouse as input devices. Therefore, we fill this gap in comparative studies and explore the best interaction method for manipulating the viewing direction in 360-degree videos on 2D displays.

3 Methodology

The following subsections describe how we address the different parts of these research problems and how we will answer the related questions with respect to the specified methods. Section 3.1 introduces the interaction methods that we will be studying. In Section 3.2, we discuss about materials and videos that were used in the experiment. Section 3.3 addresses the question why people want to manipulate the viewing direction and describes the use cases that we will be evaluating. In Section 3.4, we specify the measures that we use to verify efficiency and preference. Finally, Section 3.5 introduces the experiment design that is used to answer our questions.

3.1 Video player and implemented interaction methods

Our work is inspired by Pakkanen et al. [22] (see Section 2.3) that studied 360-degree video interaction for VR head-mounted displays by comparing three representative implementations of the most common interaction methods for VR head-mounted displays: gestures, head-pointing, and remote control. Likewise, we compare representative implementations of three of the most common interaction methods for 2D desktop interaction. In particular:

- **Graphical widgets**. GUIs, where actions are evoked by, for example, clicking on widgets or icons representing a certain functionality, are probably the most common interaction method to control standard video players on 2D displays. Probably the most obvious way to add rotation of the field of view to a 360-degree video player is therefore to add, for example, widgets depicting arrows pointing into the targeted viewing direction.

- **Hard buttons**. Using dedicated buttons on a keyboard or mouse is a very popular interaction method that is often especially appreciated in situations where fast and accurate interaction is needed. We will be testing what is probably the most intuitive way to map certain button presses to changes of the field of view, which is using the four arrow keys on the keyboard to evoke a continuous motion along the x- or y-axis.

- **Gestures**. Gestures have become popular due the omnipresence of touchscreens on mobile devices. In a 2D desktop environment with a keyboard and mouse, they are often used to manipulate the field of view in 3D games via mouse gestures. In our evaluation, we will use an approach, which most commonly used in 3D games, that is, a direct dragging of the 360-degree video by a click-and-drag gesture done with the mouse.

To perform the experiment, we developed an app for the Windows operating system containing a video player that allows watching 360-degree videos. The app was implemented using Unity cross-platform game engine version 2020.3.5f1. The video player consists of common buttons that are used for standard functions such as play, pause, stop, fast forward and rewind, and a timeline. Specifically, the fast forward button skips the next five seconds of the video and the rewind button rewinds five seconds of the video similarly to Youtube.

The video player is illustrated in Figure 1. Moreover, the app was built for monitors with an industry-standard Full HD 1080p resolution, and thus with a resolution of 1920 x 1080 since this is the most common resolution [27].

Figure 1: Interface of the 360-degree video player developed in Unity.

For the graphical widgets method, in order to add rotation of the field of view to the 360-degree video player, we added virtual buttons showing arrows representing different viewing directions . These arrows were placed at the top left of the screen in a similar way as it is done with the standard Youtube interface for 360-degree videos. By pressing each button, the video content rotates discreetly to the corresponding side by 10 steps. That is 10 degrees. Thus, if the user keeps pressing a button the video does not rotate continuously. Virtual buttons are illustrated in Figure 2.

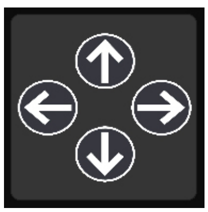

Figure 2: Virtual Buttons.

For the hard buttons, we use the four arrow keys on the keyboard to evoke a continuous motion along the x-axis or y-axis depending on which of the buttons is pressed. The video content rotates continuously with a speed of 2 steps per frame.

For the gesture method, we use a direct dragging of the 360-degree video content by a click-and-drag gesture done with the mouse. Specifically, we rotate the video content by 2 steps per frame depending on the direction we move the mouse.

3.2 Other material – Questionnaires and videos

All the questions for the questionnaires were made in Unity and were integrated into the player app. IBM SPSS Statistics was used to perform the statistical analysis of the provided answers.

To evaluate the different interaction methods, various videos were needed. These videos were obtained from Youtube. In total a selection of five 360-degree videos was made with videos fulfilling certain criteria. The first was a video recorded with a still camera and was used for the tutorials to make sure the participants understood the procedure and task they had to perform. Three others were videos of roller coaster rides and one was a video of a walking tour. They were chosen because both types contained comparable camera movements, i.e., a constant motion with a certain speed – fast for roller coaster rides, slow for walking tours. All of these videos were edited using an open source video editor called OpenShot to have a length of 1 minute and 30 seconds. Specifically, the walking tour video was split into three videos of 1 minute and 30 seconds. In addition, some videos were retrieved as stereoscopic and others as monoscopic. To convert the stereoscopic videos to monoscopic we used Ffmpeg an open-source, command-line tool. All of the videos were muted since the influence of audio was not part of our study.

3.3 Usage scenario and related tasks

Various reasons exist why people might want to change the viewing direction when watching 360-degree videos. Here, we focus on known item search tasks, that is, situations in which people try to find an item, such as an object, person, action, or event, in a video that they know about [6], [16]. Such tasks are very common and relevant in relation to 360-degree video as well. For instance, imagine you recorded a 360-degree video. Later, you remember a detail, such as a landmark you saw in a walking tour, but do not remember when and where exactly it was. Your aim is then to go through the video to find said landmark. For traditional video, you would just need to skim along the timeline to find this target. For 360-degree video, you also must look into different viewing directions when searching for it.

Because we test with random people who are unfamiliar with the videos, we must simulate such a known item search somehow. We do this with an approach similar to how this is done in the Video Browser Showdown (VBS), a well-established video search competition [28]. There they show a video clip and let people search for the said clip. In our experiment, instead of video clips, we show images that are excerpts from 360-degree videos and have a smaller size than the viewing window of our player because they just depict the item that needs to be found. People participating in the study are then given some time to find the object or place that is depicted in the image.

The selection of a video can have an impact on the search performance. To avoid that the actual content impacts our results, we chose examples from concrete use cases and comparable scenarios: walking tours and roller coaster rides.

Another factor that may affect search performance is the camera motion and location. The camera can ei-

ther be a still camera or a moving camera at different speeds. A still camera is a 360-degree camera placed on a specific point, for example on a bustling city square. A moving camera can either record from a first person perspective or a third person perspective. We categorize the different speeds of moving cameras in three categories. These are very slow motions, for example drone flights over landscapes, slow motions such as city walking tours, and fast motions, for instance roller coaster rides.
In our study, we focus on moving cameras and videos recorded from a first person perspective with slow motions and fast motions. They are the most relevant ones when it comes to manipulating the viewing directions, because for very slow motions and still camera setups, the video content does not change that fast, making it easier to find things. For drone flights, the camera is also far away from the content and thus there is less need for rotation since they cover a larger area anyhow thus reducing the need for rotating one's view.

Concretely we use 360-degree videos of walking tours for the slow camera motions and roller coaster rides for the fast camera motions. These types of videos are very popular in their respective categories and thus representative for our use case. Furthermore, known item search is a realistic use case in this context, simulating a situation where a user remembers some detail seen during a walking tour or something on the track of a roller coaster ride that they want to see again after recording it.

