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Prototyping and Evaluation of a Virtual Tower Work Station

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Abstract

While Remote Tower Solutions are readily available, the smallest aerodromes with less revenue can rarely justify the cost to go remote. For this purpose, the DLR German Aerospace Centre is in the midst of creating a low-cost Remote Tower prototype, specifically for the smallest aerodromes. The DLR prototype combines two panoramic cameras and a Pan-Tilt-Zoom-camera (PTZ), which are visualised through a Head Mounted Device in Virtual Reality (VR). The VR immersion offers both the out-the-window view of a conventional tower, as well as all necessary workstation systems and interactions. While the PTZ-camera is controlled through a combination of head movements and a handheld controller, the User Interface (UI) is operated with hands-free interactions and gestures. 22 Air Traffic Control Officers (ATCOs) and Aerodrome Flight Information Service Officers (AFISOs) tested the prototype in a validation study at DLR site. They stayed within the VR immersion for an hour, exploring the work station on their own, completing multiple tasks aimed to further deepen their knowledge of the camera controls and the User Interface, and observed live traffic of a local aerodrome in a passive shadow mode setting. During the immersion the ATCO or the AFISO was instructed to use the Think Aloud method to give direct feedback to the system. Cyber Sickness levels, the usability of the camera controls, the UI, and the system as a whole and specific potential future use cases were evaluated by standard questionnaires and a concluding interview. The feedback from both the Think Aloud Method and the following interview were analysed through a Qualitative Content Analysis regarding the ergonomics and usability of the prototype as well as the functionality as a work station. An immersion of one hour increases cybersickness slightly, but still within acceptable levels. While the UI and the system have a good usability, the PTZ controls are still lacking. Valuable points of improvement were identified.

Keywords: Virtual Tower; Remote Tower; Virtual Reality; Usability; Cybersickness

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1. Introduction

Remote Towers have become available worldwide (CANSO, 2021). Air Traffic Control Officers (ATCO) and Aerodrome Flight Information Officers (AFISO) are now able to provide Air Traffic Services (ATS) without the locational restraints of the aerodrome they are operating from. By grouping these remotely operated airports within centralised Remote Tower Centres (RTCs), synergies regarding the spent resources, cost-effectiveness, flexibility, safety, and the provided service levels can be created for the involved aerodromes (SESAR Joint Undertaking, 2019). However, due to budget constraints of aerodromes with lower revenue, such airports step away from the necessary investments or cannot afford them at all to install a Remote Tower solution (Reuschling & Jakobi, 2022a). The proposed Virtual Reality (VR) Remote Tower proposes a low-cost Remote Tower solution. Using a Head Mounted Device (HMD), the 360° view of an aerodrome is displayed in a virtual environment. Within the environment, a full tower working position is created without the need of an external console. Coupled with lower operational requirements for non-controlled aerodromes with lower service levels, like Aerodrome Flight Information Services (AFIS) or just a non-certified ground station operator (stations often called "Radio"), such a solution allows the usage of less sophisticated camera streams, reducing the cost of a full RTO setup significantly (Reuschling & Jakobi, 2022b).

Potential use cases for such a setup include (1) *AFIS on request* and (2) *Air Traffic Control* (*ATC) on request*, where the local aerodrome's service provider is able to request short term assistance from a remote ATS unit to increase the service level of the aerodrome for a limited time frame. A (3) '*Multiple Remote Tower*' on the other hand, allows multiple aerodromes to share an operator and its corresponding cost. This could potentially increase the aerodromes revenue, if it allows them to limit their expenses when extending opening hours or during off-peak periods. The usage of a mobile HMD would also open up possibilities for niche use cases. The (4) '*Tower to Go*' allows an operator to remove themselves from the physical tower, while carrying the HMD on them, and still have access to their work space. This would become beneficial when an operator is forced to be outside the tower for a certain amount of time. Last but not least, the setup would also allow for a (5) '*Permanent Remote Tower'*, moving the workstation completely into a remote virtual environment independent of any location constraint.

