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Design Study for a Virtual Work Station for Aerodrome Air Traffic Service Officers

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Abstract

Driven by the need for cost efficiency and a need for increasing the air traffic service (ATS) level the "Remote Tower" concept was developed and implemented the last years. By a relayed video stream from the airport to a remote location it allows the provision of ATS from a centralized Remote Tower Center, where valuable resources can be pooled and used more efficiently. The display of the video streams is usually realized by large panorama monitors but for cost and space reasons could also be performed via virtual reality head worn glasses for certain use cases. This design study investigates possible interface concepts for such virtual reality environments. The aim was to design a complete air control traffic (ATC) tower work station for a virtual reality environment. Previous research has primely relied on representation of the video stream and first interaction concepts in a virtual environment. By means of a contextual interview with an ATS officer and a subsequent usage context analysis, requirements for the system were defined. As a result, a basic design structure of an ATC Tower work station in VR was developed in form of mock ups. The design and its interaction concept were tested in a user survey with very positive feedback from ATS officers. In further studies an implementation of the prototypes in VR will be sought and further evaluated.

1. Introduction

Home office, flexibility, independence of location, these are all terms that are currently as well as in the future influencing our everyday lives. The world of work is shifting more and more from a stationary workplace to a "where-you-are-job". What employees mainly need is their own mind, which is not bound to a fixed location. But what if employees' thinking skills alone are not enough? What if the work environment is a major part of the job? Then the

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workplace has to come to the employees. This is exactly where the concept of Virtual Reality using glasses comes in. The office is located in these glasses and can be carried around as needed. One such workplace that cannot be separated from employees is the tower at an airfield. But here, too, there are already centralized solutions for remote controlling of airports, by means of the remote tower concept. Here, the view out of the window is replaced by high-resolution panorama screens that show a live video transmission of the airfield. This is realized with the help of cameras installed at the respective airfield.

In order to make the work location-independent and even more cost-effective, Virtual Reality goggles can help here. The employees can therefore see the respective airfield through head worn glasses and carry out all the necessary interaction steps, regardless of their location (DLR, 2020 [Video]). This would also lead to a reduction in hardware, which is expensive and needs to undergo frequent maintenance, which in turn requires qualified personnel on site. In Virtual Reality-glasses the workstation would be mainly realized by software, which can also be maintained remotely and centrally. Moreover, this option is very space-saving and does not require any additional conversions in the tower or tower-center. The focus of this work is on a design study of a virtual tower workplace. Further, the capital costs of purchasing, installing, and maintaining remote monitoring technologies cannot be afforded by the low revenues of smaller airfields. These airfields have little traffic requiring higher quality air traffic control services, so often only temporary services such as Aerodrome Flight Information Service (AFIS) or just Universal Communications (UNICOM) are provided. Commercial flights and instrument approaches are almost non-existent here, as these in turn require a higher level of air traffic control. However, since smaller airports receive only a few requests and incur high costs, those are not worthwhile. The purpose of the VR tower is to be able to provide higher-quality and more extensive air traffic control services "remotely" at the respective airfield (Jakobi, 2020). The air traffic controller is not to be replaced, but supported. The focus of this work is on a design study for a virtual tower workstation. The goal is the elaboration of a possible concept.

2. Method

2.1. Usage Context Analysis

With the help of a contextual interview, the requirements from the users in the real environment of a tower could be recorded. The air traffic service personnel at Schönhagen Airport were interviewed, which provided detailed insights into the daily work routine as well as into the work equipment used. Based on the contextual interview, the context of use for the tower workplace at Schönhagen Airport is now defined. According to DIN EN ISO 9241-11, the context of use consists of the components, user group, tasks, environment and resources. A description of this can be found in the following part, the overview context of use description.