3.4 Measured data

In order to provide insight into the research problems specified at the end of Section 1, our study evaluates three interaction concept with respect to efficiency and preference. To analyze which method is the most efficient to manipulate the viewing direction in 360-degree videos when viewed on 2D displays, we measure how fast the participant found the specified target in the image. Search efficiency was measured in seconds. For all search tasks, from the beginning of each video, a timer started which automatically measured the time until the participant found the requested image and clicked on the "Found it" button. If the participant did not find the specified target in the image, a "Not found" was recorded in the data.

To answer which interaction method is the most preferred to manipulate the viewing direction in 360-degree videos when viewed on 2D displays, we use a preference questionnaire. In this questionnaire participants had to choose which interaction method they preferred the most and the least for each type of video. In our case,we also distinguish between which interaction method they preferred the most and the least for the walking tour videos and which for the the roller coaster ride videos.

3.5 Experiment design

The experiment was conducted remotely. While the decision to do so was mostly motivated by pragmatic reasons – in particular the ongoing COVID situation – remote experiments can also have some advantages over on-location tests. For example, it may take participants less time to complete them. Moreover, it allows the participants to complete the experiment at their own pace and in a familiar, realistic environment, thus positively impacting external validity. On the negative side, there might be an impact on internal validity due to the less controlled environment and potential external influences.

Participants were provided with a link to download the app and run it on the personal computer. They needed to have a computer with Windows operating system, a mouse and a keyboard to conduct the experiment.

The experiment consisted of two types of videos per interaction method, a walking tour 360-degree video and a roller coaster ride 360-degree video, and thus two search tasks of known items for each interaction method. Two types of videos were chosen for each interaction method to test both slow and fast camera motion speeds. An image of the requested object was presented at the top right of the screen. An example of the experiment interface can be seen in Figure 3. All videos were 1 minute and 30 seconds long in order to be comparable for the experiment. There was a time limit of 3 minutes for each task since we wanted to avoid that participants might endlessly look around searching for the object, and explore which interaction method works best for 360-degree videos. Participants were aware of this time limit.

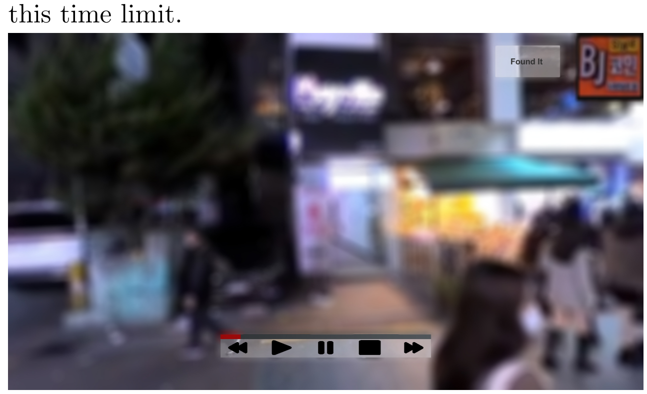

Figure 3: Example of experiment interface. Image blurred due to copyright reasons.

A within-subject experiment was conducted, meaning that each participant tested all interaction methods. However, participants might benefit from a learning effect and thus perform worse in earlier tasks than in subsequent tasks since they might learn how to perform the procedure more efficiently. To mitigate this learning effect, we included a tutorial for each interaction method and randomized the order of the interaction methods with a Latin Square Design [4]. Moreover, to avoid that the targets are always associated with the same content or that they are always, for example, at the beginning of each video, we counterbalanced the target location within each video. To achieve this, we both found targets based on the content (places for the walking tour videos and different objects for the roller coaster rides) and time (targets were at dedicated time spots). Specifically, each video was intuitively divided into 3 parts (beginning, middle, ending) and the targets were distributed in different time positions of these 3 parts for each task. In regards to the orientation, in the walking tour videos the targets were located at around 90 degrees and in the roller coaster ride videos they were located randomly.

The experiment started by presenting a scene which included instructions for the experiment procedure, details about the tasks that they had to complete and a consent form. This ensured that all participants got the same information. The participants then had to fill out some general information about themselves. These included their age, gender and how familiar they were with 360-degree videos.

After filling out some general information, the actual experiment started. For each method, the participants first familiarized themselves with the method and the user interface using a tutorial of a still motion 360-degree video. After the tutorial, the corresponding interaction method was presented. The participants first completed the search task by watching a video of a walking tour and then a roller coaster ride video. This order of videos and questions was chosen since it is natural to first watch the slow motion video and then the fast motion video. A "Found It" button was placed at the top right of the screen next to the image. Participants pressed this button after they had found the requested item in the image.

After completing both search tasks for each method, the participants had to fill out cybersickness questions, such as if they experienced any discomfort while watching the videos. Afterwards, they filled out a usability questionnaire for the corresponding method. This questionnaire was inspired by the System Usability Scale [13] and it included ten question on a 5-point Likert scale that were adjusted for our experiment. By letting participants fill out question before moving on to the next interaction method, we also minimized the likelihood of cybersickness by including a natural break.

After completing all search task for all three interaction methods, participants had to fill out which interaction methods they preferred the most and the least for each type of video. The participants' responses to the questions and their performance throughout the experiment were gathered automatically in a spreadsheet. A unique anonymous ID was contained there to differentiate participants.

There was also an optional small interview after the experiment. Five participants voluntarily participated in the interview which included questions regarding the advantages and disadvantages of each method and the opportunity to provide further comments and suggestions.

3.6 Participants

20 subjects participated in the experiment (6 male, 14 female). They were recruited online with the use of Discord, Facebook, Microsoft Teams and email. Ages ranged from 19-32 with a mean age of 25.7 years (SD = 3.51). Five participants voluntarily agreed to do a small interview after the experiment. All participants had no prior knowledge of the experiment, participated voluntarily and did not receive any form of compensation. Seven participants were not familiar at all with 360-degree videos, eight were a little familiar, three were quite familiar and two were very familiar with 360-degree videos. Due to the basic characteristics of the tasks and measurements, we do not believe that participants' experience with 360-degree videos influenced the outcome nor did we observe any related indications in the data analysis.

4 Results

In this section, we present the results from the data analysis. The data analysis was performed using IBM SPSS Statistics.

4.1 Performance Analysis

To find out which is the most efficient interaction method to manipulate the viewing direction in 360-degree videos when viewed on desktops, and thus answer our first research problem, we gathered the completion times for each task and for each method. A "Not found" was gathered whenever participants could not find an object for a task. In order to have equal number of observations for all tasks and be able to analyze the results, we replaced the "Not found" values with the mean completion times of each task [1]. To analyze the results, we performed analysis of variance.

Specifically, we performed one-way repeated measures ANOVA since we wanted to compare means of three within-subject variables. In addition, we performed a paired samples t-test to check for any statistical significance in the means between pairs of methods.

For the known item task, we measured the amount of time it took the participant to find a specific object in the scene. Figure 4 shows the average completion time per method and per video type for this task. The initial impression from this graph is that participants performed worse using the graphical widgets method compared to the gestures method and the hard buttons method in both walking tour videos and roller coaster ride videos.

