Requirements Analysis & Concepts for Future European Air Traffic Control Systems

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ABSTRACT

Since decades, Air Traffic Control Officers (ATCOs) are working with 2D representations of the airspace (RADAR). Based on the Single European Sky Air traffic management Research (SESAR) [24], some planned innovations will change the way, air traffic will be handled in the future. Therefore, the paper first presents a requirements analysis in order to understand the current workflow as well as the necessities and concerns of ATCOs for future developments. Second, the paper summarizes the conception & evaluation phase for representing air traffic not only in 2D. The results show that a user-centered design approach is essential to involve end users as much as possible to avoid undesirable development. In end user interviews, ATCOs were very open to presented hardware and interaction techniques. The focus group with more concrete concepts then resulted in uncertainties especially regarding 3D representations of complex air traffic.

Index Terms: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Graphical user interfaces (GUI), Theory and methods, Evaluation/methodology, User-centered design, Prototyping;

1 INTRODUCTION

Air Traffic Control Officers (ATCOs) have been working for decades using mainly unaltered technology based on abstract, two-dimensional visualization of airspace (Enhanced RADAR). Following the Single European Sky Air traffic management Research (SESAR) [24], some high-level goals have been defined that require major changes concerning the management and handling of the European air traffic. Among the main targets are the demands for:

- systems capable of handling up to 100% more traffic
- up to 30% reduction in departure delays
- safety improvement by up to a factor of four.

Further, in order to optimize the economic impact of flight behavior, flight courses of airplanes will be routed along trajectories in the future. This is in contrast to their organization in corridors, as they are handled nowadays. By this transition to trajectories, airplanes will approach their destination from the point of departure following an optimum flight profile similar to a parabola. Since these trajectories include a time component, they are considered as four-dimensional and accordingly called 4D trajectories. The goal of the two-and-a-half-year Austrian research project VAST (Virtual Airspace and Tower) is to develop new methods for the visualization and sonification of the complex flight paths inherent to the permanent vertical and lateral movement of airplanes. This includes the same or improved situation awareness in complex air traffic scenes, as well as conflict detection, and decision making for critical situations.

This paper presents two main research activities in the project: Requirements Analysis and Conception & Evaluation. In order to understand the current workflow as well as the necessities and concerns of ATCOs for future developments, semi-structured interviews with stakeholders and ATCOs were held early in the project. Combined with a Data-Users-Tasks Analysis [19], it formed the main foundation for the concept creation phase. Within a design studio workshop, 21 raw ideas were created and further aggregated into twelve concepts for 2D & 3D visualization, interaction, conflict detection, decision making and workplace design. To evaluate these concepts, a focus group with five ATCOs was conducted.

This paper is organized as follows: Section 2 describes the current working positions in air traffic control. Section 3 lists related work in the fields of research and industry in respect to the air traffic innovations defined by SESAR. Section 4 depicts the requirements analysis in detail. Section 5 describes the design studio workshop including its resulting concepts as well as the focus group discussion with five ATCOs. Section 6 discusses the results of the interviews and the focus group. Finally, Section 7 reflects the results and their impact on further developments within the project.

2 BACKGROUND

Air traffic control in Austria can be classified into three main control responsibilities: Area control (ACC), approach and terminal control (APP), and tower control (TWR) [18]. Research within the VAST project focuses on the tasks of approach/terminal controllers and tower controllers.

The approach/terminal controller usually handles traffic in a radius of 30 to 50 nautical miles around the airport and he/she is responsible for the traffic flow including departures, arrivals and overflights. When aircraft enter and leave the approach/terminal areas, they are handed off to the next appropriate control facility which can either be a tower, an area control facility or a bordering terminal. Approach/terminal control is responsible for ensuring that aircraft are at an appropriate altitude when they are handed off, and that aircraft arrive at suitable intervals in order to start the landing processes.

It is the task of tower controllers in general, and especially of the tower runway controllers to issue clearances, instructions and permissions to aircraft, vehicles and persons in order to fulfill the requirements for safe and efficient traffic flows in the environment of the airport. Within the scope of VAST it is assumed that the area control centers, neighbor terminals and approach controls coordinate and communicate directly to airport towers and instruct inbound aircrafts to approach an appropriate position for landing.