2.2. Overview Context of Use Description

In contrast to an air traffic control officer (ATCO) an aerodrome flight information service officer (AFISO), like at Schönhagen airport, only gives ATC related information, make recommendations, but do not grant clearances. It is not "control", it is provision of ATS information, a slightly lower air traffic service. A minimum prerequisite for working as an AFISO is a valid radiotelephony certificate. The main tasks of the employees are to maintain radio contact with the pilots and to make recommendations for operational handling. Furthermore, all flight movements have to be documented in the flight management software and, if necessary, flight plans have to be created. The working environment of the air traffic control personnel is the tower on the airfield. Since this is a one-person workstation, there is no direct social environment. Any social contact takes place via voice radio or telephone, which already lists two of the work resources used. The resources used are radiotelephone installation, PC (monitor, keyboard, mouse) with flight management software, telephone, airfield chart, binoculars, lighting console, weather information. Part of the context of use analysis is the definition of the actual scenario. The actual scenario shows which goals the users would like to achieve. The prerequisites for achieving these goals are reflected in the user needs. They serve as an intermediate step in deriving the requirements for use and are expressed in terms of resources-, informational- or competence- requirements. 23 user requirements were derived from the user needs.

2.3. Concept (HMI) Design

The user requirements form the basis for the design of the workstation. The Leap Motion concept, i.e. operation with free hands, was selected as the operating method. The user's hands are simulated in the virtual environment and displayed in the same position as the real hands. A three-dimensional interface view was chosen for the basic design of the virtual tower workplace. This is mainly due to the fact that the advantage of the virtual environment is to be used: the spatiality. To fill the virtual space, all elements that are to be used are first listed and categorized. All selected components for the virtual tower workplace are based on the previously identified user requirements and three presentation categories are implemented: "Always in view," "When required," and "Special role". Hofmann et al (2020) mention in his work that information should only be displayed when needed so as not to restrict the user's primary field of view. Similarly, the eighth Nielsen heuristic, "aesthetic and minimalist design," states that the information and content displayed should be reduced to the essentials (Nielsen, 1994). This provides the rationale for dividing the components into the classes listed above. The main task in the tower is to have an overview of the flight situation and to inform the pilots about it. All additional information and administration would get in the way of the main focus, the outside view, and take up too much space. Thus, any controls that take up a lot of space and are not in permanent use, move into the "When required" category. The radiotelephone is declared as a special role and thus falls out of the field of view and the actual user interface. How this is used in the presented concept is described in more detail subsequently.

2.4. Structure of the Concept

Before clarifying what should be seen when looking through the VR goggles, the basic framework of the image must be defined. Since the human field of vision is limited, care should be taken to show the information in an area that is sharply visible. This results from one eye at a time and is determined by the angle from the pupil to the nose. If the monocular fields are combined, this results in a field of view of 200 to 220 degrees. The overlapping area marked in blue represents the binocular field of view. This measures 114 degrees and is also the field in which people can perceive three-dimensional things. (Jay, 2016) The binocular visual area is where the most important information and interaction elements are displayed, since it can be seen at first glance.

The overall structure of the concept now results from the aspects already described. The three-dimensional VR space is to be a simplified image of a tower interior. The solution consists of three levels, which can be seen in Figure 1. The user is located in level 0. The operation of the system takes place in level 1 and the external view of the airfield can be observed in level 2. In the second zone, all those elements are visible which are always in the field of view. The area is like a view out of the window and shows a panoramic image of the respective airfield via video transmission. All elements with which the users can interact are positioned within reach on the first level. This is visibly separated from the level of the outside view and represents the desk in the tower. The so-called interaction zone is the area where the users' hands can be grasped and consequently interact with control elements. According to the manufacturer ultraleap, this area should have a maximum depth of 60 to 80cm and a field of view of 140 x 120° (ultraleap, 2021). The content should be able to be presented and operated via a surface, such as a display. Users are already used to displays from the real world and can therefore access many functions simultaneously. However, the two-dimensional UI panels must be adapted to the physical three-dimensional space. A concave curvature of the panels - especially for larger ones - can ensure that all controls can be reached comfortably.

