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Evaluation of Interaction Concepts in Virtual Reality Applications

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Abstract: Virtual Reality (VR) is widely used nowadays and, therefore, it is important to provide a high usability of this technology. In this paper we evaluate the possibilities of performing device assessment of prototypes of technical objects in VR applications: We designed three different interaction concepts for using the prototypes. We executed a case study in which the participants had to complete the task of brewing a cup of coffee with a virtual coffee machine using these interaction concepts. We observed the participants behavior during the completion of the task with the help of videos and questionnaires. Two of the interaction concepts are controller-based, one is a headset-based gaze pointer. The users of the gaze pointer performed best: They completed the task fastest and rated this concept with the highest usability score. The controller-based concepts were rated lower and the participants completed the task slower. The result of our case study can serve as a potential guideline with usability principles for VR applications concerning the design of controllers and the different interaction concepts.

Keywords: Virtual Reality, Usability, Usability Evaluation, Interaction Concepts, Interaction Design

1 Introduction

Virtual Reality (VR) is finding its way into more and more areas of the daily life. Due to this development, it is important to provide a high usability with this technology to enable a satisfying experience within virtual worlds and their wide variety of applications. The scopes of application are enormous and may provide the possibility of performing device assessment of prototypes of technical objects without having the need to have access to the physical object. Examples are printers, stereos or, like in our case, coffee machines. Therefore, the aim of our work is to find out whether these device assessments can be executed properly in VR applications and which interaction concepts are most suitable for this purpose. This paper sets some basic terms in the beginning, afterwards we embed it into the related work in this area. A description of our interaction concepts for VR as well as of the case study follow, in the end we evaluate and discuss the results.

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2 Foundations

VR is defined as “an artificial environment which is experienced through sensory stimuli (as sights and sounds) provided by a computer and in which one’s actions partially determine what happens in the environment” [Vir17]. Several different approaches such as CAVEs (Cave Automatic Virtual Environments), headmounted displays or simple devices which display stereoscopic pictures are used to create VRs [DBJ13]. At the beginning of our implementation in October 2016, the HTC Vive [HTC17], the Oculus Rift and the Playstation VR were the only VR headsets that used motion controllers and supported positional tracking [Sh16]. The HTC Vive provided the best 360 degree tracking so we chose a Vive for our case study. It comes with two controllers which allow to interact with the environment. The design of the controller with its buttons and their names can be seen from different angles in Figure 1: The trigger with its two pressure points is on the back of the controller, two grip buttons are positioned on each side. The large trackpad and the menu and system button are on the front of the controller. In VR applications, a virtual representation of the controller, which we call *virtual controller*, is shown on the display of the headset. To interact with the virtual environment, *control elements* such as the controllers or the headset can trigger certain actions. Those actions are called *interaction tasks* and they can only be performed on *interactable objects*: After touching an interactable object it can be grabbed with the control element, be attached to and moved together with it. Those actions correspond and are called *touch* and *grab action*, the latter also includes moving the grabbed object. *Use actions* trigger reactions of the used or a distant object, e.g. if a light switch is used, a light bulb somewhere else might turn on. The *interaction techniques* define how those interaction tasks are executed. For example, it is possible to touch an object by moving a control element close to it or by using raycasting with a laser beam.

For the evaluation of our case study, we used an adapted *System Usability Scale* (SUS). This questionnaire consists of ten different statements concerning several aspects of the usability of the tested system. We slightly changed some statements to allow us to evaluate the usability of the grab and use action. Every statement is rated with a score from 0 (worst) to 10 (best). To evaluate the whole tested system, the SUS score is calculated from the sum of the scores of the individual statements. The SUS score then ranges from 0 (worst) to 100 (best) points. The average SUS score is 69.5 points [BKM09].