3 RELATED WORK

Referring to the high-level goals described in the introduction, this section provides an overview of work related to the planned SESAR [24] innovations in the fields of research and industry and illustrate its relevance for the research project VAST.

3.1 Research

Novel visualization methods for air traffic management have been proposed in various research papers before. For example, Azuma et al. describe a testbed for the construction and evaluation of conflict detection, resolution, and visualisation tools for a free flight environment [2]. They combine a 2D plan view display with a 3D perspective view display. Bourgois et al. developed a 3D stereoscopic system for real time visualisation and manipulation of data in air traffic control [3]. They show a comprehensive interface for the air traffic controller to view, interpret and interact with complex flight data and support information affecting the controller's actions. Hurter et al. describe novel visualisation forms for monitoring the aircraft position on a radar [11] and a trajectory visualisation tool that tackles the difficulties to explore the visualisation of multiple trails [12]. Multidimensional data exploration is based on scatterplots, brushing, pick and drop, juxtaposed views and rapid visual design. Vuckovic et al. explore whether the visual presentation of relative position vectors improves conflict detection in conditions representing some aspects of future airspace concepts [25]. They evaluate a Multi-Conflict Display to facilitate conflict detection and their results indicate that this enhances performance on complex search tasks and at high traffic volumes. Within the C-SHARE project, Klomp et al. developed an exocentric representational model for 4D trajectory management for short-term perturbation management in airspace environments [15]. Their representation enables humans and automated agents to correct small scale system perturbations that take place on individual flights. Imbert et al. evaluate five air traffic control notification designs in their ability to capture attention during an ongoing supervisory task, as well as their impact on the primary task [13]. Their performance measures show that the best design achieved a balance between attentional power and the overhead cognitive cost to primary task performance. Buschmann et al. present a real-time animated visualisation technique for massive 3D movement trajectories using an efficient GPU-based implementation [6]. [4, 5, 17] showed that by providing additional acoustic information about aircraft positions the identification of potential conflicts or alerting situations could be significantly accelerated.

3.2 Application in Industry

The introduction of 4D trajectories requires not only a change in air traffic management procedures but also causes a variety of necessary changes in the system landscape of an air traffic service provider. The biggest changes hereby are seen within the flight management system [10]. It also affects systems like the communication systems or other supporting tools [1]. To manage these huge changes, a stepwise approach was undertaken within the European research program SESAR. Within SESAR, the concept of initial 4D trajectories (i4D) was introduced as the first step towards more predictable flights. The core characteristic of i4D is making sure that trajectories are always synchronized between air and ground, which enables more efficient handling and certainty of flight profiles. First trials were executed in 2012 and 2014 with the goal of starting very large-scale demonstrations in real airline conditions by 2019 [23]. It illustrated the importance of an advanced Human Machine Interface (HMI) for making the new information fully usable. [7, 8] designed auditory displays providing auditory information and alerts at ATCOs workspaces for Airservices Australia, which were evaluated as supportive and beneficial seven month after theirs implementation.

4 Requirements Analysis

The project team follows the design study methodology by Sedlmair et al. [22] who defined 'problem characterization and abstraction' as the first main contribution of a design study. End users often don't know exactly what they want, but they know very well what they don't want or what cannot work in their specific setting [21]. The project team applies user-centered design [20], which first clarifies the requirements. Therefore, the needs of users and stakeholders, the exact tasks and the data required for them are collected. Various methods were used, which are described in this section.

4.1 Semi-structured Interviews

To understand the current workflow, the needs and concerns of ATCOs for future developments, semi-structured interviews [16] with both stakeholders and ATCOs from three different European countries were held.

4.1.1 Method

Participants: Four male stakeholders with an age between 40 and 55 years participated in the interviews. They are working globally in the fields of human factors, sales, public safety and project/product management. All participants are familiar with the air traffic control environment and are working on a number of projects in this field. Furthermore, end user interviews were held with fifteen ATCOs from three different European countries: Austria (Austro Control, Approach), Germany (DFS, Approach) and Bulgaria (BULATSA, Tower and Approach). In total, eleven male and four female ATCOs, aging between 25 and 48 years, with less than a few months to 26 years of experience were interviewed. All interviews were conducted in-person, except for the Bulgarian ATCOs, which were held via video conferencing.