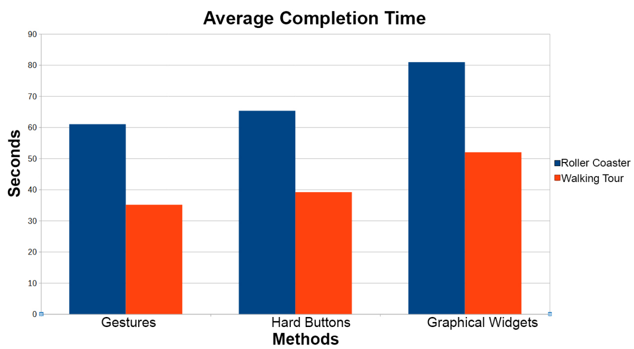

Figure 4: Average completion time for each method and for each type of video.

To see if there are significant differences between the means of these 3 methods, we performed a one-way repeated measures ANOVA test for each type of video and for both types of videos combined. The results show that there was no statistically significant difference between the three methods for the walking tour videos ($F(2, 38)=3.814$, $p=0.167$). Similarly, there was no statistically significant difference between the three methods for the roller coaster ride videos ($F(2, 38)=1.568$, $p=0.076$). In addition, we observe from the results that generally there was no statistically significant difference between the three methods ($F(2, 78)=4.222$, $p=0.098$). Moreover, one participant did not find the requested object using the gestures method in the walking tour video, two participants did not find the requested object using the hard buttons method in the walking tour video, and one participant did not find the requested object using the graphical widgets method in the walking tour video.

Since there was no statistically significant differences between the methods, we proceed in checking for any statistical significance in the means between pairs of methods. Thus, we performed a paired samples t-test. From the results shown in Figure 5 and in Figure 6, we observe that there was no statistically significant difference between most of the pairs of methods in both types of videos. However, there was significant evidence that participants performed better in the gestures method than in the graphical widgets method during the walking tour video ($p=0.026 < 0.05$).

Pairs	Mean dif	Std. Dev	p
G – H	-4.048	21.801	0.417
G – V	-16.884	31.188	0.026
H – V	-12.836	31.571	0.085

Figure 5: Paired samples t-test results for the walking tour videos (G:gestures, H:hard buttons, V:virtual buttons) .

Pairs	Mean dif	Std. Dev	p
G – H	-4.31	50.626	0.708
G – V	-19.918	51.404	0.099
H – V	-15.608	56.549	0.232

Figure 6: Paired samples t-test results for the roller coaster ride videos (G:gestures, H:hard buttons, V:virtual buttons).

4.2 Method Preference

Preference differed a little between the walking tour videos and roller coaster ride videos. In the walking tours 55% chose gestures as their favorite method to manipulate the viewing direction in 360-degree videos and the rest 45% preferred hard buttons. Method preference for walking tour videos can be seen in Figure 7. The participants almost unanimously picked graphical widgets as their least favorite method with a rate of 90%, with gestures and hard buttons getting 5% each.

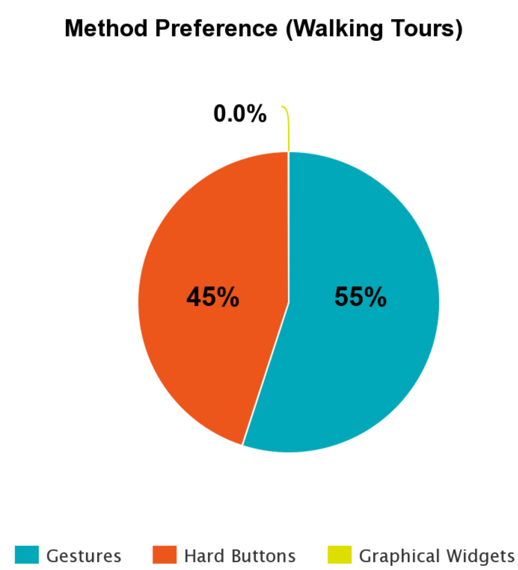

Figure 7: Method preference for walking tour videos.

In the roller coaster ride videos 55% picked gestures as their favorite method to manipulate the viewing direction while 40% preferred hard buttons and 5% preferred virtual buttons. Method preference for roller coaster ride videos can be seen in Figure 8. The least favorite method was again graphical widgets with an 80% rate.

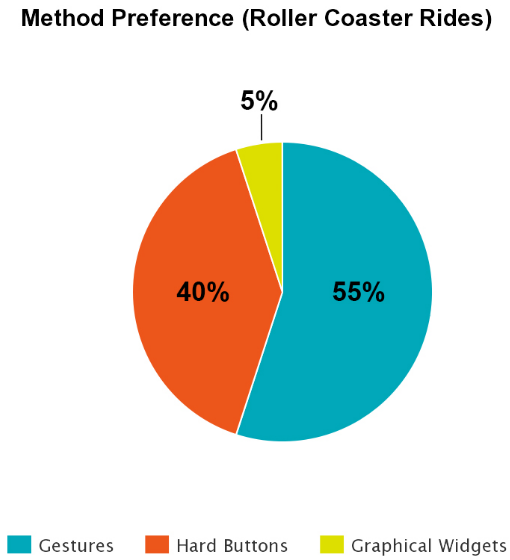

Figure 8: Method preference for roller coaster videos.

The overall favorite method was gestures with a 55% rate and hard buttons were close second with a 42.5%. The least favorite method out of the three was by far graphical widgets with an 85% rate.

4.3 Cybersickness

The participants mostly reported no discomfort or minor discomfort while using gestures or hard buttons, with only 5% reporting a lot of discomfort while using gestures and 10% while using hard buttons, both in the roller coaster ride videos. In walking tours the vast majority reported no discomfort at all while using these two methods (85% for gestures and 80% for hard buttons) and the rest only minor discomfort.

While using graphical widgets, though, discomfort was more acute for the participants. With 30% reporting minor discomfort and 10% a lot of discomfort in walking tours and 35% reporting minor discomfort and 15% a lot of discomfort in roller coaster ride videos.

5 Discussion

Our research aimed at exploring which interaction concept is the most effective and which is the most preferred to manipulate the viewing direction of 360-degree videos on desktops. Through representative implementations of these concepts and an experiment we aimed at answering these research problems. Several aspects were investigated including how fast participants can find objects in different types of 360-degree videos and which method they preferred for manipulating the viewing direction of these types of 360-degree videos.

While the quantitative data seems to suggest that participants performed better at finding the objects using the gestures method, in both walking tour videos and roller coaster ride videos, the results from the statistical analysis showed that the differences between the three methods are not significant to validate which method is the most efficient for manipulating the viewing direction. This might be partly due to the low number of participants (20 subjects). However, this could also imply that all three methods are equally efficient for manipulating the viewing direction in 360-degree videos.

Paired samples t-tests were performed to check for any statistical significance in the means between pairs of methods. No statistically significant difference between most of the pairs of methods in both types of videos was observed. Still, there was statistical significance between the gestures method and the graphical widgets method during the walking tour video. Participants characterized the graphical widgets method as “tiring” and “uncomfortable”, but described the gestures method as “comfortable”, “easy to control and understand how it works”. These answers could potentially explain the statistical difference between the gestures and the graphical widgets method. Furthermore, the gestures method allowed participants to control every direction of the view, while the graphical widgets method allowed them to move in the four depicted directions.