To select the display, there is an always present menu panel with a slight downward glance. The window with the required information opens after pressing the corresponding menu item. It partially overlays the view of the airfield and is therefore only displayed when required. The menu moves in line with the user's head movement so that it can be viewed permanently. No matter where the user's eye is at the moment, the menu can be operated immediately with a slight downward glance. One user requirement says, "Users must be able to recognize and select multiple information and interaction elements on the system in parallel," up to three "displays" can be shown (see Figure 2). How many are in the current field of view and which content is displayed where is subject to the user's wishes. Through a drag and drop" control, the displays can be individually adapted. This also goes hand in hand with a point mentioned in Blessmann's (2020) conclusion. This states that users should be able to influence interactive objects and thus help to shape the virtual environment (Blessmann, 2020). Also, in the interaction principles, under the guideline of

controllability, it is recommended that the user interface can be individually designed. (DIN EN ISO 9241-110:2020). In order to follow the already known conventions from the real world (Nielsen, 1994), the decision for text input is based on a conventional keyboard. This is only displayed when it is needed. That means, it opens only when a title block is pressed.
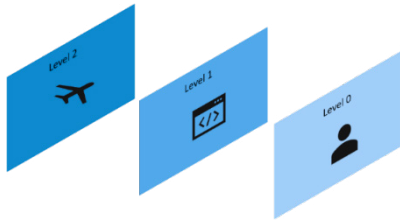

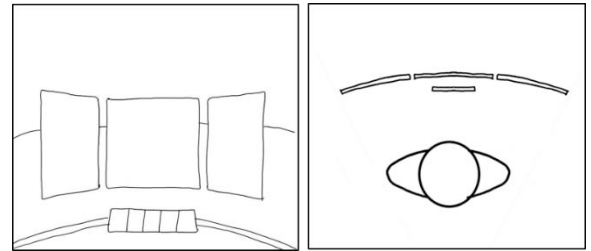Fig. 1. Structure of the VR Room in Layers

Fig. 2. Basic Structure of the Concept with three virtual UI-Panels

2.5. Concepts for the individual Interaction Elements

After the description of the basic structure, the various interaction and information elements are described in more detail below. The task is to accommodate all relevant information and to support users in reaching their destination as safely and quickly as possible. The concepts created are illustrated using Schönhagen Airport as an example. First the external view is described, which forms the basis of the workplace and is permanently perceived by the user. It contains the camera image, the time, the cardinal directions and the identification of the corresponding airfield. Since it is not an interaction layer, the outside view is not within the user's reach. The content presented is therefore purely information. The derived user requirements provide the rationale for the displayed content. For this design study the outside view design was adopted from a pre-study performed by Reuschling & Jakobi (2020). This solution is space-saving, is located close to the other information, therefore does not need to be searched for and accordingly fits into the overall composition. Below this display, the outside view should be visible in the form of the camera image.

The most important point is the radiotelephony. This was assessed as a special role and has no direct place in the user interface. The reason for this is that the radiotelephony function should not be searched for in the room and be activated by several steps. Tower employees must be able to access the radiotelephony function quickly as well as at any time, and in some cases, they must also be able to make changes in the flight management system at the same time or, for example, read off information about the weather. Since the visual resources of the users are already being used, it would not be in the interest of usability to display such an important function as radiotelephony visually as well. Therefore, this function should be coded separately. A haptic button outside the interface is being considered for this purpose. This can be attached to the index finger with the help of a ring and thus always carried along. This gives users the important haptic feedback that is also provided in the real tower by the pushbutton on the microphone. There, they know that they are in active voice communication by holding down the button. This feedback should be preserved and placed separately from the rest of the interface. The possible ring with a haptic button is shown in Figure 3 and can be made, for example, by a Velcro fastening, for example, and can be variably adapted in size to the finger. If this is worn on the index finger, the button can be pressed with the thumb. This leaves, apart from the (left) thumb, the hands free to the system, and multitasking tasks can be performed without overlapping the human resources used for this purpose.

An application that has not yet been integrated into the interface is the zoom function. This is to be provided to the binoculars in the tower. The display poses a hurdle in that the corresponding level is located outside the operating range of the users. The goal is to be able to take a closer look at a section of the outside view, for which it must be determined which segment it should be. In order to be able to integrate this feature two different solutions were considered: control by gesture or by selection via menu. *Control by gesture*: Users are asked to perform a specific gesture with their hand to activate the zoom function. A suitable movement for this is moving the thumb and forefinger apart (see Figure 4). This gesture is associated with zooming in and out since the everyday use of touchscreens and thus also corresponds to the second Nielsen heuristic "correspondence of system and reality" (Nielsen, 1994). After

triggering the function, the second level (outside view) is to be released for interaction. The user can then drag a rectangle with his finger over the desired area. The rectangle then shows an enlargement of the section (see Figure 5).