Design & Procedure: The stakeholder interviews where held in separate meetings. The end user interviews were carried out mostly during work breaks and took one hour at maximum. At the beginning, the interviewee filled out a demographic questionnaire and signed the consent form. Then, he/she got informed about the overall project scope and goals. As an initial question, he/she had to describe a typical working day and tools used on a daily basis. Afterwards, (except for six interviewees) questions regarding planned SESAR innovations were asked to get an impression of the familiarity of the future developments. The main part of the interview focused on technology assessment. The presented technologies were: Augmented Reality (AR), Virtual Reality (VR), Cave Automatic Virtual Environment (CAVE), Tangible User Interfaces (TUI), Gesture, Voice, Pen and Touch Control, Big Walls and Eye Tracking. For each technology, the interviewees were asked to give their opinion in relation to potential benefits in the current and future work environment and give a rating.

Apparatus & Materials: For the technology assessment, each technology was prepared on a printed sheet of paper with an image and short title. The interviewee was asked to write down the technology title on a post-it note during the interview. To rate the technology, the interviewee placed the post-it notes around his/her imaginary working position. The nearer the technology was placed to the working position the more usable the technology is seen by the interviewee.

4.1.2 Results

SESAR innovations: The stakeholders mentioned, that currently no existing solution on how to visualize 4D trajectories is known. Both stakeholders and ATCOs mentioned some challenges in conjunction with the planned 4D trajectories:

- **Trajectory planning:** Unplanned situations like adverse weather conditions, runway closures or necessary instructions by ATCOs do not only affect a single flight but probably leads to the necessity to re-plan a larger number of flights.
- **Crossing Traffic:** Concurrent arrivals and departures make it difficult to create a parabola without conflicts especially when air traffic is still growing.
- **Airport bottleneck:** The airport causes a bottleneck due to maximum capacities resulting that aircraft can't fly the most direct route to the airport.
- **Handover:** Another challenge is seen in the coordination between sectors ('handover'). If every aircraft has its own route instead of following e.g. a standard instrument departure route, it becomes more difficult to perform the handover. There has

already been some demonstrations but they have been undertaken under demo conditions and controllers were not able imagine this in a real setting.
- **Data quality & alignment:** Future solutions will require the exchange of data between the various stakeholders to make the solution really work. Currently, data is quite heterogeneous and not distributed in the same way or is simply not available to the air traffic control.
- **Role changes:** The way 4D trajectories are expected to work changes the role of an air traffic controller more to a monitoring role.

Technology assessment: The stakeholders see the best acceptance in the use of tablets and Augmented Reality (AR) as ways of visualizing information, but AR more in the tower setting for live runway visualizations. For interacting, the best acceptance and practicability is seen in the use of touch input and pen input.

The interviewed Air Traffic Control Officers were very interested in the presented technologies and almost all would try all of them. There is no clear picture in regards to preferences of the presented technologies. It can be seen that the CAVE has the lowest rating. Regarding interaction techniques, tangible user interfaces are not seen as an interesting technology as most controllers rated it low. Looking more closely at the comments, they show that the highest ratings have been given to technologies the controllers are in some way familiar with. As such, controllers mentioned on-going projects regarding eye-tracking and speech recognition which both have the highest ratings. Some technologies are rated low for approach use but higher for usage within a tower controller environment. This is especially true for Augmented Reality.

4.2 Data-Users-Tasks Analysis

Section 2 describes the general working positions mentioned to define the target group within the project's scope. To provide better insights to the target group, the Data-Users-Tasks triangle by Miksch and Aigner [19] is used. Generally, this high-level framework is structured around three major questions:

- What kind of data are the users working with? (*data*)
- Who are the users of the solution(s)? (*users*)
- What are the (general) tasks of the users? (*tasks*)

Data: The data to be used for air traffic control are combined datasets from different radar stations as well as the aircraft themselves. These combined datasets can be specified as multivariate time-oriented streaming data with a discrete timescale and a single granularity, typically presented on an enhanced RADAR and additional support tools.
Users: Air Traffic Control Officers (ATCOs) are very well-trained experts who have a very good spatial sense, no color blindness and they have to be stress-resistant. They are trained to a specific position (e.g. tower runway controller) and sector.
Tasks: Depending on the shift plan, the controller has to fulfill the following tasks of his or her assigned position: 1) As 'planning controller' (coordinator), he/she is responsible for pre-planning flights, the coordination with adjoining sectors and the support of the radar controller; 2) As 'radar controller', he/she controls the traffic within the assigned sector and is responsible for the separation of aircraft; 3) The 'tower controller' is responsible for the arriving and departing traffic from and to the airport.