In total, four participants did not find the requested objects while watching the walking tour videos. Specifically, one did not find it using the gestures method, two using the hard buttons method and one using the graphical widgets method. Looking at the specific participants’ responses in the usability questionnaire for each method, most of them stated that they agreed that it was hard to find the requested object. Moreover, they did not feel excited to find the requested object. In addition, the participant that did not find the requested object using the gestures method strongly agreed that it was tiring to use the corresponding method. We notice that the participants did not find the object in all methods during the walking tour videos. This might be due to the fact that the video content in the walking tour videos contains a lot of information. This means that a lot of people walk around and there are a lot of different places and stores, thus making it harder to find the requested object.

When it comes to preference there was a slight inclination towards gestures in both walking tours and roller coaster rides. Participants stated that they felt the method was the most immersive and easy to understand. Some also claimed that it felt more natural since it felt like they were moving their head around to see different places.

Hard buttons came close second with participants mentioning it was the method they felt the most familiar with, because arrow keys are a popular way to navigate in video games too and the only disadvantage is that it was slower to manipulate the viewing direction than the gestures method.

Graphical widgets was the most unpopular answer, but people stated it was the most precise method out of the three. It was also, almost unanimously chosen as the least favourite method, with participants mentioning that it was "tiring and irritating", it gave the least movement freedom and it takes a lot of time to press them because you have to look in two different places (Both the virtual buttons and the scene to find the object).

Discomfort did not seem to affect the results since in most cases it was low. Graphical widgets seemed to cause slightly more discomfort compared to the other two methods and it might have played a role on participants choosing it as their least favorite method. Also discomfort appeared to be more acute in roller coaster ride videos and that could be due to the fast camera motion and not due to the implementation of the methods.

6 Conclusion

Compared to traditional videos, 360-degree videos add another dimension of interaction by allowing people to "look around" in a scene. Such an interaction can be particularly difficult to control when 360-degree videos are watched on a desktop, since the viewpoint is changed by rotating the actual video content. In this thesis, we aimed at providing concrete knowledge on which interaction method is the most efficient and which is the most preferred to manipulate the viewing direction in 360-degree videos when viewed on desktops.

To answer the above research problems we tested representative implementations for three different interaction concepts. These interaction concepts were a gesture-based method, a method using hard buttons and a method using graphical widgets. For the gesture-based method we used a direct dragging of the 360-degree video content by a click-and-drag gesture done with the mouse. For the hard buttons method we used the four arrow keys on the keyboard. For the graphical widgets method we added virtual buttons showing arrows that represented the different directions.

Our results showed that there was no statistical significance in performance between the three methods. Therefore, we cannot conclude which of the three methods is the most efficient to manipulate the viewing direction in 360-degree videos when viewed on desktops. However, there was a statistical significance between the gestures method and the graphical widgets method during the walking tour video, meaning that participants found the requested objects faster using the gestures method than using the graphical widgets method.

While quantitative analysis cannot validate which method was the most efficient to manipulate the viewing direction in 360-degree videos, qualitative feedback showed that participants preferred the gesture-based method over the other two methods in both types of 360-degree videos (walking tours and roller coaster rides). Moreover, the graphical widgets method was the least preferred method in both types of 360-degree videos.

Although additional experiments are needed to make a conclusive statement, our results showed that the gesture-based method is the most preferred method and could potentially be the most efficient to manipulate the viewing direction in 360-degree videos when viewed on desktops. Thus, we believe that this thesis could serve as a basis for interesting follow-up research in this area.

6.1 Future work

For future work, it would be interesting to conduct the experiment in a controlled environment using longer videos. In this thesis, we used exclusively 1 minute and 30 seconds videos to keep the duration of the experiment rather short, since it was conducted remotely due to the ongoing COVID-19 situation.

Furthermore, we used videos of roller coaster rides and walking tours. These were variations of roller coaster rides and a virtual tour (city tour of Seoul). In future work, we would like to see different genres in selection of videos.

Moreover, in this thesis, we presented three representative implementations for our three concepts. These were the mouse for the gesture method, the arrow keys on the keyboard for the hard buttons method and four virtual button representing arrows for the graphical widgets. Future research could explore different representative implementations for these concepts. For example, motion capture for the gestures method, the use of an external controller for the hard buttons method and a different visualization for the graphical widgets.

Since the experiment was conducted during summer vacation, the number of participants was low. It could be interesting as future research to perform the experiment with a larger number of participants in order to test whether the results would be different.

We decided to disable the audio since we argued that it would add little value to the experiment and it was not the purpose of this study. Still, it could be worthwhile to consider adding audio in future research, regarding manipulation of the viewing direction in 360-degree videos, to confirm whether audio has an impact on this aspect.

Finally, for our experiment, we used known item tasks as we believed they would help us answer our research problems. It would be interesting to conduct the experiment using different types of tasks in future work.

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Appendix A Initial literature study to specify the research

This literature review was done at the beginning of the thesis to identify gaps in the state of the art plus opportunities for further exploration and to specify the final focus of this research. It is structured as follows: In the first section we discuss video interaction methods for 2D displays that have been proposed over the years. In the second section we explore several ways of interacting with 360-degree video. Specifically, ways on how users can manipulate the timeline and viewing direction in 360-degree videos. Moreover, we present some comparative studies on 360-degree video interaction and user experience. In the third section we summarize this literature review and draw conclusions.

A.1 Video interaction on 2D displays

Several video interaction methods for 2D displays have been proposed over the past few years. Specifically, different ways to browse, summarize and manipulate the timeline in videos exist. Users are able to interact with videos on 2D displays by using the keyboard and mouse as input methods or by performing different gestures using their hands on touch screens. Therefore, in this section we will discuss different methods of interacting with traditional videos on 2D displays such as desktops and mobile devices.

A.1.1 Desktop video interaction

Several techniques for browsing video content on desktops have been presented. Matejka et al. [17] propose Swift, a technique that supports real-time scrubbing of online videos by employing a small, low resolution copy of the video during scrubbing. Specifically, when users move the seeker bar, the video switches to low resolution and then switches back to full resolution the moment they release the mouse button. Moreover, they conduced a user study were participants performed different seeking tasks. Their results showed that users performed tasks faster using their proposed Swift scrubbing technique compared to common online video scrubbing technique.

Nquyen et al. [20] propose a 3D volume-based interface, known as Video Summagator, for video summarization and navigation. Video Summagator constructs a video as a space-time cube using real-time rendering techniques and video time as the third dimension. In contrast to [17] where users are able to only use a seeker bar for video browsing, they can directly interact with the cube by performing tasks such as zooming, scaling and rotation. Furthermore, they can navigate to an interesting part of the video by clicking and selecting the corresponding area in the summarization. Another interesting method for video browsing was proposed by Pongnumkul et al. [26]. In this study the authors present a content-aware dynamic timeline control for video browsing. In their approach, the authors use an elastic slider and present important video scenes based on a key clip hierarchy. The important video scenes are presented at a convenient speed as the users skim through a video.

Some authors, such as Azzopardi et al. [2], propose a video browsing interface that is designed for young children. This browsing interface allows children to easily discover and browse online videos without the need of textual queries. The authors' system uses the metaphor of a globe that includes series of carousels. These carousels contain videos. The children can navigate through space by browsing left and right to access videos of related content, and up and down to access videos of different content.