3 Related Work

There already has been some research in the field of interaction techniques in immersive virtual environments, especially in late 1990s and early 2000s. During that time, head mounted displays were usually combined with several sensors for tracking a users hand motions [BH99][BH97] and eyes [Ka03], while controller-based input devices were not common. The researchers often had to deal with problems of inaccurate tracking hardware, slow system responses, and a high latency in general [Ko03]. This made it impossible to

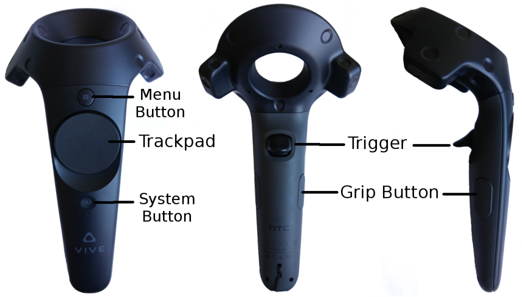


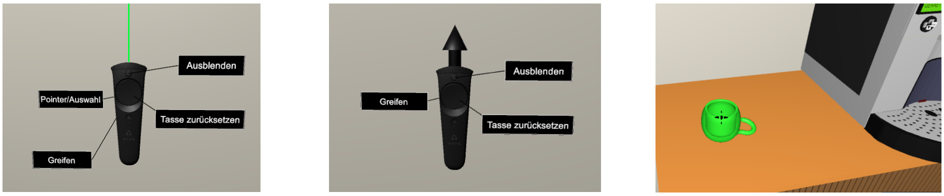
Fig. 1: The design of a controller of the HTC Vive with its buttons and their names.

focus completely on the interaction concepts and the results might have been distorted. The focus of most case studies lies on the interaction task of grabbing and moving objects, especially distant ones [BH99][BH97]. Several techniques were developed from usability tests which showed that ray-casting and extension of the users arms are not ideal for a good usability [BH99]. The result were techniques such as HOMER (Hand-centered Object Manipulation Extending Ray-casting) which uses ray-casting for the selection and grabbing of the objects. The grabbed object is then attached to a virtual hand and can be manipulated with the help of this hand (hand-centered manipulation) [BH97].

In [Sc02], several User Interface Concepts of Augmented Reality (AR) Systems are evaluated. This topic is closely related to our approach of undertaking case studies for usability engineering [Sc02]: In their approach, Schmidt et al. applied the methods of using questionnaires, interviews, observing the users interaction, and thinking aloud. They described them as ideal to get a detailed evaluation of the system. For our procedure, especially the recording of the results, we used this approach of Schmidt et al. as a guideline. After the early 2000s, there has not been much research in this area.

4 Interaction Concepts

In this paper, we implemented three interaction concepts to evaluate their usability. We call them laser controller, arrow controller and gaze pointer. Both the laser and the arrow concept use one controller as control elements while the gaze pointer is headset-based. VR offers the usage of tooltips on the virtual controllers. Tooltips are small labels that are connected to a button of the virtual controller. A text on the label describes the buttons functionality in one or two words. Our two controller-based concepts use tooltips. The interaction concepts are shown in Figure 2. Other implementations and key assignments are possible, but based on recent VR applications we decided for the following specifications for our case study.



(a) The laser controller with its four tooltips, the green laser beam is enabled.

(b) The arrow controller with its three tooltips, an arrow is attached to its front.

(c) The cross-hair of the headset-based gaze pointer in front of the green colored cup.

Fig. 2: The appearance of controller-based interaction concepts laser controller (a) and arrow controller (b) and of the headset-based gaze pointer (c). The tooltips of the controller-based concepts are the black labels that describe the functionality of the related button.

4.1 Laser Controller

For the laser controller, a laser beam can be used to point at and use objects in the VR. The laser beam radiates from the top of the virtual controller and can be activated by pulling the trigger to the first pressure point. Four controller tooltips (see Figure 2a) describe the controller functionality in this concept:

- *Ausblenden (Hide)* on the menu button: toggle controller tooltips
- *Pointer/Auswahl (Pointer/Selection)* on the trigger: enable laser beam (first pressure point) and trigger use actions (second pressure point)
- *Tasse zurücksetzen (Reset cup)* on the trackpad: reset scene to its original state
- *Greifen (Grab)* on grip buttons: grab a grabbable object

To touch an interactable object, the controller has to be moved close to the object until its surface collides with the surface of the other object. In this concept, the controller moves through the touched interactable object. After touching an object, two things happen to indicate that the object can be grabbed:

- The touched object changes its color.
- The tooltip text of the tooltip *Greifen (Grab)* changes from white to red.

