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Developing a Functional User Interface for VR Simulations within Agricultural Equipment Contexts

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Abstract

This study investigates the optimization of VR simulation interfaces for agricultural machinery, emphasizing the critical role of skill development and targeted education in enhancing agricultural efficiency. By utilizing eye-tracking technology, the research evaluates user experience (UX) across two menu designs - panel and radial -in VR settings. Results highlight the significance of intuitive menu design in facilitating user navigation and information access, with the panel menu outperforming the radial menu in usability. Despite some preferences for the radial menu's features, the panel menu is favored for its user-friendly design and ease of access, particularly in agricultural simulations. The findings suggest that effective VR interface design, supported by focused training, can significantly improve operational efficiency in agriculture.

Keywords

UI, VR, Eye-tracking, panel menu, radial menu, usability, UX, agriculture.

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Introduction

By using VR simulators, researchers can safely test and refine human-machine interfaces without risking the safety of human workers. This approach allows for the optimization of new control systems, ensuring that they are user-friendly and efficient. Additionally, the use of VR simulators can provide valuable data on human behaviour and decision-making in complex scenarios, which can inform the design of safer and more productive construction equipment. In this way, the combination of human capital and technology can lead to improvements in both productivity and safety in the construction industry. In a study evaluating advanced human-machine interfaces for hydraulic excavators, researchers found that immersive VR simulations improve efficiency and ergonomics without causing mental or physical strain on operators (Morosi and Caruso, 2021; Makarov et al., 2021; Dhalmahapatra et al., 2021).

VR consists of a computer-generated virtual environment where the user can interact with the environment and objects. Well-designed VR can help people immerse themselves in what feels like a believable reality-like experience (Quesnel and Riecke, 2018). Although VR is not new, thanks to recent developments in immersive technologies, especially in visualization and interaction, VR is becoming increasingly attractive to scientists. The latest displays for VR head-mounted displays (HMDs), such as the HTC Vive or Oculus Rift, allow users to experience a high degree of immersion (Radianti et al., 2020) instead. The immersion describes the technical capabilities of a system; it is the physics of the system. The subjective correlate of embeddedness is presence. If a participant in VR perceives naturally using his or her senses, then the most straightforward inference the brain's perceptual system can make is that what is perceived is the participant's virtual environment (Slater and Sanchez-Vives, 2016).

Menus are an integral part of digital product user experience (UX), allowing users to easily navigate and find the features or content they need. It also gives users a sense of control over the app and makes it easier for them to interact with it. Studies have shown that a quality and intuitive menu can significantly improve a product's overall friendliness and usability and can be a critical factor in achieving success in the marketplace (Merritt and Zhao, 2021).

In the desktop application, the menu is created as a list of individual items to offer, where each item is associated with a specific command. Alternatives to this approach are pie menus, where each item is shaped like part of a pie and has the same proportion of the whole, making them efficient in terms of Fitts' law. These bids are usually designed to execute simple commands, with more complex tasks, such as multiple selections, which should be executed using other user interface elements (UI). These menus could be applied to VR, but the Fitts Act states that multiple aspects of VR offerings should be considered in development (Monteiro et al., 2019).

Fitts' law is used to evaluate human-computer interactions and to estimate movement time and difficulty index. However, Fitts' law is generally useful for measuring and estimating movement times between objects on the same axis or in the same dimension. In other words, the measurement axis can be either horizontal or vertical and cannot be used to measure both axes simultaneously (Nookhong and Kaewrattanapat, 2022).

User experience (UX) refers to a user when interacting with a product or service. This experience can be encountered in various activities, such as ordering food in restaurants, shopping, or commuting to work. However, the quality of the experience can vary depending on the context, as seen in the examples of a stressful morning car journey or a leisurely walk through a park. In contrast, usability is defined as the degree to which a particular entity can use a given system to achieve specific objectives effectively, efficiently, and satisfactorily within a well-defined context of use (Hassenzahl and Tractinsky, 2006). It encompasses three main factors related to the user's characteristics and objectives and the context of use: effectiveness, efficiency, and satisfaction. When evaluating usability, the goal is to ensure that aspects such as efficiency and effectiveness are consistent with the product under test (Quesnel and Riecke, 2018).