The aim of this study is to evaluate such a VR Remote Tower solution created at the German Aerospace Centre (DLR). The DLR prototype, also called the 'Virtual Tower', was tested regarding its usability and induced cybersickness levels, to determine whether it can provide a functioning workspace, and regarding the proposed use cases to verify the feasibility from the viewpoint of potential operators.

2. DLR Virtual Tower prototype setup

The hardware setup of the Virtual Tower prototype consists of two panoramic cameras, providing a 360° view of the Braunschweig Wolfsburg airport, a pan-tilt-zoom camera (PTZ), which is freely movable on the horizontal and vertical axes, as well as a Vive Pro Eye VR headset (VIVE, 2024b) combined with a Leap Motion (Ultraleap, 2023) sensor (Reuschling & Jakobi, 2022a).

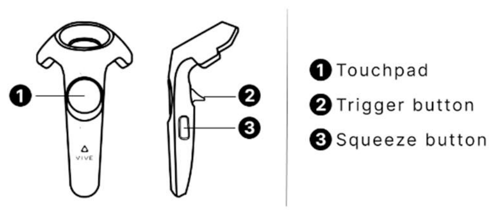


Fig. 1. (left) Virtual Tower setup within the virtual environment; Fig. 2 (right) Vive Pro controller (adapted from VIVE (2024a)).

Within the VR environment, the 360° view of the aerodrome is always visible. The PTZ camera stream is superimposed onto the background within a separate window which can be toggled on and off and moved using a Vive Pro controller (VIVE, 2024a). The PTZ camera offers a more detailed view of the segment behind it.

There are two modes of controlling the movement of the PTZ camera; In the *trigger-based movement* of the PTZ, the position of the user's head is utilised by pressing the trigger button of the VIVE Pro controller (Fig. 2), causing the PTZ to follow the user's head movement until released. In the *touchpad-based* movement, the PTZ window is moved relatively to its current position by clicking in any direction on the touchpad of the controller, causing the PTZ to move into this direction. To zoom within the PTZ window, the squeeze button on the side of the controller has to be held down while swiping over the touchpad, with clockwise motions resulting in the PTZ zooming into the scene and vice versa.

The Virtual Tower also includes a User Interface (UI) which provides the user with the tools of a tower working position. The UI is based upon, and further improves, Opower & Jakobi's (2022) prototype design. The UI is operated through hand gestures, utilising a Leap Motion sensor which recognises hand movements within a radius of 60cm (Ultraleap, 2023). Panels are moved via means of grabbing and dragging, whereas interactions on the panels are implemented through poking motions. The virtual environment also includes a Head-Up-Display (HUD), adapted from Blessmann (2020) and Hoffman et al. (2020), which displays important weather information as well as a compass line indicating the cardinal direction the user is facing. Additionally, two audio streams provide ambient aerodrome sound and the live radio transmissions of the local tower frequency.

3. Theoretical framework and research questions

The aim of this study is to evaluate the current Virtual Tower prototype in regard to its usability, induced cybersickness levels, as well as the potential feasibility of the different use cases. There are multiple definitions and constructs for usability (Lewis & Sauro, 2021). This study is following the framework provided by the International Organization for Standardization (1998) which defines usability as the effectiveness, efficiency, and satisfaction of an object during an interaction.

In addition to the fields arising from the usability framework, it is important to also consider VR related aspects. Souchet et al. (2022) define five VR induced symptoms and effects. These consist of cyber sickness, visual fatigue, muscle fatigue, acute stress, and mental overload. Cybersickness is a large concern within VR, as it is estimated that a third of VR users will experience discomfort during an immersion inside VR (Stanney et al., 2020). There are multiple theories which try to explain why and how VR induces cybersickness (Souchet et al., 2022; Stanney et al., 2020). One of the more prevalent theories describes cyber sickness as a consequence of mismatched sensory cues (Stanney et al., 2020). As the Virtual Tower is operated from a stationary environment, sensory mismatches are kept minimal. Following the sensory conflict theory, the immersion within the Virtual Tower should not lead to critical cybersickness levels.