In all the aforementioned studies for browsing video content on desktops, users are able to interact with videos using the keyboard and mouse as input method. Therefore, in our study we will use both of these ways as means of interacting with the video content.

A.1.2 Mobile video interaction

In this subsection we will look into different methods to interact with video content for mobile touch devices. In our study we will focus on desktop 2D displays. However, it is interesting to discuss these methods since mobile devices also consist of 2D displays.

A lot of methods for interacting with mobile video content have been studied and proposed over the years. In these studies, users are able to interact using their hands since most of the mobile devices that have been developed the past few years consist of touchscreens. Hürst et al. [9] introduce the idea of the mobile zoom slider for video navigation on mobile devices. The mobile zoom slider allows users to skim through a video on different granularity levels. The zoom slider can be enabled by tapping at any position of the screen and can be controlled by horizontal dragging. Additionally, when the users tap at the top of the screen, the seeker bar uses the finest resolution of the scale for scrolling, while when they tap at the bottom it uses the coarsest scale. Furthermore, to evaluate their interface, the authors conducted a user study where the participants performed simple navigation tasks.

Hürst and Merkle [10] further present a video browser for PDAs that is designed for one-handed interaction. The interface allows users to scroll through a list of thumbnails that represent the video content by applying different gestures. Users are able to perform these gestures with their right thumb on the right side of the touch screen while they hold the device in landscape orientation. To evaluate and verify the usability of their interface, the authors conducted a user study where they asked participants to perform certain browsing tasks.

Additionally, Huber et al. [7] introduce Wipe'n'Watch, an interface for within video navigation and between semantically related videos navigation on mobile touch devices. Users are able to navigate between keyframes by using horizontal wipe gestures. The interface is subdivided into two areas. The upper area of the interface shows the content of the video and the users can wipe there to navigate within the video. The lower part consists of a grid layout that contains an overview with thumbnails of all key frames. For the purpose of between video navigation, the authors introduce vertical wipe gestures that allow users to jump between videos that are related to the current topic.

Wu et al. [29] present a video browser for mobile devices, which is controlled by titling and rotating the device. Thus, the users can interact with the video by using a single hand. In contrast to [10] and [7], users are able to control the video by tilting and rotating the devices without using their fingers. The users can fastforward and rewind videos by titling the device. The speed of these functions is determined by the tilting angle. The greater the angle the faster users can seek through a video. Furthermore, by shaking the device either to the left or the right, users can activate frame-by-frame fast forwarding or rewinding. Additionally, the authors conducted a user study where they showed that users are able to quickly adapt to this interaction technique.

Other studies for mobile video navigation allow users to directly manipulate objects in the scene. Karrer et al. [12] propose PocketDRAGON, an interface for mobile devices where the users are able to navigate through the video by using a direct interaction technique. This technique allows the users to directly interact with objects in the video. For instance, in a football video scene, users can tap on the ball, drag it to a certain position and navigate to the exact frame where the ball was there.

Furthermore, Meixer et al. [18] present a mobile player that contains annotations allowing users an interactive non-linear video experience. Their mobile video player's user interface is presented as a split screen. One side of the screen is used for video playback and the other side of the screen is used to display annotations. These annotations can be images, text or links to other parts of the video. Moreover, if more than one annotations are available for the current video scene, a scrollable stack is displayed. Users are able to tap on components of the stack and get to the specific annotation.

Researchers also experimented with other visualizations of a video content. Hudelist et al. [8] present a video browser for tablets that visualizes the content of a video as a 3D filmstrip. Users are able to manipulate the filmstrip using various gestures. Users are able to perform a drag gesture with their finger to get an overview of the video. Furthermore, it is possible to tilt the filmstrip by dragging vertically using two fingers. By single tapping on a keyframe, users are able to start and stop playback on the filmstrip. In contrast, a double tap on the filmstrip starts full screen playback.

A.2 360-degree video interaction: Manipulation of the timeline and viewing direction

360-degree videos are recorded by omnidirectional cameras that are able to capture all viewing directions of a scene [15]. Compared to conventional videos that allow users to only view a certain point-of-view, 360-degree videos allow them to explore the virtual environment of the video by giving them freedom to look omnidirectionally instead of limiting them to a fixed point-of-view [3]. Users are able to watch 360-degree videos through VR devices, mobile devices or personal computers. In this section we will discuss different methods for the manipulation of the timeline and viewing direction of 360-degree videos using the aforementioned devices.

A.2.1 Viewing direction manipulation in 360-degree videos

With the emergence of 360-degree videos, researchers tried to find ways to interact with them. Specifically, methods to manipulate the viewing direction. Neng and Chambel [19] present a video player for the visualization and navigation of 360-degree hypervideos or omnidirectional videos. Users are able to see a part of the whole video content and they can drag the viewport horizontally to explore the virtual space. Additionally, the user interface of the video player provides two orientation options. The first option is a circle that resembles a pie chart where the only piece of the pie indicates the user's viewing direction. The second option is a minimap that displays a smaller version of the whole 360-degree video content and contains a rectangle that indicates the user's viewing direction. Furthermore, the user interface has small indicators on the side area of the video and on the minimap, to visualize hotspots and hyperlinks that are not in the field of view.

Kang and Cho [11] further present a new system to automate spatial navigation in 360-degree videos on a 2D display. Their system computes a camera path that shows the most important parts in a 360-degree video and produces a normal field-of-view video based on that path. Additionally, the users are able to manually change the viewing direction by dragging a mouse and the system updates the path based on the users' intentions.

A lot of research has been done on ways to manipulate the viewing direction in 360-degree videos using a VR device. Petry and Huber [25] present a new way on how to navigate in Omnidirectional videos (ODV). In their approach they make use of an Oculus Rift and a Leap Motion controller. Specifically, the viewing direction in the video scene is realized by the head rotations.

Pai et al. [21] further present GazeSphere, a navigation system that allows hands-free interaction and smooth transition between 360-degree video environments in VR using head rotation and eye gaze tracking. Specifically, users are able to transition from one point to another by rotating their head. From their user study, the authors showed that users were able to adapt to this technique without any noticeable motion sickness.

Furthermore, Pakkanen et al. [22] explored three different Virtual Reality (VR) interaction methods for controlling 360-degree video playback in a web-based player. These methods were remote control using graphical buttons in the user interface, pointing with head orientation, and hand gesture interaction. Their findings indicated that gesture interaction was worse than the other two methods. Additionally, they concluded that either the remote control or the pointing using head orientation with a graphical user interface would be the best interaction methods for controlling 360-degree videos in VR environments. From their findings we can assume that our gesture-based method for the manipulation of the viewing direction in 360-degree videos will be the worst method. However, this study was conducted using a VR device whereas we will explore different methods for the manipulation of the viewing direction in 360-degree videos on a 2D display.

Other studies explore techniques for automatic re-orientation of the viewing direction in 360-degree videos. Pavel et al. [24] introduce re-orientation techniques that help users see the most important content and prevent them from getting lost when shots change in 360-degree videos. One technique automatically reorients the user's viewing direction at each cut to the most important content of the video. The other technique allows users to manually reorient their viewing direction to the most important content of the video. The areas with the most important content of the video are defined either manually or automatically. However, automatic re-orientation of the viewing direction is out of the scope of our study.