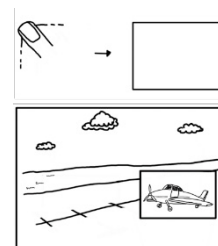Fig. 3. Haptic Button for the Index Finger (Radiotelephony)   Fig. 4. Zoom Control via Gesture   Fig. 5. Selected Zoom Area

Selection via menu: In this case, in the menu of the first level (interaction level) there would be a further point for selecting the zoom function. If this button is pressed, the further procedure can take place as with the gesture control. This means that the outside view would become interactive and display zoom sections by dragging rectangles. All interaction and information elements displayed on demand can be activated via the menu. The individual contents are described in more detail below. These are shown on the three interaction surfaces and can be moved as desired. The interfaces are presented as high-fidelity prototypes.

Since it is a three-dimensional space, the interface of the display should also be adapted to this concept. In the course of this, the choice falls on the neomorphism design. This is a mixture of skeuomorphism and flat design, i.e. a design option that imitates the real world and one that reduces to the essentials and thus often abstracts. The prominent appearance of buttons is the hallmark of neomorphic design and can be created through shadow and highlight accents (Bjork, 2021). Users are thus given the feeling of buttons and elements as if they were in reality. The buttons should have the appearance that they can really be pressed. Although the haptic feedback is missing when using the VR glasses, at least the tactile feeling can be increased and the users can be given corresponding feedback.

Consequently, the first application is the airfield map. This is a purely informational screen that provides information on the surroundings of the airfield and the corresponding traffic pattern. Above of the airfield map the following information can be viewed: Title of the current page, coordinated world time as well as a button to close the respective application.

Another application are the settings. The background of the application is kept in a dark shade to create a clear contrast to the bright exterior view. As the time of day progresses, the brightness of the outside view decreases so that it increasingly resembles the hue used in the preset Dark Mode. In this case, the Dark Mode can be deactivated. The interface then appears in a brighter tone and thus stands out from the surrounding outside view. Thus, the separation of the different layers is still given. The next item in the menu is the phone. The VR goggles have headphones and a microphone integrated. Thus, the headset does not have to be removed to make a call, but can also be used for that due to the integration of contact lists and the possibility to dial numbers. On the right side the design of the neumorphistic buttons are shown as an example. The characteristic effect of such a button is caused by the clever placement of dark as well as light color accents on the edge of the respective button. An opposite allocation of the colored frames causes an optical indentation of the area, which can be used for entering further phone numbers.

One of the two main tasks in the tower is the documentation of aircraft movements and the overview of the current air traffic. Figure 6 shows the planned basic structure of the flight management system. The administration shall be divided into the three parts "Flight Recording", "Completed Movements" and "Flight Plans". Below this, the flight strips falling into the respective area shall be listed. In "Active Air Traffic" you will find all flight movements that have just taken off or are in the landing approach. The aircraft are therefore in the airspace of the airfield. This also includes aircraft in an aerodrome circuit or in local flight. Aircraft that are moving on the runway are listed in the "Runway" area. Aircraft that are taxiing on the ground of the airfield to move towards or back from the runway are listed in the "Taxiing" category. A bar in the upper part of the display with the headings "Sign", "Type", "Departure", "Destination", "Style", "Takeoff time", "Landing time", and "Additional" serves as orientation as to which information can be recognized in the flight strip. The area at the bottom of the screen is for interaction options. The button on the left leads to the creation of a new flight strip. Next to it is a back arrow, which is supposed to undo the last action. On the right side there are buttons for deleting and editing the previously selected flight strip. On the edge, the current

main runway (HR) is shown, which can be changed to the other one by pressing the button. If a flight movement is currently no longer relevant, it moves to the "Completed Movements" either after taxiing (with inbound flights) or takeoff (with outbound flight). Flight plans that have already been entered in advance and are not created by AFISOs itself can be viewed under the "Flight Plans" tab. Half an hour before they become relevant, these should be automatically moved to the "Flight Recording" area.