Both effects can be seen on Figure 3a with the arrow concept, which behaves identically in this case. The text color of the left controller tooltip has become red and the originally white cup has colored grey. While the controller touches a grabbable object, it can be grabbed by pressing the grip buttons. After an object has been grabbed, the tooltip text of the grip buttons changes from *Greifen (Grab)* to *Loslassen (Release)* to indicate that the object can be released by pushing the grip buttons again. The laser beam in this interaction concept triggers use actions. When the laser beam is activated and then hits a usable object, the object changes its color to green (see Figure 3b). It changes to its original color when the laser beam is moved away. To trigger a use action when an object is green, the user needs to pull the trigger to the second pressure point and release it afterwards.

4.2 Arrow Controller

In the arrow concept the virtual controllers have an arrow attached at the front. This arrow indicates that the controller can be directly used to point at things and to trigger use actions without the need to push buttons on the controller. As a consequence, the arrow controller uses only three tooltips (see Figure 2b):

- *Ausblenden (Hide)* on the menu button: toggle controller tooltips
- *Tasse zurücksetzen (Reset cup)* on the trackpad: reset the scene
- *Greifen (Grab)* on the trigger: grab a grabbable object

Touching objects with this interaction concepts works similar to the laser concept: the controllers surface has to collide with an interactable object which will highlight after it is touched. In contrast to the laser controller, the arrow controller does not move through objects when they are touched but pushes them away. On the one side this should emphasize the possibility to use the controller similar to a hand without pressing buttons. On the other side this should provide a more realistic feeling because this is the behavior that would be expected in a real, i.e. non-virtual, world. In this interaction concept, the grab action is triggered by pulling the trigger instead of pressing the grip buttons while a grabbable object is being touched (see Figure 3a). Another difference to the laser concept is that the object is attached as long as the trigger is being pulled. As soon as it is released, the object will be detached. The adjustment in color of the controller tooltips is the same as for the laser controller. When the tip of the controller is moved closer than a predefined threshold distance to usable objects, the closest object to the arrow will be colored green (see Figure 3c). This indicates which object will be used if the controller is moved closer. The use action itself is triggered when the tip of the arrow hits the green object. This behavior should simulate the behavior of a hand in the real world, where the arrow is the index finger which interacts with an object by pushing it.

4.3 Gaze Pointer

The gaze pointer can interact with the environment with a cross-hair that is positioned in the field of view of the user. To start the equivalent action of touching an interactable object, the cross-hair needs to be in front of it (see Figure 2c). After targeting at an interactable object it starts to change its color slowly from its original color to green as visible in Figure 2c. As soon as an object is looked at for a threshold time of two seconds, the object changes its color completely and the grab action is triggered. The grabbed object is then attached to the cross-hair and moves along with it. To release a grabbed object in this interaction concept the user has to break the force that attaches the object to the cross-hair. This can be achieved by slightly moving it into another object. Another variant is that the object has a defined destination into which it automatically snaps if a certain distance to the position is reached. The use action works similar to the grab action: to trigger a use action a usable object has to be targeted for a predefined threshold time of two seconds with the cross-hair. When a usable object like a button of a coffee machine is being targeted, it changes its color to green first. During the next two seconds it slowly becomes red and at the end of the time span, the use action is executed.

To simplify the placing of the objects, we implemented a feature that supports the users in all interaction concepts: When an object is being moved into a predefined area with a controller-based concept, the color of the tooltip text that says “Loslassen” (“Release”) changes from white to red. This indicates that the object should be released there and will be placed correctly. With the gaze pointer, the object automatically detaches and places itself on the right spot when it enters the correct area.

(a) The grab action with the arrow controller: when an interactable, grabbable object (cup) is touched, the tooltip text color changes from white to red.

(b) The laser controller with the activated laser beam, a tooltip (pictogram of an empty cup) of a usable object (coffee machine button) is activated.

(c) The arrow controller in front of a button, the tooltip (“milder Kaffee”) of the closest usable object (left button of the coffee machine) is enabled.

Fig. 3: The grab (a) and use actions (b, c) of the laser (b) and arrow controller (a, c).