From the studies that we discussed in this subsection, we notice that a lot of research has been done on methods for the manipulation of the viewing direction in 360-degree videos using VR devices. Still, not many studies exist on methods for the manipulation of the viewing direction in 360-degree videos on 2D displays.

A.2.2 Timeline manipulation in 360-degree videos

Other than the manipulation of the viewing direction, researchers also studied ways to manipulate the timeline in 360-degree videos. Neng and Chambel's [19] 360-degree video player provides thumbnails of the video's scenes represented by cylindrical projection. This allows users to have an overview of the video's content over time. Furthermore, the users are able to click on a thumbnail and navigate to the specific time and viewing angle.

Li et al. [14] introduce an algorithm that constructs Route Tapestries from 360-degree videos similarly to slit-scan photography technique. Furthermore, the authors present Tapestry player which is a desktop-based 360-degree video player prototype that uses Route Tapestries for timeline navigation. In order to evaluate their video player, they conducted an experiment where the participants completed target finding tasks using their video player and two baseline techniques. Their results showed that participants completed tasks faster than the other two techniques and missed fewer targets.

Petry and Huber [25] present a new way on how to manipulate the timeline in Omnidirectional videos (ODV). Specifically, temporal navigation is achieved by using hand mid-air gestures. For instance, the user can play a video using a push gesture, pause a video by keeping his arm stretched, and fast forward or rewind a video by moving his hand left or right.

In this subsection we discussed methods to manipulate the timeline in 360-degree videos. However, in our study we will focus more on the manipulation of the viewing direction in 360-degree videos.

A.2.3 Comparative studies on 360-degree video interaction and user experience

After focusing on different interaction methods for viewing direction manipulation and timeline manipulation in 360-degree videos, we will now discuss comparative studies on 360-degree video interaction and user experience.

Van den Broeck et al. [5] conducted a comparative study on the 360-degree video viewing user experience on mobile devices using different interaction techniques. Specifically, they used a smartphone where the users were able to navigate through video space using dynamic peephole navigation, a tablet where they used touch as input modality to explore the video content, and a head mounted display (HMD) where the users could use their full body to navigate the virtual space of the 360-degree video. Their results showed that users preferred watching 360-degree videos on a smartphone since they were more familiar with the navigation controls compared to the other techniques. Moreover, their results suggested that 360-degree videos with moving viewports offer immersive viewing experience but they are cognitively demanding and cause discomfort.

Passmore et al. [23] explored users' viewing experiences of panoramic videos across different viewing platforms. Specifically, participants viewed an eight minute 360-degree video using a desktop, a handheld device and a Gear VR. Their findings showed that participants felt immersed using Gear VR. In contrast, participants felt removed while viewing the 360-degree video on desktop or handheld device. However, in all conditions they were interested in exploring the 360-degree video environment.

Zoric et al. [30] investigated the viewing and interaction with panoramic videos using a TV screen. Specifically, they focused on content interaction. To explore this they conducted two user studies. In the first user study, the users were able to interact with the video content by using a second touchscreen of a tablet. In the second user study, the users were able to use wide hand gestures to interact with the video content that was displayed on a large screen. In both studies the users were able to perform interactions such as zooming in and out, and navigate through the video space by tilting and panning. Their results revealed that navigation in panoramic videos should be intuitive and fast enough to cover relevant movement in the scene.

In this subsection we discussed studies that investigated users' experiences and interactions with 360-degree videos. However, we notice that in most of these studies, researchers used VR devices to conduct them. In our thesis, we will conduct a comparative study between three different interaction methods to explore which one of them is the most desired for manipulating the viewing direction in 360-degree videos on desktops using the keyboard and the mouse as input devices. Therefore, it is safe to say that our thesis will be one of the first comparative studies to explore the best interaction method for manipulating the viewing direction in 360-degree videos on 2D displays.

A.3 Summary and Conclusions

Video interaction has been studied a lot over the past few years. In this literature review we discussed video interaction for traditional 2D videos viewed on 2D displays. Specifically, we looked into desktop video interaction and mobile video interaction. Many studies explored ways to browse, summarize and manipulate the timeline in videos. In these studies the keyboard and mouse were used as input devices on desktops and hands as input methods on mobile devices.

In recent years, another type of media emerged. These are 360-degree videos that allow users to look omnidirectionally and explore the virtual environment of a video. We discussed several studies that focus on methods to manipulate the viewing direction and timeline in 360-degree videos using VR devices and personal computers. However, we noticed that little research has been done on methods regarding the manipulation of the viewing direction in 360-degree videos on 2D displays.

Furthermore, we explored studies that investigated users' experiences and interactions with 360-degree videos. However, in most of these studies, researchers focused on VR devices without considering 2D displays.

The main focus of this thesis is to explore which is the most effective and preferred method for manipulating the viewing direction in 360-degree videos on desktops. This will be done through a comparative study between three different interaction methods. These will be a gesture-based method, a method using hard buttons and a method using graphical widgets.

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Appendix B Further details about the executed research

B.1 Materials

We decided to develop an app for Windows operating system. The app was implemented using Unity cross-platform game engine version 2020.3.5f1. Moreover, the video player's buttons and the buttons for the graphical widgets method were downloaded from Unity's asset store. Three different versions of the app were built. The order that the interaction methods were presented was different in each version of the app to avoid any order effect. The different orders of the interaction methods are presented in Figure 9. A mouse, a keyboard and a Windows personal computer were needed to perform the experiment. Moreover, there was an introduction and consent form screen at the beginning of the experiment. This screen is shown in Figure 10.

Condition 1 - Gestures	Participants	Interface #1	Interface #2	Interface #3
Condition 2 - Hard buttons	1	1	2	3
Condition 3 - Virtual buttons	2	2	3	1
	3	3	1	2
	4	1	2	3
	5	2	3	1
	6	3	1	2
	7	1	2	3
	8	2	3	1
	9	3	1	2
	10	1	2	3
	11	2	3	1
	12	3	1	2
	13	1	2	3
	14	2	3	1
	15	3	1	2

Figure 9: Different orders of interaction methods for the 3 versions.

