Abstract—This paper presents the results of an exploratory concept study conducted with four aerodrome air traffic controllers (ATCOs) of the German air navigation service provider DFS. Different configurations of a context-adaptive assistance system combined with augmented reality were tested and evaluated against a conventional tower controller working position (CWP). During the simulation runs eye tracking data was recorded to analyze head up and head down times for the different CWPs. Post-run assessments of workload, situational awareness and system usability were conducted. The best rated CWP was coupled to an experimental tower flight data processing system (TFDPS) and a 3D controller, which allowed both indirect and direct interaction with flight data in the augmented outside view. This particular CWP also revealed 68% mean dwell times for head up in contrast to the conventional tower CWP with only 43% mean dwell times. The ATCOs also experienced the lowest workload levels and the highest situation awareness with this configuration. According to the ATCOs’ feedback, the combined use of indirect and direct interaction with augmented flight data allows a flexible and intuitive use while working with such an assistance system. The results of the present study encourage a paradigm shift for flight data handling in combination with augmented reality: away from a solely display system to an interactive operating system.


II. BACKGROUND, PROBLEM STATEMENT AND MOTIVATION

The integration of augmented flight data within the tower environment has become a growing research interest within the last years [4],[5]. The demonstrators however displayed information for all aircraft regardless of the ATCO’s specific information needs and the operational context. This will cause information to overlap and hence to over-clutter the ATCO’s primary field of view. At mid-size and hub airports with higher numbers of aircraft movements this issue becomes even more severe. According to [5] it would be of particular interest for which aircraft in the ATCO’s field of view which information has to be displayed. This motivates an information display that not only considers information related to a specific aerodrome control function (e.g. local, ground and clearance delivery controller) but that is also related to the current operational context. In addition to that unsolved matter, the interaction with augmented tower flight data and topological data has also not been investigated, yet.

In response to the above described issues and research gaps a novel operational concept for a context-adaptive augmented reality based assistance system for aerodrome air traffic controllers was proposed by [6]. The operational concept development, implementation and validation are part of an ongoing PhD thesis which started in 2015. As a starting point of the PhD thesis extensive workshops and work domain analyses were conducted at two air traffic control towers. Based on that, first system requirements and conceptual designs were derived. Consequently, a series of concept studies were carried out in 2016 and 2017 with aerodrome ATCOs. This user-centered design approach according to ISO 9241-210 combined with ecological interface design methods pursues the aim to develop an operational concept by means of concept studies in close collaboration with ATCOs. The use of small-scale concept studies and its iterative process of concept evaluation and system enhancement are supposed to identify the most promising CWP design. Additionally, the most appropriate data collection methods for the final human-in-the-loop simulation campaign can be identified and revised if needed. Both are important requirements in order to validate the envisioned assistance system properly.
This paper presents the results of an exploratory concept study that was motivated by the most important finding of the first study: the mandatory coupling of the TFDPS with the augmented outside view. This provides the ATCOs with immediate feedback on the current aircraft status and thus helps to maintain adequate situation awareness [7]. In section III the concept element “integrated information management” will be outlined. Its examination will be described in section IV. The study results (section V), and conclusion (section VI) finalize this paper.

III. INTEGRATED INFORMATION MANAGEMENT

The operational concept [6] consists of three key elements: a) context-aware information adaptation b) integrated information management and c) attention guidance. Within this paper the focus lies on the integrated information management. For more details on the other concept elements please refer to [6], [7]. One feature of the context-adaptive assistance system depicts the integration of augmented reality. Hereby, relevant flight data are projected into the aerodrome controller’s outside view in dependence of the current operational context (e.g. aircraft status, visibility conditions). The integration and synchronization of head down systems with the outside view is referred to as “integrated information management”. Additionally, the ATCO can adapt the display of information according to his needs. Thus, the concept incorporates and allows the interaction with augmented information by coupling the augmented view with head down devices and additional input devices (see Figure 1.).

Figure 1. Illustration of the integrated information management concept: (bottom left) direct interaction via 3D Controller enabling flight data handling within the augmented outside view (bottom right) indirect interaction with a touchpen based TFDPS. Both data entry methods are interconnected and synchronized (upper left) context menu entry shows a selected aircraft label with an issued line-up clearance. According to the current aircraft status the subsequent menu entries are “cleared for take-off”, “undo last action”, “[x]: cancel ” (upper right) TFDPS selected aircraft label with a given taxi clearance. The augmentation can be realized either with a head mounted AR display (e.g. MS Hololens), a spatial AR display.or a combination of both.

IV. CONCEPT STUDY

The follow-up concept study took place in March 2017 at the simulation facilities of the DLR Institute of Flight Guidance. Four tower air traffic controllers participated in the study. The focus on the present study was laid on understanding basic mechanisms and challenges of human-machine interaction when fusing augmented reality with information adaptation. Thus, a functionality-driven approach instead of a technology-dependent approach was applied. With sufficient concept maturity, the next step will be the concept transfer, i.e. the implementation of a concrete technical solution.

A. Research Objective and Hypotheses

The main research hypotheses H1 and H2 were as follows:
H1: “An augmented outside view with integrated information management (H1.1) leads to longer head up times (H1.2) yields improved situation awareness (H1.3) yields lower workload when compared to a conventional tower controller working position.”

H2: “Direct interaction in the augmented outside view yields (H2.1) higher situation awareness and (H2.2) lower workload compared to indirect interaction.”