The following section illustrates the processes for both landing and taking-off aircraft. The initial situation for both scenarios in this case is the "Planned" zone. If a planned, departing aircraft (blue strip) starts taxiing on the apron in the direction of the runway, the "Tx" button on the flight strip must be pressed. This will move the aircraft to the "Taxiing" field, from where it will be moved to the "Runway" field when it reaches the run way by clicking on the runway icon.
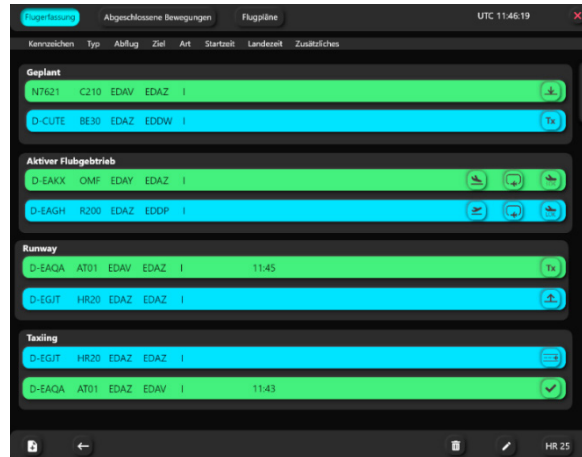

Fig. 6. Flight Management (High Fidelity Prototype)

If the aircraft has now taken off, this can be indicated by the button with the arrow pointing upwards. The flight strip is thus in "Active Flight Operation". If the aircraft leaves the zone of the airfield, it can be removed from the relevant area by clicking on the upward pointing aircraft symbol (departed). It will then appear in the "Completed Movements" tab. If a planned arriving aircraft (green stripe) announces its intention to land, it can be moved to the "Active Flight Operation" by pressing the downward pointing arrow. Once the aircraft has landed, the flight strip can be moved to the "Runway" area by selecting the appropriate icon. In the next step, the aircraft on the apron is transferred to the "Taxiing" zone by means of the "Tx" button. As soon as the movement is completed, this can be noted by clicking on the check mark. The strip can then be found in the "Completed Movements".

Flight plans are not always posted in advance. If the pilot of an aircraft reports to the aircraft without a flight plan, it is the task of the tower staff to independently enter the movement into the flight recording system. If a flight strip is to be edited, it can be selected by selecting it and opened in the detailed view with the edit symbol (pencil). Further weather data and runway lighting are to be found in the menu.

3. Usability Test

After elaborating the UI panels as high fidelity prototypes, they were now evaluated by means of a user study. Since the evaluation was carried out during the development of the system, this was a formative testing. The aim was to detect potential problems early on and thus to be able to adapt the product.

3.1. Method

A qualitative usability test using the Thinking Aloud method was used to analyze the interfaces. The test persons interacted with the user interface and were asked to speak their thoughts aloud while working on the task. This was to capture the users' views and motivations. Interview participants who work in the tower as Air Traffic Control Officers (ATCOs) or AFISOs were selected for the sampling. A total of five people participated in the study: one woman and

four men. Among the participants were three AFISOs and two ATCOs. Table 4 lists all the materials needed for the test. The survey was conducted remotely via "Skype for Business" from March 8 to March 22, 2022 and was recorded to simplify the evaluation. For this reason, one computer was required for the interviewer and one for the participant. The prototypes were shown using Adobe XD and were interactive in places. After the experiment, the subjects were asked to complete the System Usability Scale (SUS) questionnaire. This was distributed in advance and returned as a document to ensure that it could be completed without observation by the experimenter.