The following research questions are therefore of special interest for this paper;

(1) Is the Virtual Tower prototype usable regarding its controls and user interface? And, if not, which aspects or functions regarding the interface and control design should be improved to increase the usability of the Virtual Tower prototype?
(2) To which extend does the immersion in the Virtual Tower induce cybersickness levels?
(3) How do ATCOs and AFISOs assess the feasibility of the Virtual Tower across different use cases?

4. Methods

4.1. Participants

15 ATCOs and 7 AFISOs between 22 and 66 years (M = 39.30, SD = 13.34) participated in the study. One ATCO was female. All participants were either currently working or had worked at German aerodromes. The participants had their licence for an average of M = 8.70 (SD = 8.41) years.

System Usability Scale

To measure the general usability of a system, the System Usability Scale (SUS) has been widely established (Brooke, 1996). As the means of this study is to examine the camera movement, the User Interface, and the Virtual Tower as a whole, the SUS was repeated three times for each participant. To adjust each measure to the components, the words "the system", which were used in the original questionnaire, were exchanged with "the camera movement", "the User Interface", and "the system as a whole", respectively. A German translation was used to assess the SUS (Rummel, 2016). The SUS provides a SUS-score ranging from 0 to 100.

4.2. Simulator Sickness Questionnaire

The Simulator Sickness Questionnaire (SSQ) is a measure for simulator sickness (Kennedy et al., 1993). While it was originally created for sickness experienced during flight simulators, it is also used to quantify cybersickness levels (Bimberg et al., 2020; Stanney et al., 1997). The SSQ consists of 16 symptoms, which are rated on a four-point scale, ranging from "none" to "severe". From these symptoms it is possible to calculate three subscales: nausea, oculomotor disturbance, and disorientation, as well as the total simulator sickness scores.

4.3. Qualitative Analysis

There are two sources of data for the qualitative analysis: comments made by the participants during their immersion in the virtual environment using the think aloud method and an interview afterwards. The analysis of the collected data will follow the Qualitative Content Analysis of Mayring (2014). The analysis will follow an inductive approach, summarizing the collected statements. The analysis was performed with MAXQDA 2022 (VERBI Software, 2021).

The think aloud method is a usability testing method meant to produce verbal data from participants while engaging in a task (Ericsson & Simon, 1984; Lewis & Sauro, 2021). Participants are instructed to verbalise their thoughts and actions during the operation of a system. The think aloud method used during the study was adapted to correspond to Boren and Ramey's (2000) theoretical fundament, allowing a more active role on behalf of the researcher during the think aloud period, like intervening when a participant is unable to continue with their exploration or prompting the use of specific functions if the participant fails to locate them. To gain further insight into the participants experience with the Virtual Tower prototype, a structured interview was conducted with the participants after the immersion, consisting of three parts; the experience with the input modalities, the design of the UI, and an evaluation of five potential use cases. The interview was conducted in German with open-ended questions.

4.4. Study Design and Setup

The study was divided into two main parts; the immersion within the Virtual Tower and a following interview. During the immersion, the participants were first asked to explore the system on their own for up to 20 minutes. Then, they completed two task blocks concerning the camera movement and the UI interactions. The tasks provided the participants with further insight into the system and deepened their experience with the controls. Finally, the participants experienced the Virtual Tower in a passive shadow mode trial, where they were tasked to follow the traffic while listening in to the live radio transmissions, lasting up to 20 minutes. Both during the exploration and passive shadow mode, the participants were asked to verbalise their experience using the think aloud method.