UI usability is essential because it assesses the product's pragmatic aspects related to the behavioural objectives that software must achieve. In the context of virtual reality (VR) games, usability evaluation should carefully consider the influence of VR features and gameplay goals (Radianti et al., 2020). For instance, a limited field of view can hinder the user's ability to step back and see the bigger picture in critical situations. This demonstrates the role of usability in achieving learning objectives in simulations and real-world situations. However, different games may have different requirements, and user testing on focus groups is necessary for game development. Previous studies have shown that usability also affects assessing factors that enhance learning (Fernández-Manjón et al., 2011). Therefore, usability evaluation is crucial in improving the overall user experience and achieving the desired outcomes in simulation training for participants to concentrate on the task, not the menu.

Various interaction techniques have been developed in virtual and augmented reality. While object selection, manipulation, travel, and pathfinding techniques are already in existing taxonomies and have been described in considerable detail, application control techniques still need to be sufficiently considered. However, these are needed by almost every mixed reality application, e.g., alternative objects or options. They are also needed for all kinds of real-world applications. For this purpose, there are many different techniques for selecting from three-dimensional (3D) menus (Dachselt & Hübner, 2006).

According to a study by Gebhardt et al. (2013), the most common approach for selecting a technique for VR menu ray-cast type. Users can directly point to the object for selection using a virtual ray cast, as a "laser pointer" does in the real world. Another method is to use a virtual fingertip to select from a menu. This uses a one-to-one mapping method, which is very intuitively similar to the real world. The limitation of this method is that the user experiences great difficulty in perceiving depth in the virtual environment. In addition, the user can only select from menus within arm's reach.

The most immersive VR systems typically include HMDs and handheld controls. HMDs are used in specific areas of medical practice and education, but their use proliferates. This kind of technology is also being applied in other various fields. Using a headset, the user can move and rotate in 3D space as if there they are. Also, the digital environment responds directly to the user's movements. HMD echnology can provide the user with complete immersion in the virtual environment (Salovaara-Hiltunen et al., 2019).

Our research mainly focused on developing and testing an effective user interface for virtual reality (VR) simulations in agricultural machinery environments based on previous research. Our study's objective was to optimize this UI's position and layout so that it could be tested afterward from the view of UX. Therefore, also compare and replicate the research but with augmentations from the way of our collective knowledge about the ideal position and coordinates of the panel menu, therefore using eye-tracking technology in the usability study.

We have not yet been able to identify a similar UX evaluation of VR technology used for simulations in agriculture, although similar machines are used. Therefore, research potential can be identified here.

The following sections summarize the necessary overview for familiarisation with the issue and introduce the essential background processes for the testing and data collection. We present the individual testing steps and then present the results with graphs and scale. We conclude with comments on the results and possible future research directions.

Materials and methods

Our paper also reports on a study conducted by Monteiro et al. (2019) on 51 participants who were presented with two different types of menus in a virtual reality environment. The menus were presented in four possible combinations and placed in two locations: fixed on a wall and attached to the user's hand. The study measured various factors, including menu usability, user satisfaction, interaction time, and the number of unnecessary steps. The results indicated that participants preferred the traditional panel menu in the virtual reality environment and performed better with it than with the radial menu. Therefore, the study highlights the importance of considering the type of menu and its location when designing menus for virtual reality environments.

Similar to the study conducted by Monteiro et al. (2019), our research involved a total of 50 participants. 40 was used to identify the appropriate menu position. A further 10 were used to test the actual environment. The object of the study was to identify a better solution between the two options. We look for errors and identify better solution based on their minimization. This allows us to rely on the methods presented by Nielsen (2012) and Virzi (1992), who present that it takes about five testers to identify 80% of usability errors.

Our sample included 18% women 82% men, with an average age of 24 years. Potential visual deficits were not addressed due to the focus of the study. 8 participants commonly wear glasses or contact lenses. None of the participants complained about any vision problems in the VR environment. 18 participants have used VR technology before, 2 of them work with it on a regular basis. The average length of the test trial and, thus, working in the VR environment lasted 24 minutes.

Thanks to the equipment available in our VR laboratory, we could utilize eye-tracking technology.