5 Case Study

To evaluate the interaction concepts, we performed a case study. The setup of this case study is described in the following section followed by the results. Afterwards, we discuss the results and the threads to validity.

5.1 Setup

In this case study, we set up a virtual room. It consists of two main objects as shown in Figure 4: A cup and a coffee machine which are both located on a bureau. The users task in this room is to grab the cup and place it at the correct position on the coffee machine. Afterwards, one of the buttons of the coffee machine which brews coffee has to be activated.

Three buttons accomplish this task: one for mild coffee, one for strong coffee and one that brews two cups of coffee (framed red in Figure 4). We decided for a coffee machine because the task of brewing coffee consist of several sub tasks and therefore covers a wide variety of the available actions in VR. Furthermore, the real coffee machine is easy to transport for the control group study and it can be assumed that most people have some experiences in using coffee machines.

For carrying out the case study, an interaction concept is randomly selected by the application for every participant. The interactable objects in this case study are the cup, which is grabbable, and the buttons of the coffee machine, which are usable. To perform this task, the users have to use the touch, grab, and use action of the three interaction concepts. The touch and grab action are used for moving the cup and the use action for pushing the buttons of the coffee machine.

For documenting our case study, we used several methods such as combining logging and recording videos of the screen with the picture that the participant saw in the VR. We also asked the participants to answer a SUS questionnaire which we slightly adapted to differentiate between grab and use actions. A data set of the recordings and results can be found at `https://doi.org/10.5281/zenodo.571138`.

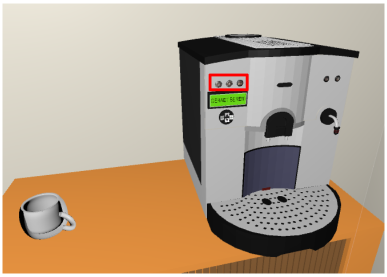


Fig. 4: The experimental setup: the cup and the coffee machine. The buttons that brew coffee are framed red.

66 participants took part in our case study. Every interaction concept was used 22 times. The majority of our participants was male (72.3%), only 27.7% were female. Furthermore, our participants were relatively young: 21.2% were younger than 15 and only 15.2% older than 35 years, in between the distribution was equal. 43.9% of our participants claimed that they have no previous experience with VR, only 18.2% stated that they are "very experienced".

We executed a similar case study with a control group for the device assessment of the coffee machine itself. This enabled us to distinguish between the usability problems of the interaction concepts in VR and the design problems of the coffee machine revealed by the device assessment. In contrast to our experimental group, the control group had to use the real coffee machine while the task remained the same: The participants in this group were also asked to brew a cup of coffee. The real coffee machine served as a blueprint for the virtual one and had, hence, the same functionality and design. This control group study was less formal. We explained the task to the participants and asked them to brew a cup of coffee while telling their thoughts. The participants were observed and their behavior documented in form of short notes. The control group consisted of seven people from twenty to seventy years old, both male and female.

5.2 Results

System Usability Scale. The overall mean SUS score of our case study is 64.9, which is slightly lower than the average score of 69.5. The gaze pointer reached the highest score in most statements and in total (68.9), while the arrow concept was rated worst (59.5). The arrow concept ranks in between with a total score of 66.1. Our adapted SUS contained a statement for each the intuitiveness of the grab and use action. The results of those two statements for every interaction concept can be seen in Table 1. For the gaze pointer, both statements were rated best of all three interaction concepts. For the arrow concept, they were rated worst.

	Laser Concept		Arrow Concept		Gaze Pointer	
Question	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Grab intuitive	6.14	3.16	5.00	3.45	6.25	3.92
Push button intuitive	5.34	3.21	5.11	3.13	6.93	3.69
Mean/Total	66.14	39.37	59.48	47.13	68.94	35.84

Tab. 1: Results of the System Usability Scale for the statements concerning the intuitiveness of the grab and use action from all three interaction concepts. Comparison of the statements between each concept: maximum (green) and minimum (red) means highlighted.