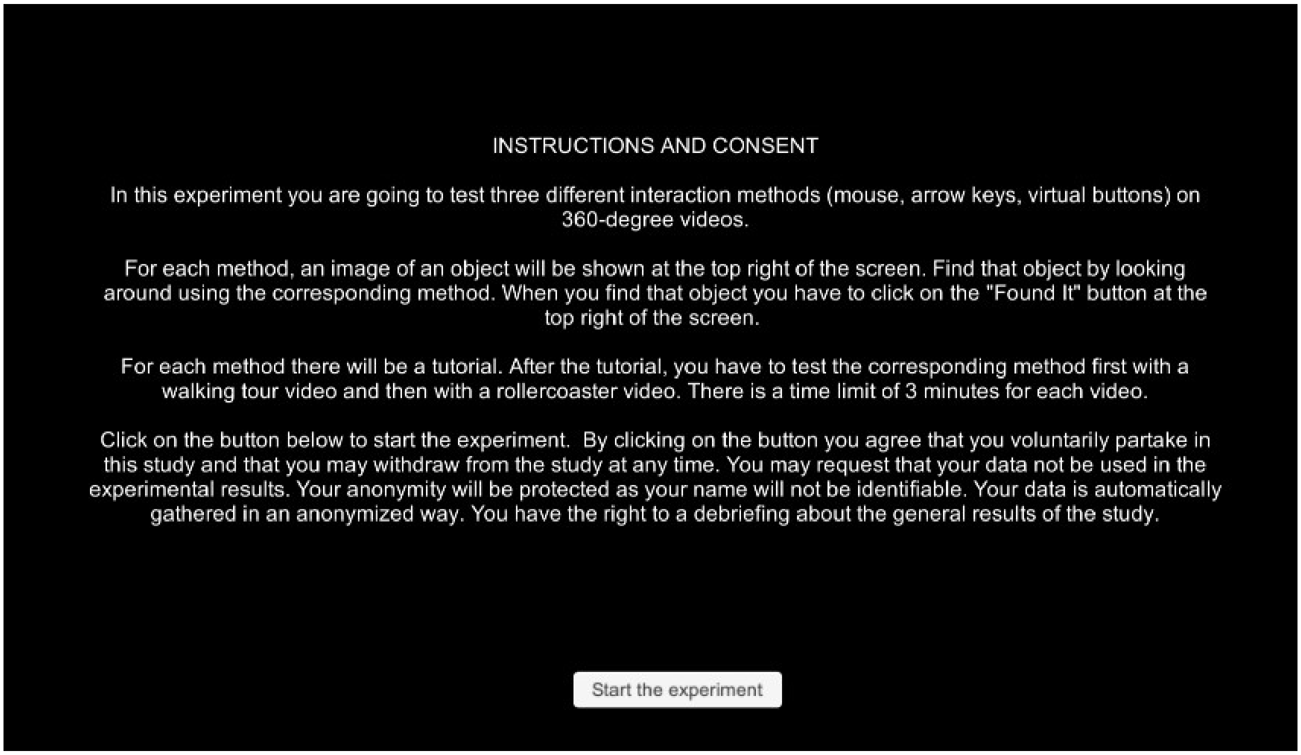

Figure 10: Introduction screen.

In total 5 360-degree videos were used for the experiment. 3 roller coaster ride videos, 1 walking tour video and a still camera video. The videos were retrieved from Youtube. These videos were edited to have the same length using an open source video editor called OpenShot. Below there are links to the original videos on Youtube:

Roller coaster ride videos:

- `https://www.youtube.com/watch?v=k4amiQ9A9D4`
- `https://www.youtube.com/watch?v=jAOOqns_nf0`
- `https://www.youtube.com/watch?v=-PO9x-NEak8`

Walking tour video:

- `https://www.youtube.com/watch?v=LR02eOYLMTM`

All the credits of the videos go to their respective owners.

B.2 Questionnaires

During the experiment, participants had to answer several questions. The different questionnaires are explained in detailed below.

B.2.1 General Information

At the beginning of the experiment, participants had to fill out some information about themselves. The questions are shown below.

- Age
- Gender

- How familiar are you with 360-degree videos?

For the age they had to fill out their age. For the gender there were 4 options. These were male, female, other and prefer not to tell. For the last question there were 4 options. These were Not at all, A little, Quite familiar, Very familiar.

B.2.2 Cybersickness

After finishing the tasks for each method, participants had to answer some questions regarding any discomfort that they might have felt while using the corresponding method for both types of videos. Participants had to choose between 3 options. These were no, minor discomfort, a lot of discomfort. The questions are presented below.

- Did you experience discomfort, nausea or dizziness while watching the walking tour videos?
- Did you experience discomfort, nausea or dizziness while watching the rollercoaster videos?

B.2.3 Usability

To find out if there were issues regarding the methods, we asked participants 10 usability questions. These questions were asked to the participants after finishing the tasks for each method. The answers were in a 5-point likert scale ranging from strongly disagree to strongly agree. The aforementioned questions are shown below.

- It was easy to use the interaction methods.
- It was tiring to use the interaction methods.
- I think that I would use these interaction methods to explore 360-degree videos.
- The interaction methods helped me to easily explore the video content.
- It was easy to understand how to use the interaction methods.
- I found the interaction methods complex.
- The interaction methods were responsive.
- The interaction methods felt natural and intuitive.
- I felt excited to explore the video content and find the requested objects.
- It was hard to find the requested objects.

B.2.4 Subjective method preference

At the end of the experiment, participants had to choose their favorite and least favorite method for each type of video. With their responses, we could find out which method was the most preferred interaction method to manipulate the viewing direction in 360-degree videos when viewed on 2D displays for each type of video. The questions are presented below.

- Which interaction method was your favorite for the walking tour videos?
- Which interaction method was your least favorite for the walking tour videos?
- Which interaction method was your favorite for the rollercoaster videos?
- Which interaction method was your least favorite for the rollercoaster videos?

B.3 Small interview

After the end of the experiment there was an optional small interview. Participants were asked to state some advantages of each approach, some disadvantages of each approach and if any comments they on generally or about the experiment. In total, 5 participants voluntarily participated in the small interview. Below there are some example answers from the participants for each question.

- What are some advantages of each approach?
  - "The mouse was easy to understand how it works."
  - "You could control every direction with the mouse."
  - "The arrow keys on the keyboard were the most familiar for most users."
  - "The arrow keys on the keyboard were easier to control, compared to virtual buttons and mouse you don't have to look where you press so you can focus on the video content."
  - "The virtual button were the most obvious method."
  - "Virtual buttons were a little more precise than arrow keys and less tiring if you are not looking for something."
- What are some disadvantages of each approach?
  - "Someone might have only a touchpad from a laptop. Thus, the mouse method is not very easy to use."
  - "You could easily lose control with the mouse."
  - "The arrow keys on the keyboard were fast."
  - "The arrow keys on the keyboard had no disadvantages compared to the other two methods."
  - "It takes a lot of time to press the virtual buttons because you have to both look where you press and look on the video content."
  - "The virtual buttons were the most tiring method."
- Any comments?
  - "Mouse was by far the best and most enjoyable method. It made the video more immersive since it felt like I was moving my head. Virtual buttons were tiring."
  - "I had fun exploring all the different places and courses of this experiment."
  - "An exciting way to stroll through a city and find out more details about a place."

B.4 Statistical analysis results

In order to analyze the results of the experiment, the data has been compared using statistical tests. These include paired sampled t-tests and one way repeated measures ANOVA tests as well as descriptive statistics and frequency test. These are presented in the next sections.

B.4.1 Descriptive statistics

In this section we present descriptive statistics including means for the completion time for each method and type of video.

Descriptive Statistics

	Mean	Std. Deviation	N
Time_g_w	35.1061	8.64030	20
Time_h_w	39.1539	20.51475	20
Time_v_w	51.9903	27.89978	20

Figure 11: Descriptive statistics for each method for the walking tour videos.

Descriptive Statistics

	Mean	Std. Deviation	N
Time_g_r	61.0031	38.58249	20
Time_h_r	65.3138	35.35473	20
Time_v_r	80.9213	38.63463	20

Figure 12: Descriptive statistics for each method for the roller coaster ride videos.