The SSQ was assessed directly before and after the immersion. Following the post-immersion SSQ, the participants filled out the SUS-scales. Both the SUS and the SSQ were filled out in a paper-and-pencil version. Then, the participants were given the opportunity for a short break before starting the interview.

The study was conducted at the HMI-laboratory of the Human Factors department of the DLR Institute of Flight Guidance. The participants were seated on a chair in the middle of the room, to allow safe movement while keeping the VR headset on. The headset was connected to a PC via a 3m long cable. Two loudspeakers were set up in the room to allow audio transmission. A microphone was set up about a meter away from the participants.

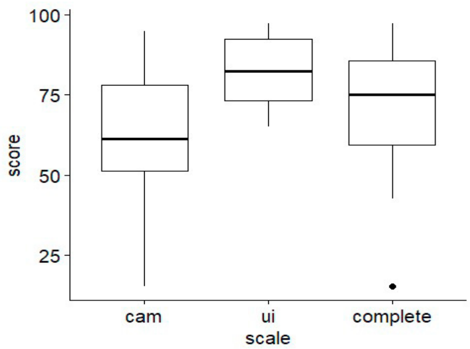
5. Results

5.1. System Usability Scale

The participants rated the usability of the system on three different scales. For the camera controls, the SUS values were *M* = 62.0, *SD* = 22.0, the UI interaction was rated as *M* = 82.5, *SD* = 11.5, and the total system as *M* = 70.8, *SD* = 20.34. Fig. 3 shows the median values and distribution of the measurements.

5.2. Simulator Sickness Questionnaire

The SSQ delivers values for three different subscales and a total SSQ score and was measure pre- and post-immersion. Nausea (Pre: *M* = 4.54, *SD* = 11.5; Post: *M* = 9.99, *SD* = 15.8), oculomotor disturbances (Pre: *M* = 10.5, *SD* = 14.3; Post: *M* = 11.9, *SD* = 11.9), disorientation (Pre: *M* = 6.63, *SD* = 16.8; Post: *M* = 14.6, *SD* = 23.1), and total SSQ (Pre: *M* = 8.73, *SD* = 15.1; Post: *M* = 13.7, *SD* = 17.4). Fig. 4 shows the median values and distribution of the measurements.



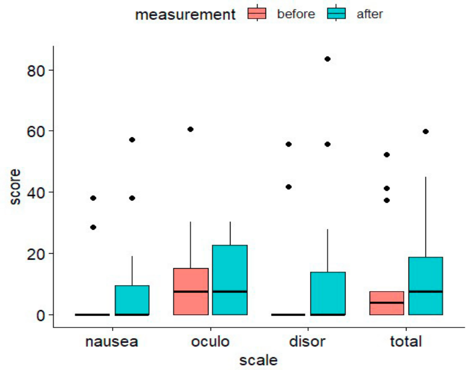


Figure 3: (left) Boxplot of SUS score values; Figure 4: (right) Boxplot of SSQ-score values pre- and post-immersion

5.3. Qualitative Analysis

5.3.1. Usability

From the comments made by the participants, there were issues in both the camera controls and the UI interaction which impacted the usability of the system. For the camera controls, the participants criticised issues regarding the controller and the precision of the camera movements. There were multiple comments during the think aloud periods about participants not finding specific buttons and being frustrated with the controller layout. Additionally, the participants had issues with both the trigger-based and the touchpad-based movement when targeting objects. With the trigger-based movement, participants experienced shakiness when moving the PTZ camera, leading them to miss their targets, whereas the movement speed of the touchpad-based movement was perceived as either too large when zoomed in, resulting in them overshooting their target, or too small when zoomed out.

While the participants perceived the usability of the UI as good, seeing as it was generally regarded as suitable for its tasks and easy to understand, the lack of precision regarding the hand tracking had a heavy impact on the usability of the UI. The participants often encountered the problem of their input not being recognised properly, especially in the case of pressing smaller buttons, leading to different errors in the system and when grabbing, and more importantly, letting go of the panels.