5 Conception & Evaluation

Based on literature research and the key results in the requirements analysis, the project team developed as many ideas as possible not only for the user interface but also for workplace arrangement using innovative hardware technology. This section describes the methodology of the design studio, the resulting concepts and the evaluation within a focus group discussion.

5.1 Design Studio

Using design studio [9], experts from different domains get together in groups, developing as many raw ideas as possible given a limited amount of time. Many design iterations ensure that ideas will be developed further. This section describes, how the design studio was performed within the project VAST.

5.1.1 Method

Participants: A design studio was conducted by the interdisciplinary project consortium, which consists of eleven experts in information visualization, user-centered design, public transport and audio design.
Design & Procedure: With the target group and typical tasks in mind, the team was divided into three groups. First, as many concepts as possible had to be created individually with pen and paper within five minutes. Second, the ideas were presented to the group. Third, the group members had four minutes to give feedback to the concepts in terms of 'What are suggestions for improvement?' and 'In what way does the idea solve the problem?'. The process was then repeated iteratively twice, including a reshuffling of the group members.

5.1.2 Results

At the end of the session, 21 raw ideas consisting of sketches and a very short description were the result. In a further step, the ideas were then aggregated into twelve concepts for 2D & 3D visualization, interaction, conflict detection and decision making of air traffic, and workplace design.

As an example, two concepts will be presented in this paper. Figure 1 illustrates the concept of a combined view to observe both vertical and lateral movements of the air traffic. Figure 2 illustrates a concept for conflict detection using parallel coordinates [14] which are representing movements of the aircraft over time. The first three axis (from left to right) represent the positions with longitude, latitude and height (= flight level) of all aircraft at a given time. The right axis is a time slider to look into the future to detect possible warnings of not fulfilled separation. If two lines are marked in yellow, the possibility of a collision exists for two aircraft with the same flight path. If two lines are marked red, two airplanes will be in the exact same position.

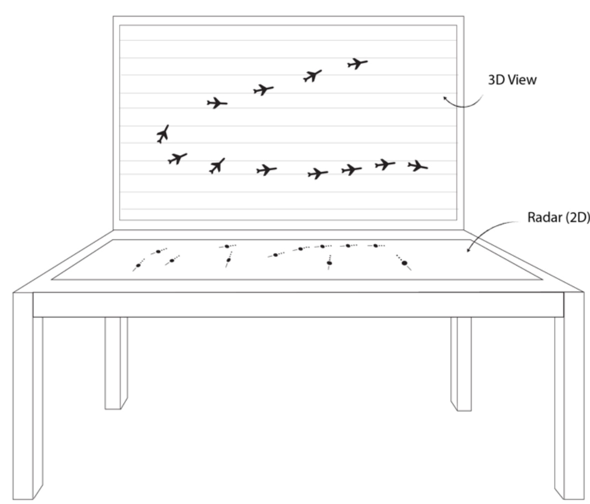

Figure 1: A concept for a combined view of a 2D RADAR and a 3D view to visualize height.

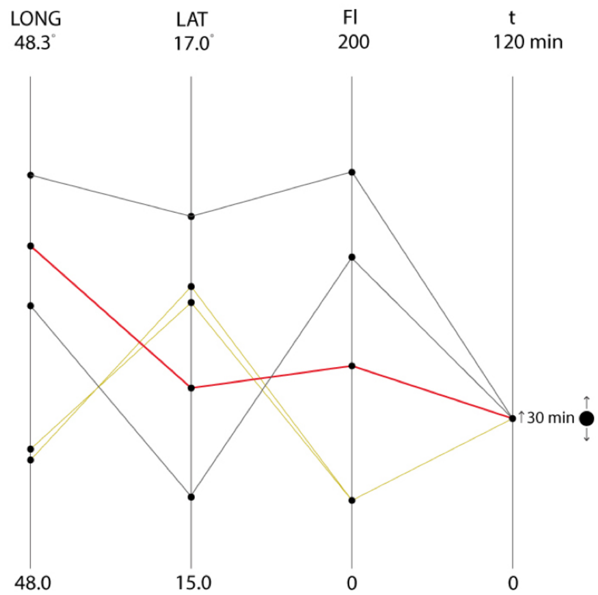

Figure 2: A concept for detecting conflicts in the near future using parallel coordinates.