Eye-tracking interfaces use real-time eye movements as a mode of user interaction. This interface can be valuable when other interaction modes are unavailable or not preferred, such as when users have severe motor impairments or when their hands are occupied with other tasks. Although eye-tracking may not be as precise as using handheld controllers in VR, it can be much faster than traditional input devices (Špakov et al., 2014; Sibert and Jacob, 2000). Techniques for visualizing scan paths, such as heatmaps, are useful for analyzing the way subjects process information (Goldberg and Helfman, 2010). By using a fap that shows the degree of fixation accumulation, researchers can gain insights into the patterns of visual attention exhibited by subjects while performing a task (Wang et al., 2014). A heatmap can reveal which areas received the most visual attention and which areas were ignored during the task (Cai, Sharma, Chatelain and Noble, 2018).

Testing itself contained two testing processes. First, we focused on the panel menu and its position due to the more straightforward processing of the results from the scene. The first process of the testing had a general focus and helped to lock the menu in the proper position. The second process was first connecting the mentioned environment. Then select the machinery's attributes (model, color, equipment), in our case, a tractor.

The first testing consisted of several parts:

- Introduction;
- Introduction to the VR HW controls;
- Setting the menu parameters;

- Usability testing;
- Guided interview.

Participants were informed of the testing and reassured that they were not the ones being tested, but the environment and any missteps or controls were perfectly fine. VR technology was unfamiliar to most participants and made them a little nervous about interacting with the tester in a virtual space. Participants were familiarized with the technology and taught how to operate menus, which was a central part of the testing. The participants made decisions about parameters in a specific order:

1. Distance of the menu from the user;
2. The size of the menu;
3. Height of the menu from the ground;
4. Scroll left/right;
5. Rotation.

Before beginning the main tasks of the study, it was important for participants to become familiar with the research environment. To achieve this, participants were first given a set of simple tasks to complete, allowing them to become more comfortable with the research environment and the tasks that were to come.

During VR user interface testing, the Concurrent Think-aloud method (CTA) is often used. This method allowed us to test different aspects of the user interface and get immediate valuable feedback from users. Once the UI testing is complete, there is a short phase during which the tester interacts with the test user to gain further insights into their experience of using the product. This process is called a guided interview or Retrospective Think-aloud (RTA) and is usually conducted immediately after testing (Prokop et al., 2020).

The equipment we used has the I-VT fixation, a classification algorithm based on velocity, which identifies eye movements by analyzing the velocity of directional shifts of the eye (Olsen, 2012).

After usability testing, the respondent completed a questionnaire using the standardized System Usability Scale (SUS) method, which consisted of 10 sentences to evaluate various aspects of usability. The questionnaire used a Likert scale to assess ease of use, confidence, inconsistencies, and need for technical assistance. SUS scores provide a measure of overall usability and are considered a valuable evaluation tool (Brooke, 1996, p. 194).

Measurement results are reported in Unity units, where 1 unit corresponds to 1 meter in real space. The default menu position was 1.5 meters above the virtual floor and 5 meters from the user. The results can be divided into two categories: relevant and irrelevant. The relevant parameters are the height of the menu located on the Y-axis and the distance of the menu from the user on the X-axis. The less relevant parameters are the slope of the menu along the Z-axis and the size of the menu. Participants were most comfortable with menu positions between 1.16-1.86 meters from the virtual floor. Regarding the distance from the user, the ideal intervals ranged from 4.7 to 5.2 meters. Less than half of the participants changed the default menu position.

The second testing process, as mentioned before, was based on the study conducted by Monteiro et al. (2019). In this research, the authors compared the panel and radial menus. Thanks to the virtual reality laboratory, which includes eye-tracking HMD Vive pro eye, we were able to get diverse data. We compared a static panel menu with a radial menu positionally locked to the hand. Participants used a ray cast to control the panel menu and a touchpad for the radial menu, with finger tracking.

The second testing (for both menus) consists of several parts:

- Introduction;
- Introduction to the VR HW controls;
- Usability testing;
- Guided interview;
- SUS

Menu parameters were taken from the first testing process. We took coordinates and made a panel menu, which corresponds with the panel menu from the study by Monteiro et al. (2019). The changes were made on the base of Fitt's law; we adjusted the buttons to a space in the body of the menu for shorter distances between buttons. The radial menu was based on the research of Salkanovic et al. (2020), which was the implementation and analysis of pie menus for mobile touch devices. Then we start the usability testing of both menus. Tasks were assigned in a specific order for the participant to perform:

1. Change the color of the tractor to red;
2. Change the type of the tractor to New Holland;

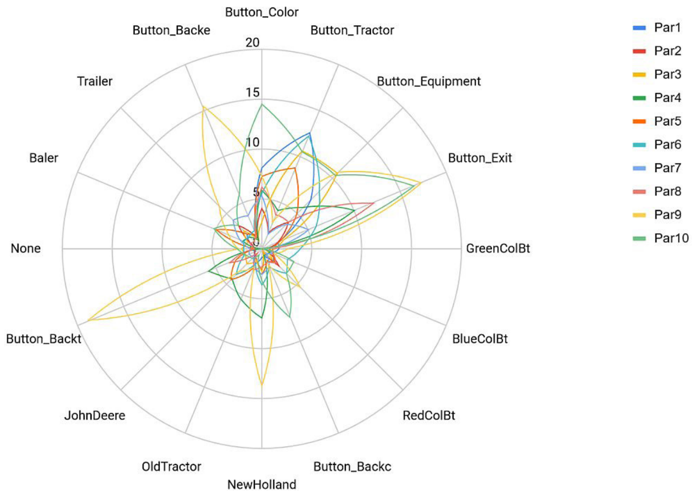
3. Change the equipment to a trailer;
4. Change all parameters mentioned before based on preferences, and please share experiences with a menu out load.

We collected heatmaps from every button in the radial menu and panel menu. We also collected the total fixation duration of participants looking at the buttons, then the first fixation time and first fixation length.

Results and discussion

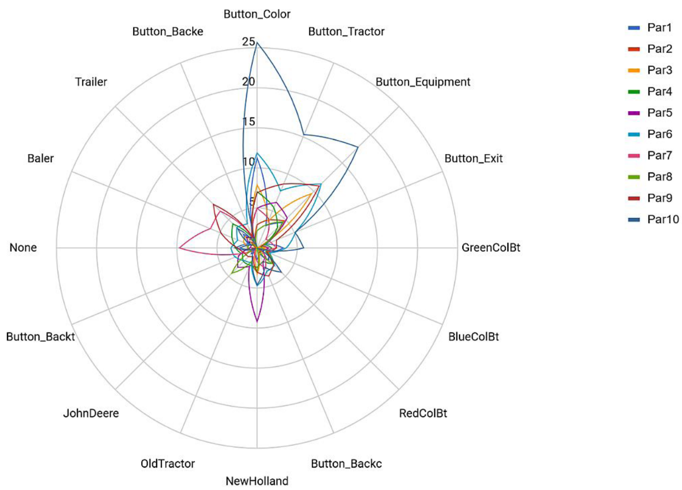
The testing demonstrated the value of using VR technology in user experience research. As VR technology continues to gain popularity, it presents exciting opportunities for improving simulations and other types of content. Although we know that the test sample of our participants was not significant, we believe this study is a gate to our more complex research in the future.

In terms of eye-tracking results, the heatmaps show that most participants only focused on the part of the button for the panel menu buttons. Most of the buttons in the panel menu had two or fewer points of higher concentration. In comparison, heat maps on buttons of the radial menu had a much more vast field and usually more than 2 points of higher concentration. When we look at the data of total duration on the buttons, we can say that participants spend much more time looking at buttons of the radial menu (see Figures 1, 2), which tells us the dispersion on the graph, where the middle line shows us duration in seconds. Most participants spend more than 5 seconds concentrating on the buttons. On the other hand, when testing the panel menu, most of the participants fit up to 5 seconds.



Source: own processing

Figure 1: Total duration in seconds (Radial menu).



Source: own processing

Figure 2: Total duration in seconds (Panel menu).

Observing both data sets, we can say that even though both menus do not have some great value, in most cases, the results are better for the panel menu. Furthermore, these results correspond to the obtained heat maps (see Figures 3, 4).