Video Analysis. With the help of the videos we were able to measure the duration the participants needed to complete different sections of the task. We divided the task into sections: overall duration from start to completion, from start to grabbing the cup, from grabbing the cup to placing it, from a placed cup to seeing the upper buttons and from that point of time to fulfilling the task. The results of this analysis can be found in Figure 5, where the timespans needed to complete the sections are shown according to the interaction concepts. The x-axis shows the different sections of interactions while the y-axis shows the time in seconds. The bars represent the interaction concepts. The gaze pointer users performed fastest in the overall completion of the task as well as in the sections of grabbing the cup and seeing the upper buttons. In contrast, the users of the controller-based concepts were faster in the placing of the cup.

Furthermore, the video analysis allowed us to figure out general and interaction concept specific problems. The general problem that occurred most often is that 14 participants did not see the row of upper buttons that is used to brew coffee, but only the lower left buttons. The problems with the laser controller are diverse: As far as the grab action is

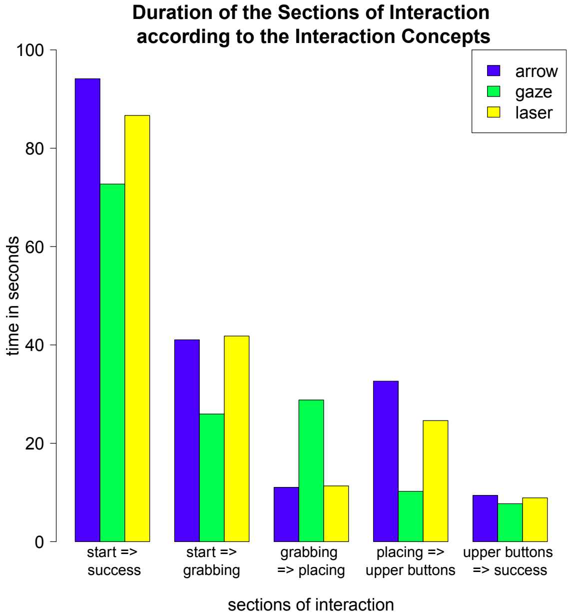


Fig. 5: The duration needed to complete the different sections of the task.

concerned, seven users tried to grab the cup by pressing the trackpad or trigger instead of the grip buttons. The release of the cup was also difficult for seven participants because they held the grip buttons during the grab and did not realize they had to press the buttons again to release the cup. For the use action, two other problems occurred with the laser controller: Ten participants tried to trigger the use action on the coffee machine by moving the controller closer to its buttons. Another six participants pressed the trackpad to trigger the use action, which led to a reset of the cup. For grabbing the cup with the arrow controller, nine participants pressed the trackpad to trigger this action. Another eleven participants tried to trigger the use action on the coffee machine by either pressing the trackpad or pulling the trigger. The only problem that occurred more than twice with the gaze pointer is that the cup was detached from the cross-hair more than five times for five participants because the participants broke the force that bound the cup to the cross-hair.

Control Group. It took the participants of our control group between ten to thirty seconds to complete the given task. As for the qualitative aspects, they had one main problem: The meaning of the pictogram on the top left button which shows an empty cup meaning “mild coffee” did not seem clear to most of the participants. Due to that, they chose to press the next button with a pictogram of a full coffee cup and therefore brew a strong coffee.

5.3 Conclusion

Based on our evaluation of the SUS score and the video analysis, the gaze pointer performed best and its users completed the task fastest. The arrow concept ranked lowest and therefore is least usable. The difficulties that arose with the control group do not intersect with the problems of the experimental group. The only problem of the control group with the design of the pictogram of the top left button did not occur in the experimental group. Therefore it can be concluded that the usability problems that occurred with our application are caused by the interaction concepts with the VR and not by the design of the coffee machine. This also leads to the conclusion that our interaction concepts need to be improved before VR-assisted device assessment reveals the same usability problems as the real coffee machine. Due to the lack of similar research, we cannot compare our results with other approaches. The following section presents our results for improving the interaction concepts.