5.2 Focus Group

To get feedback in terms of acceptability and practicability, the project team conducted a focus group to discuss the concepts. This section describes to methodology as well as the results.

5.2.1 Method

Participants: Five male ATCOs from Austro Control (Approach Control) attended the focus group which was held in April, 2017. Four of them were already familiar with the project and also participated in the interviews.
Design & Procedure: The focus group lasted two hours. All twelve concepts were presented to the group, followed by a discussion and voting. Each participant voted individually by placing a red, orange or green post-it to the presented concept.
Apparatus & Materials: The concepts were printed out for every participant. Also, post-it notes in three different colors were available for voting. The focus group team itself consisted of a moderator, who was guiding through and an observer, who was responsible for audio recording and note taking.

5.2.2 Results

Regarding the 3D concepts, one key finding was, that for ATCOs, the main tasks consist of comparing numbers to ensure aircraft are keeping the cleared flight levels and separation. For these tasks, the ATCOs consider a three-dimensional representation of air traffic as not needed. There was also a fear of being lost in the three-dimensional space without concrete information of depth and of absolute numbers. Given this fact, ATCOs can make just estimations, which will lead to critical situations. But in the situation of holding aircraft on certain flight levels, a lateral visualization representing the height tends to be useful. Another finding was that if the visualization will switch from a 2D to a 3D view, it takes a long time to gain orientation in the new scenery. Rotating a view is also not efficient, because ATCOs are familiar with a visualization were the geographical North is always on top and rotating the view would lead to confusion. As a result, all 3D concepts were rejected (voted red). Regarding 2D concepts, ATCOs found it interesting to represent the wake turbulence category as different icons, because it is just represented as a letter currently. The concept also uses color coding or different aircraft sizes to visualize height. For ATCOs this is not imaginable because already many colors are used to present information. Regarding the concepts for conflict detection and decision making, the ATCOs argued that especially in the approach area, decisions have to be made very quickly and there is no time for playing around with options. In addition, currently poor availability of real-time combined flight data leads to inaccurate predictions. Regarding sound, ATCOs mentioned that current implementations use sound poorly and constant auditory feedback warnings will lead to blanking it out quickly.

6 Reflection & Discussion

This paper presents a requirements analysis as well as a conception and evaluation in the field of air traffic control to identify future possibilities for visualizations of complex air traffic, taking account of planned SESAR innovations. As part of the requirements analysis, semi-structured interviews were held with both stakeholders and Air Traffic Control Officers. In summary, especially the ATCOs were open to presented hardware and interaction techniques. The focus group with more concrete concept ideas then revealed some uncertainty especially as to 3D visualization, decision-making concepts and sound. The reasons therefore can be the following:

- **High satisfaction:** In both semi-structured interviews and focus group hardly any problems regarding the use of the currently provided software and work environment were mentioned. ATCOs seem quite satisfied with the tools provided to control air traffic and larger changes are not necessary for the current workflow.
- **Vague ideas about changes:** With the planned changes to 4D trajectories, the altitude can change constantly. It is not that clear what this means in terms of visualization and if other concepts can have a more positive impact on effectiveness and efficiency. Further, in such a complex domain, it will help to visualize concepts more concretely and not only with 'pen and paper' to gain a clearer picture if they are suitable for future workplace design.

7 Conclusion

The given results show that a user-centered design approach is essential to involve end users as much as possible to avoid undesirable development. A limitation of the early stages of this process is that the hand-drawn, non-interactive concepts can't illustrate the solutions in detail. Thus, based on the gathered feedback, the concepts will be aggregated into three concepts which will be prototypically implemented to create a more realistic test scenario. The so-called low-fidelity prototypes will provide interactivity and will visualize the air traffic in a more realistic way. The ideas shown in Figure 1 and 2 will influence the final three prototypes. The goal is to test the three prototypes to find out if they can improve conflict detection, decision-making, and situational awareness for typical Approach scenarios. If some improvements can be measured, this should affect the ACTO's opinion about limitations of the current system and the need for a multidimensional representation.

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