Descriptive Statistics

	Mean	Std. Deviation	N
Total_time_g	48.0546	30.55411	40
Total_time_h	52.2338	31.45564	40
Total_time_r	66.4558	36.34579	40

Figure 13: Descriptive statistics for each method for both types of videos.

B.4.2 One-way repeated measures ANOVA

In this section we present full results from the one-way repeated measures ANOVA tests for each method and type of video.

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

					Epsilon[b]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.826	3.440	2	.179	.852	.927	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Time

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Time	Sphericity Assumed	3108.259	2	1554.130	3.814	.031	.167
	Greenhouse-Geisser	3108.259	1.704	1824.504	3.814	.039	.167
	Huynh-Feldt	3108.259	1.854	1676.260	3.814	.035	.167
	Lower-bound	3108.259	1.000	3108.259	3.814	.066	.167
Error(Time)	Sphericity Assumed	15483.216	38	407.453			
	Greenhouse-Geisser	15483.216	32.369	478.338			
	Huynh-Feldt	15483.216	35.231	439.473			
	Lower-bound	15483.216	19.000	814.906			

Figure 14: One-way repeated measures ANOVA for each method for the walking tour videos.

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.980	.370	2	.831	.980	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Time

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Time	Sphericity Assumed	4392.748	2	2196.374	1.568	.222	.076
	Greenhouse-Geisser	4392.748	1.960	2241.016	1.568	.222	.076
	Huynh-Feldt	4392.748	2.000	2196.374	1.568	.222	.076
	Lower-bound	4392.748	1.000	4392.748	1.568	.226	.076
Error(Time)	Sphericity Assumed	53219.906	38	1400.524			
	Greenhouse-Geisser	53219.906	37.243	1428.990			
	Huynh-Feldt	53219.906	38.000	1400.524			
	Lower-bound	53219.906	19.000	2801.048			

Figure 15: One-way repeated measures ANOVA for each method for the roller coaster ride videos.

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.966	1.325	2	.516	.967	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Time

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Time	Sphericity Assumed	7444.498	2	3722.249	4.222	.018	.098
	Greenhouse-Geisser	7444.498	1.934	3849.764	4.222	.019	.098
	Huynh-Feldt	7444.498	2.000	3722.249	4.222	.018	.098
	Lower-bound	7444.498	1.000	7444.498	4.222	.047	.098
Error(Time)	Sphericity Assumed	68759.631	78	881.534			
	Greenhouse-Geisser	68759.631	75.416	911.733			
	Huynh-Feldt	68759.631	78.000	881.534			
	Lower-bound	68759.631	39.000	1763.067			

Figure 16: One-way repeated measures ANOVA for each method for both types of videos.

B.4.3 Paired samples t-test

In this section we present full results from paired samples t-tests for each method and type of video.

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	Time_g_w - Time_h_w	-4.04779	21.80121	4.87490	-14.25107	6.15549	-.830	19	.208	.417
Pair 2	Time_g_w - Time_v_w	-16.88428	31.18800	6.97385	-31.48071	-2.28784	-2.421	19	.013	.026
Pair 3	Time_h_w - Time_v_w	-12.83649	31.57109	7.05951	-27.61221	1.93924	-1.818	19	.042	.085

Figure 17: Paired samples t-test for each method for the walking tour videos.

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	Time_g_r - Time_h_r	-4.31062	50.62644	11.32042	-28.00452	19.38329	-.381	19	.354	.708
Pair 2	Time_g_r - Time_v_r	-19.91819	51.40383	11.49425	-43.97593	4.13954	-1.733	19	.050	.099
Pair 3	Time_h_r - Time_v_r	-15.60757	56.54867	12.64467	-42.07317	10.85802	-1.234	19	.116	.232

Figure 18: Paired samples t-test for each method for the roller coaster ride videos.

B.4.4 Preference results

In this section we present full results from the frequency analysis for the method preference.

Statistics

fw

N	Valid	20
	Missing	0

fw

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	11	55.0	55.0	55.0
	2.00	9	45.0	45.0	100.0
	Total	20	100.0	100.0	

Figure 19: Frequency analysis results for the favorite method for walking tour videos.

Statistics

lfw

N	Valid	20
	Missing	0

lfw

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	1	5.0	5.0	5.0
	2.00	1	5.0	5.0	10.0
	3.00	18	90.0	90.0	100.0
	Total	20	100.0	100.0	

Figure 20: Frequency analysis results for the least favorite method for walking tour videos.

Statistics

fr

N	Valid	20
	Missing	0

fr

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	11	55.0	55.0	55.0
	2.00	8	40.0	40.0	95.0
	3.00	1	5.0	5.0	100.0
	Total	20	100.0	100.0	

Figure 21: Frequency analysis results for the favorite method for roller coaster ride videos.

Statistics

lfr

N	Valid	20
	Missing	0

lfr

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	2	10.0	10.0	10.0
	2.00	2	10.0	10.0	20.0
	3.00	16	80.0	80.0	100.0
	Total	20	100.0	100.0	

Figure 22: Frequency analysis results for the least favorite method for roller coaster ride videos.

B.4.5 Cybersickness results

In this section we present full results from the frequency analysis for the cybersickness for each method and each type of video.

Statistics

CW_gesture

N	Valid	20
	Missing	0

CW_gesture

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	17	85.0	85.0	85.0
	2.00	3	15.0	15.0	100.0
	Total	20	100.0	100.0	

Figure 23: Frequency cybersickness analysis results for the gesture method for walking tour videos.

Statistics

CW_arrow

N	Valid	20
	Missing	0

CW_arrow

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	16	80.0	80.0	80.0
	2.00	4	20.0	20.0	100.0
	Total	20	100.0	100.0	

Figure 24: Frequency cybersickness analysis results for the hard buttons method for walking tour videos.

Statistics

CW_virtual

N	Valid	20
	Missing	0

CW_virtual

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	12	60.0	60.0	60.0
	2.00	6	30.0	30.0	90.0
	3.00	2	10.0	10.0	100.0
	Total	20	100.0	100.0	

Figure 25: Frequency cybersickness analysis results for the graphical widgets for walking tour videos.

Statistics

CR_gesture

N	Valid	20
	Missing	0

CR_gesture

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	16	80.0	80.0	80.0
	2.00	3	15.0	15.0	95.0
	3.00	1	5.0	5.0	100.0
	Total	20	100.0	100.0	

Figure 26: Frequency cybersickness analysis results for the gesture method for roller coaster ride videos.

Statistics

CR_arrow

N	Valid	20
	Missing	0

CR_arrow

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	14	70.0	70.0	70.0
	2.00	4	20.0	20.0	90.0
	3.00	2	10.0	10.0	100.0
	Total	20	100.0	100.0	

Figure 27: Frequency cybersickness analysis results for the hard buttons for roller coaster ride videos.

Statistics

CR_virtual

N	Valid	20
	Missing	0

CR_virtual

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	10	50.0	50.0	50.0
	2.00	7	35.0	35.0	85.0
	3.00	3	15.0	15.0	100.0
	Total	20	100.0	100.0	

Figure 28: Frequency cybersickness analysis results for the graphical widgets for roller coaster ride videos.