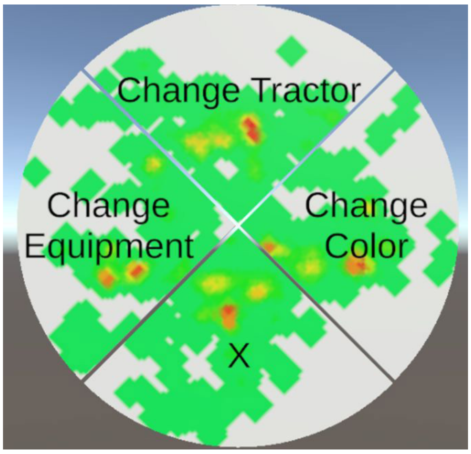


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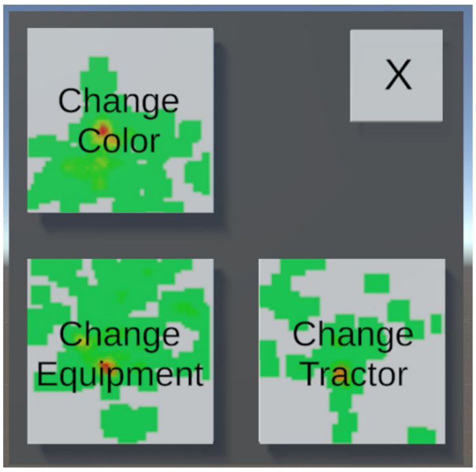
Figure 3: Heat map (Radial menu).



Source: own processing

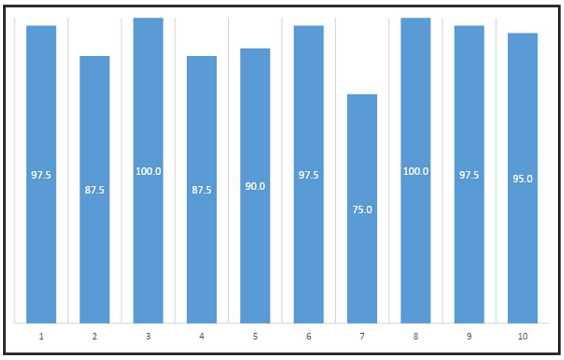
Figure 4: Heat map (Panel menu).

During the CTA and RTA, participants consistently mentioned that the panel menu was easier to handle, visually appealing, and intuitive. They appreciated having the menu close to the point of interest (the tractor). However, the radial menu was also deemed functional but difficult to handle, especially when switching between the menu and tractor or raising the hand. Even though some participants compared the handling of the radial menu to phone-like activity, they did not consider it for an advantage.

The SUS value is scored on a scale from 0 (worst) to 100 (best), with scores below 68 considered below average and scores above 68 considered above average (Bangor, Kortum and Miller, 2008).

In our study, the arithmetic means SUS score of all 10 participants was 92 for the panel menu and 71 for the radial menu.

This indicates that both menus are above average in terms of usability. Mainly the panel menu indicates a significantly above-average score, even for individual participants (see Figure 5). Where the bottom line shows the participant and the column shows the score.



Source: own processing

Figure 5: Individual panel menu SUS survey results (SUS score).

Conclusion

Our project focused on enhancing the user interface of virtual reality simulations for heavy machinery, recognizing the importance of specialized education and skill development in agricultural techniques. Therefore, our efforts were aimed at advancing the VR simulation interface specifically for use in agricultural machinery contexts. To assess the user experience effectively, we utilized eye-tracking technology, with a special focus on evaluating the design and usability of both panel and radial menus.

Our findings revealed that both panel and radial menus were rated highly for usability, though the panel menu was notably superior. Heat maps showed that users tended to interact with only certain buttons on the panel menu, while the radial menu's usage was more evenly spread. Additionally, it was observed that users spent more time engaging with the radial menu's buttons.

Feedback from Concurrent Think-aloud (CTA) and Retrospective Think-aloud (RTA) methods consistently favored the panel menu for its intuitiveness, visual appeal, and ease of use, attributed to its strategic placement near the user's focal point, the tractor. On the other hand, despite being functional, the radial menu was found to be less user-friendly, especially in tasks requiring the user to alternate focus between the menu and the tractor or to perform actions like raising the hand. Our research indicates a preference for the panel menu in terms of usability and overall user experience, notwithstanding certain benefits of the radial menu as noted by participants.

Our study delved into the challenges of applying traditional usability and UX research methods to VR environments, highlighting difficulties in navigation compared to standard computer interfaces. We recognized the potential for enhancing VR interaction in agriculture by adapting established methodologies for VR settings. While thoroughly examining these alterations was outside our scope, it presents a valuable direction for future studies. This exploration is particularly relevant when considering tools like the User-Technological Index of Precision Agriculture (UTIPA). The index is based on evaluating technological advancement and applicability for agricultural practice (Masner et al., 2019). That could benefit from improved VR UX to support precision agriculture communities.

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