3.2. Procedure of the Study

After signing the consent form, the topic of the interview was briefly explained. The test persons were given the controls of the device so that they could operate the UI independently. They had to complete a total of five main tasks: Task 1: Planned Approach, Task 2: Planned Departure, Task 3: Circuit of the Airfield, Task 4: Local Flight & Task 5: Create Flight Strip which were subdivided into 22 subtasks. These all took place in the flight management application. Afterwards, the other interfaces were shown and freely discussed in an open conversation. The focus of the evaluation was to find out whether the users could identify the interaction elements as such and navigate independently through the application despite the unfamiliar interface. After the interview, the test persons were thanked for their participation and help, and they were asked to fill out and return the SUS questionnaire and send it back.

3.3. Results

Usability: First, the assessment of the system by means of the System Usability Scale is described. This is an established questionnaire for measuring usability. It contains ten questions on a five-point Likert scale from "Strongly disagree" to "Strongly agree" (Brooke, 1995). After calculating the score, the result is a value of 83.5. As shown in Figure 7, Brooke's SUS value of the application is classified under the category "very good" (Brooke, 1995). This means that the usability of the flight administration already has a high score to show for itself.
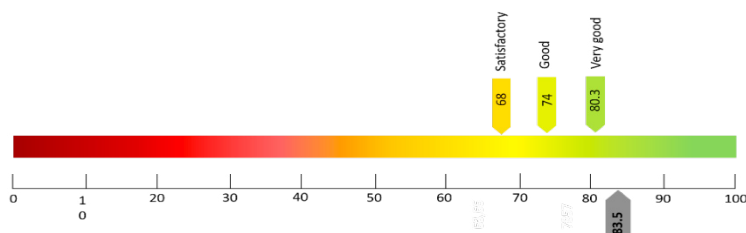

Fig. 7. SUS Classification according to Brooke

Participants' comments: By using the Thinking Aloud method, some comments could be captured during use, which will be discussed below. The structure of the four fields ("Planned", "Active Flight Operations", "Runway", "Taxiing") was correctly interpreted by all respondents. Two of the participants expected to be able to move the flight strips to other areas by tapping and dragging them. The buttons on the flight strips were not identified as such at first, but were declared as indicating symbols. After a short time, this view changed and the buttons were used to move the flight strips. One participant found it difficult to assign the symbols to the correct functions. However, the four other participants solved this without any major problems.

3.4. Discussion

With regard to the results of the usability evaluation, there are some open points that should be considered in future versions of the design. For example, it is considered useful to display the expected takeoff and landing times in the "Planned" area of the flight management. On the one hand, this should serve the classification of the flight movements

by the users, on the other hand, the system must know at which time the flight strips are transferred from the tab "Flight Plans" to the tab "Flight Recording". Furthermore, the areas "Runway" and "Taxiing" can be combined into one category. Since the aircraft are on the runway for only a short time, moving them to the "Runway" area means additional effort. To move the flight strips, a two-way solution should be followed, so that the flight strips can be moved both by pressing the buttons provided for this purpose, and by tapping and dragging the rectangles to the next area. Partly there was confusion in connection with the meaning of the symbols. The symbols should therefore be tested in future with a larger sample in order to ensure comprehensibility. Furthermore, the plus button to add a new flight strip seemed to be easy to overlook and should be made more concise in a future version.

4. Conclusion

The interfaces created as part of this work represent the necessary functions for an AFIS working position. In versions based on this, therefore, additional types of ATS with higher level services should also be worked out. The reason for this is that, for example, clearances of the controllers must also be marked as such in the system and it is partly in the area of responsibility to stagger the aircraft movements. This requires further functional and interaction possibilities, which should be integrated.

A further step should be to implement the design concept in a prototype environment to evaluate the application in a human-in-the-loop experiment. This way, it can be analyzed how users cope with the design and the way of interaction. In the course of this, it is also important to determine a suitable display size for the UI panels and the content displayed on them.

The representation of the AFIS working position in VR offers further possibilities beyond the previously known scope. These need to be found out and evaluated. For example, it is conceivable that the use of VR glasses will eliminate the need to work night shifts. Due to the different time zones, those controllers can become active who are currently working during the day. The airfields where it is currently night are therefore added to their area of responsibility. The use case possibilities will expand in the future, which is why it is of great importance to further develop and improve the system.

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