B. Experimental Setup

As depicted in Figure 2, the experimental tower CWP consisted of conventional head down systems and was arranged as follows: (1) a touch-pen based experimental tower flight data processing system(TFDPS), (2) a weather display, (3) an airborne radar display, (4) a ground radar display and a headset connected to a foot-switch for the radiotelephony (RTF). The ATCOs were responsible for departing and arriving aircraft within the control zone of Hamburg Airport. Instructions were issued via RTF to the simulation pilots who in turn entered the commands into the simulation environment. Since a technology-independent approach was chosen, the augmented aircraft labels were generated within the simulated outside view, i.e. no head up display was used.

C. Experimental Design and Procedure

TABLE I. shows the four CWP configurations that were examined in four subsequent simulation runs. Prior to the first simulation run, 45 minutes of training was applied to familiarize with the different configurations. Each run was followed by post-run questionnaires and debriefings. During each simulation run eye-tracking data was recorded in order to assess dwell-times for defined head up and head down areas of interest (AoI). The order of the configuration sequence was systematically varied in order to control learning and sequence effects.

![Schematic layout of the experimental tower CWP](image)

Figure 2. (left) Schematic layout of the experimental tower CWP. (right) AoIs for outside view: 2 – 5. AoI for head down systems: 1, 6 – 9.

D. Scenarios

Hamburg Airport (EDDH) was used for the simulation study. The scheduled IFR movements (25 arrivals, 25 departures within a 45 minute trial) for each scenario were higher than the actual capacity parameters for EDDH. Additionally, VFR flights and events (e.g. runway checks) were included. The scenarios were equally balanced regarding workload peaks. For all scenarios, the standard configuration for Hamburg was used: runway 33 for departures and runway 23 for arrivals. All scenarios took place under visual meteorological conditions.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Mean Dwell Times (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Head up</td>
</tr>
<tr>
<td>C1</td>
<td>43.0</td>
</tr>
<tr>
<td>C2</td>
<td>57.7</td>
</tr>
<tr>
<td>C3</td>
<td>89.7</td>
</tr>
<tr>
<td>C4</td>
<td>68.1</td>
</tr>
</tbody>
</table>

A. Eyetracking

TABLE II. shows the mean dwell times to Aol where the ATCOs spent looking at. Comparisons of the eye-tracking data between configuration C1 and C2 reveal that head up times increased from 43.0% to 57.7%. For configuration C3 the head up times increased even up to 89.7% when ATCOs interacted directly with the augmented outside view. The mean dwell times for configuration C4 for head up (68.1%) were the second longest. When comparing the head up times between the conventional CWP (C1) with the CWP enabling direct and indirect interaction with augmented flight data, the difference amounts to a rise of 25% in terms of prolonged head up times.
B. Workload

As shown in Figure 3, the analysis of the unweighted NASA-TLX ratings revealed the lowest workload scores for configuration C4 (M: 33.0, SD: 1.0), followed by configuration C2 (M: 38.0, SD: 3.9) and C1 (M: 40.0, SD: 1.9). This is inline with the debriefing results and structured usability questionnaire where all participants stated the little time it requires to learn the handling, as well as the flexible and fast data entry by either TFDPS or 3D controller. The highest workload score obtained configuration C3 (M: 53.0, SD: 1.9).

C. Situation Awareness

3D-SART was applied to assess situation awareness. The 3D SART uses a 100-point scale from 0 (low) to 100 (high). With scores ranging from -100 to +100. The 3D SART ratings as depicted in Figure 3, revealed highest situation awareness scores for configuration C4 (M: 72.0, SD: 5.1), followed by configuration C2 (M: 60.3, SD: 8.1) and the lowest scores for configuration C3 (M: 22.3, SD: 7.9).

D. Usability

For the assessment of usability the SUS calculates a score which can be interpreted as a percentage value: As shown in Figure 3, overall usability for the configurations C1 (M: 60.0%, SD: 5.0%), C2 (M: 63.3%, SD: 3.8) and C4 (M: 62.3%, SD: 15.2) were rated almost equally. SUS scores within this range represent an acceptable usability. Only configuration C3 (M: 42.5, SD: 7.5) showed poor usability which may be due to fact, that ATCOs were not allowed to use the TFDPS.

VI. CONCLUSION AND OUTLOOK

The results of this exploratory research study are promising despite their descriptive nature: among the tested CWPs, configuration C4 was rated as the most beneficial and best-suited CWP for an augmented reality based flight data handling. This was also reflected within the behavioral data: mean dwell times for head up increased more than 25% compared to a conventional tower CWP (hypothesis H1.1). This substantial increase of head up time could be a strong indicator for improved situation awareness. This was also reflected in the subjective data: according to the ATCOs ratings configuration C4 promotes the situation awareness at most (hypothesis H1.2). In addition to that, workload ratings were the lowest when compared to the other CWP configurations (hypothesis H1.3). Thus, the results support the hypotheses H1.1, H1.2 and H1.3. However, hypothesis H2.1 and H2.2 could not be confirmed. Despite the high dwell times for head up in configuration C3, direct interaction in the augmented outside view did neither automatically yield higher situation awareness (hypothesis H2.1) nor lower workload (hypothesis H2.2). This was possibly due to the absence of the TFDPS which is an important tool for flight planning, insufficient training and unusual working method. Future work will focus on the enhancement of the interaction concept and examine the suitability of the operational concept under all-weather operations. For the final validation campaign a sufficiently large sample size will be determined in order to apply inferential statistics and test for significant effects. In summary, the results of the present study encourage a paradigm shift for flight data handling in combination with augmented reality: away from a solely display system to an interactive operating system.

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