5.3.2. Potential Use Cases

The comments made by the participants regarding the potential use cases can be summarized into functions, suitability, and issues concerning the hardware. Most of the points were repeated for each use case, which is why the results in respect to individual use cases will follow after a general overview.

The functions of the Virtual Tower were seen as generally positive for a tower workstation. Especially the flexibility of the system was emphasized. As the layout of the workstation is fully virtual, participants mentioned that the Virtual Tower enables a flexible work environment for both the individual user, as they could configure the layout to cater to their needs, as well as for the aerodrome. Specific functions could be adapted from one aerodrome to another. Participants also suggested implementing various functions which could be beneficial for the working position. These included a tracking function for the PTZ camera, radar visualisation, and tools for communication with the ground personnel. These functions were especially requested for use cases concerning ATC services.

For the suitability regarding the different use cases, participants could generally see the Virtual Tower as viable, providing there were advanced in the development and the technology used. Participants saw opportunities for saving resources, like tower upkeep and personnel cost and to increase their service level. It was mentioned that especially for smaller aerodromes these savings could be sensible. Participants also stated that the usage of cameras could lead to gain a better surveillance when following traffic, as they allow more detailed observations. There were however, also concerns regarding the implementation of the Virtual Tower. Participants voiced uneasiness in the cases of safety issues, especially system malfunctioning. Some participants were also critical whether the implementation of a Virtual Tower would lead to significant cost reductions for the aerodromes. Additionally, the use cases of ‘Multiple Remote’ and ‘Tower to go’ received mixed responses. A Multiple Remote Tower solution with VR glasses would only function if there is enough time between movements and no possible overlap. For the ‘Tower to Go’ there were concerns that the operator would not have a suitable working environment when leaving the tower and a ‘professionalisation’ of such a use case would not be advisable.

The VR glasses themselves were regarded as positive, as they provide a 360° workspace with spatial depth and therefore convey the feeling of being in a tower, but were also criticised for their resolution, wearing comfort, chance of digital fatigue, and possibility of failure.

6. Discussion

6.1. Usability

For the Virtual Tower to be a further development of a Remote Tower working position, it has to be usable. For this purpose, the usability of the controls and the UI are integral to evaluate and improve upon. The results of the SUS can be assessed using different metrics found in the literature. According to Bangor et al.’s (2009) scale, the SUS-scores indicate that while the current usability of the UI ($M = 82.5$) can be considered as good, the usability of the camera controls ($M = 62.0$) and the complete system ($M = 70.8$) are only OK. Compared to a mean usability score of over 500 different studies ($N = 5000$, $M = 68$), the usability of the camera movement is below-average (Sauro, 2011).

Following the results of the qualitative content analysis, there were three main issues identified which had an impact on the usability of the camera movement. Two issues were determined for the UI interaction. As the participants struggled with the input of the Vive Pro controller, it would be reasonable to implement a virtual counterpart of the controller within the virtual environment and to consider using a different controller for the input. Additionally, the participants encountered difficulties while targeting and following objects. To improve the precision of the trigger-based movement, a dampening effect, similar to the one seen in Chang and Cohen (2017), could help to reduce the natural shaking of a user’s head. For the touchpad-based movement, adjusting the movement speed of the PTZ in relation to the zoom factor could enhance the effectiveness of the movement as well as user satisfaction.

To further increase the usability of the UI interaction, two measures could be regarded moving forward. The participants were struggling when pressing different buttons; sufficient spacing and larger buttons could already improve the precision when interacting with the UI. On the other hand, it would also be sensible to upgrade the hand tracking sensor to a newer generation. The accuracy of the Leap Motion sensor, which was used in this study, drops when an object is further than 250mm away (Guna et al., 2014, Vysocký et al., 2020). It is presumable that a newer generation hand tracking sensor has greater precision than the one used in this study, and could therefore increase the usability, especially in terms of error rates and user satisfaction, of the Virtual Tower. The VR environment familiarisation should be considered as a mitigating effect in these results. Difficulties which the participants reported when interacting with the system could be improved with more training and familiarisation.