Grab Action. The grab action with the laser concept received higher SUS scores than the arrow concept, but it took the participants with this concept slightly longer to complete it. These results can partially be explained with the design of the rigidness of the cup. As it can be observed in the videos, a lot of participants pushed the cup because the arrow controller did not move through it as it did with the laser concept. Therefore, the controller should not be rigid and push grabbable objects around. Furthermore, the participants expected to trigger the grab action by pressing the trackpad (arrow concept) or the trackpad and trigger (laser concept). Both buttons seem to be the most prominent buttons of the controllers and therefore are tried first for interactions. In consequence, it took the laser concept group longer to find the correct button for the grab action (grip buttons) than the arrow concept group (trigger). Grab actions should therefore be triggered by pressing a prominent button like the trackpad or trigger. Due to the lack of pressing wrong buttons, no obvious mistake could be observed for the gaze pointer. The high score of the SUS statement concerning the intuitiveness of the grab action and the short completion times with the gaze pointer indicate that less is better: Less controllers and buttons increase the usability of an interaction.

Use Action. Similar to the grab action, the use action should be triggered by the usage of a prominent button. The lack of a tooltip that told the users of the arrow concept how to activate a button of the coffee machine might have led them to try to press any controller button to get the desired result. On the other side, ten users of the laser concept wanted to activate the coffee machine by pressing no button at all but by moving the controller close to the coffee machine as it would have worked with the arrow concept. Therefore, it is up to the developer to decide whether use actions should be triggered by pressing a prominent button or by moving a controller closer to the object that should be used. If the latter is chosen, the controller design, e.g. with an arrow that “points” somewhere, should indicate this behavior and display the threshold that will trigger the action. The use action of the gaze pointer is very similar to the grab action.

Placing the Cup and Seeing the Upper Buttons. For placing the cup, the participants with the controller-based interaction concepts had little difficulties and accomplished the task much faster than the gaze pointer users. One problem that occurred seven times with the laser concept concerns the release of the cup: Pressing the grip buttons twice, once for grabbing and once for releasing an object, seems to be less intuitive than pressing them just once. A grabbed object should therefore stay attached as long as the grab button is pressed to mimic real world behavior. The problem of the too quickly detaching cup with the gaze pointer could be solved by increasing the force that binds a grabbed object to the cross-hair. Furthermore, the space between the object and its aim should be left free so that the cup cannot hit other objects.

In the subtask of seeing the upper buttons of the coffee machine, the arrow concept users were significantly slower than all other users. This could be explained by the positioning of the coffee machine buttons: After placing the cup, the controller had to be moved upwards to the correct buttons of the coffee machine. The buttons closest to the placed cup where the lower ones. As a consequence, the participants tried to interact with those buttons. Within the laser concept, this problem did not occur because the controller was usually held further away from the coffee machine. This allowed the participants to watch the whole coffee machine and due to this, they saw the upper buttons as well. The users of the gaze pointer were fastest to see the upper buttons. This might be due to the reason that the gaze pointer is based on looking at objects closely.

5.4 Threats to Validity

Several circumstances may have distorted the results of our case study and due to that some of the results have to be regarded critically. The distribution of the interaction concepts was not perfect even among our participants with their different preconditions. Interviews and the thinking aloud technique might have helped to get a better insight in the participants process of dealing with the given task by telling their exact thoughts and problems. In addition, our controller layout was chosen with care but still there might be better usable ways to configure the controller. For example, we did not implement a controller-based grab action using a laser beam and similar to this, other combinations can be imagined.

6 Summary and Outlook

In this paper, we defined three concepts for interacting with virtual prototypes of technical devices in a VR. Two concepts are controller-based and one gaze-pointer based. The concepts can be used when performing VR-based device assessment of technical prototypes. We evaluated the usability of the interaction concepts in a case study. In general, the gaze pointer performed best as far as both the completion time of the task and the SUS score are concerned. This can be affiliated to its minimalist design with no need to learn how to use the controllers. The controller-based arrow concept performed worst, for the completion time as well as for the SUS score. The reason can be found in the design of the controller and the grab and use action. Hence, for performing device assessment of prototypes of technical objects in VR, the design of the interaction concepts needs to be chosen with care.

An interesting topic for further research is to evaluate how controller-based interaction techniques can be improved further, or if controllers can be replaced with other devices such as the Leap Motion [Lea17]. The Leap Motion is a small device that can be attached to the front of the headset of the HTC Vive. It tracks the users hand motions and creates a hand model that is displayed on the screen of the Vive headsets.

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