6.2. Cybersickness

Additionally, to the usability of the system, the cybersickness levels induced by the Virtual Tower are essential for its operability. If the Virtual Tower induces critical levels of sickness while it is used, it should not be considered for critical operations like ATS. Kennedy et al. (1993) identify an SSQ score of 20 and over as an indicator for a “bad simulator”. This score has been previously criticised, seeing as the original sample consisted of highly trained military pilots (Bimberg et al., 2020). There is also further evidence that the cut-off score is not suitable for VR environments, as VR immersions generally lead to higher sickness scores than flight simulators (Bimberg et al., 2020; Stanney et al., 2020). A systematic review of cybersickness in newer HMD’s suggests increasing the cut-off value for a “bad simulator” from 20 to 40, as this indicates a drop-out rate of 33% (Caserman et al., 2021). Considering the cut-off value of both 20 and 40 being an indicator of a “bad” simulator, the Virtual Tower shows very acceptable levels of cybersickness. On average, the participants report a total SSQ score of $M = 13.7$ ($SD = 17.4$) after an hour within the Virtual Tower. Additionally, participants already entered the immersion with comparatively high total SSQ values ($M = 8.73$, $SD = 15.1$).

These results can be explained in part by considering the sensory mismatch theory and the stationary nature of the Virtual Tower. As the user is firmly seated, and does not move within the environment, cybersickness levels are kept minimal. However, the SSQ scores do show high variability, with occasional outliers which report high cybersickness levels. Following Stanney et al.’s (1997) research, kinematics are only one of five areas which influence cybersickness (technical system factors, user characteristics, time spent in immersion, exposure over time, and kinematics).

In general, the reported SSQ scores show that the Virtual Tower can be used at least as a short-term working station. However, user characteristics which could influence the susceptibility to cybersickness should be regarded when selecting operators. Other VR induced symptoms and effects, which could be induced by the Virtual Tower like muscle fatigue and mental overload, should be studied in the future when the prototype has been further developed.

6.3. Qualitative User feedback on the use cases

Overall, the Virtual Tower was seen as a potential solution for a future Remote Tower working position. However, many of the positive opinions were conditional on the prototype going through more development and technological advances. At the time of writing, these advances could be established in the foreseeable future, and in some cases, are already available, like Ultraleap’s (2024) Leap Motion 2 hand tracking sensor. Especially the controls could become more user-friendly with new emerging technologies and the above discussed potential improvements (see 6.1.). If these issues were resolved, the participants saw the implementation of the Virtual Tower, particularly in the use cases of ‘*AFIS*’ or ‘*ATC on request*’, as achievable and potentially beneficial to increase local service levels when needed. For the ‘*Multiple Remote’* and the ‘*Tower to Go*’ use cases, further elaboration seems to be needed. Participants voiced concerns about flight movements overlapping in the ‘*Multiple Remote’* case, so predetermined separation should be considered. For the ‘*Tower to Go’*, only specific working areas should be used to operate the Virtual Tower from, as it was mentioned that the operator should not be disturbed in their work. Last but not least, the feedback received for the ‘*Permanent Remote Tower’* saw a full VR workstation as potentially feasible, but more as a far future concept.

As previous implementations of digital towers show, transitions to a remote system can be a challenge for operators (CANSO, 2021). These reservations could be observed in the concerns voiced by the ATCOs and AFISOs participating in this study. Especially outages of the system and the hardware were regarded as worrying. Considering these reservations, keeping the operators in the loop and showing that these digital solutions can work through validation exercises and familiarisation, are integral in gaining the acceptance of ATCOs and AFISOs for the Virtual Tower moving forward.

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