Immersive solutions for future Air Traffic Control and Management

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Abstract

In this paper we review the activities of Air Tra c Control and Management (ATC/M) and expose scenarios that illustrate current and future challenges in this domain. In particular we look at those challenges that can be tackled with the use of immersion. We introduce the concepts of an immersive Remote Tower and Collaborative Immersive Trajectory analysis. These make use of immersive technologies such as Head Mounted Displays (HMDs) or large, tiled displays to immerse users in their tasks, better supporting the management and analysis of the complex data produced in this domain.

Author Keywords

Air Tra c Control, Air Tra c Manamgent, Oculus Rift, Head-mounted dispay, Trajectories Visualisation, Remote Tower, Immersive Analytics

ACM Classi cation Keywords

H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous.

Introduction and Background

Air Tra c Control and Management (ATC and ATM) are activities involving the management of critical data at di erent times. In ATC, Air Tra c Controllers (ATCos) have to analyze copius information in real-time to

maintain tra c uidity and security. In ATM, expert analysts analyse o line large amounts of recorded data|such as aircraft trajectories|in order to understand past situations and improve future procedures. ATC is a multi-modal computer-supported cooperative work (CSCW) activity that involves \live" aircraft data visualisations along with many unstructured and complex data sources like audio communications. The main purpose of ATC is to maintain a safe distance between aicraft. With a predicted continual increase [3], air tra c is becoming more and more dense and complex to manage in real-time and also to analyse o -line to improve its security and uidity. Therefore, research and development in this domain remains very active and seeks to provide new solutions to improve security in this context. The focus of this paper is to present a set of innovative Immersive solutions for ATC/M that aims to support the ATCos and managers work in this increasingly complex environment. In this context, we introduce the concept of an Immersive Tower that aims to provide new real-time support and Collaborative Immersive trajectory analysis. This, in turn, aims to provide new ways to enhance remote aircraft trajectory analysis.

There is previous work investigating ATM and ATC from di erent perspectives, including tangible interaction, augmented reality and data visualisation.

Augmented Paper Strip

Air Tra c Controllers (ATCo) monitor tra c through real-time radar screens and communicate to pilots with radio systems. In addition, controllers use paper strips: one strip per aircraft with its planned ight route and additional information. Controllers can annotate, grasp, move, and organize these paper strips on a stripboard, using these tangible interactions to organize their mental

picture [11]. Unfortunately, paper strips do not bridge the gap between the physical and digital worlds. Once printed the paper strip cannot be updated, nor can the information reported on the strip be used as input into the system. This strong limitation hinders the development of more advanced ATC systems. For example, ideally more accurate future aircraft locations, complex con ict detections and resolutions all need to be available in real-time. Taking this limitation into account, the Strip'TIC (Stripping Tangible Interface for Controllers) system has been developed. This prototype combines augmented paper and digital pens on a multitouch glass stripboard, using vision-based tracking and augmented rear and front projections [8]. In this system, the user can manipulate the paper strips as tangible objects and use gestures to ful ll air tra c management [13]. Strip'TIC is the rst attempt to support ATC activity with an immersive environment augmented with tangible objects (paper strips) and multi-modalities (pen, touch, tangible objects). The work presented in this paper is a direct extension of this Strip'TIC prototype.

Air Tra c Data Analysis

Air Tra c Analysis can be performed with many di erent tools to extract knowledge from real-time or recorded information (i.e aircraft trajectories). All of these tools can help to better understand tra c structure and evolution thanks to di erent metrics and interaction techniques [5]. Tra c can be analyzed from a ow perspective; the users can better compare recorded trajectories and dig into their temporal evolution [14]. Flow can also be visually explored thanks to simpli cation techniques like Edge Bundling [7]. The dynamics of such ows can be analyzed with dynamic network [6] and schematization techniques [9]. Flow dynamics can also be extracted with visual analytics tools [1]. Finally, this ow

analysis can provide unexpected information like meteorological parameters (i.e. wind direction) [4]. Few interaction techniques exist to manipulate a large quantity of aircraft trajectories. Fromdady shows the rst instance of such a paradigm [10].

Remote Tower and immersive environnement

To maintain and improve safety and e ciency in ATC, the service providers need to constantly innovate with new systems and devices. The Remote Tower (RT) concept belongs to one of the most recent innovations [12]. The RT (Figure 1) ful lls ATC services from a location remote from the original control tower. A mast is deployed on the air eld with various sensors (cameras, radio antenna, etc.) and a video stream with additional information is transmitted to a remote site thanks to network communication systems. Many countries have started developing RTs to lower the building costs compared to actual tower and to provide ATC services in low-tra c or di cult-to-access aerodromes. In order to better understand the RT challenges, we summarize in the following the design requirements of this concept:

Figure 1: Typical Remote Tower room.

Figure 2: Mast with cameras for the Remomte Tower concept.

Lowering costs: the RT project aims primarily to reduce operating costs and maintenance of small air elds. When the tra c density of an air eld is low, it is not pro table to maintain a control tower and its associated infrastructure.

Increasing the exibility of air navigation service. The opening hours of an air eld and the remote tower system operating mode could be adapted to the tra c density.

Restoring service in aerodromes with di cult access. Using a remote tower system, the technology is able to re-establish air navigation service in areas that are di cult to access or have unfavorable climate.

An alternate solution for large airports: in airports where the tra c density is high, it can be bene cial to have an additional control position. This also maintains continuity of service should any problems occur.

Further, a relatively high tra c-management capacity can be maintained.

Increasing capacity: air tra c is expected to double in the next twenty years [3]. It is therefore essential for airports with high tra c density to increase their capacity. Furthermore, RT will provide a suitable solution when the tra c capacity has to be reduced due to low visibility conditions.

Usage Scenarios

Taking into account the RT design requirements, we identi ed many scenarios where immersive environments may improve ATC activity. These scenarios were designed during one brainstorming session with two HCI researchers, one research engineer and two expert ATCo.

Scenario: low visibility It is 9pm and there is heavy fog at the airport. Tra c density is high, which creates additional pressure on the ATCo. The ATCo cannot see either end of the runway and is controlling tra c following low-visibility rules. Since the ATCo cannot directly see the tra c, it is essential to use stop bars (mandatory stop locations close to the runway) to prevent undesirable actions. One aircraft is on nal approach and another aircraft is waiting on a holding point for the departure. The ATCo has given the incoming aircraft a landing authorization and is waiting for the pilot to report when it has vacated the runway. After receiving the report, the ATCo gives the line-up authorization (i.e. clearance) for the holding aircraft and turn o the stop bar lights. Due to the low visibility rules, this common situation takes much longer time than normally, so the capacity the airport decreases markedly. One solution is to

use thermal/infrared vision with virtual labels. Due to the low visibility, the ATCo turns on thermal vision to enhance the monitoring. This enables the controller to view the aircraft that is waiting at the holding point and the aircraft on nal approach. The ATCo can additionally see the information displayed in the virtual labels that are linked to the aircraft. When the aircraft has landed and the ATCo con rms by the position of the labels that the landing was successful and it has passed the waiting aircraft, clearance for the waiting aircraft to line up on the runway is given. As the aircraft starts moving, the ATCo receives feedback of the action on the label. The thermal/infrared vision allows the controller to see when the runway is vacated and can give take-o clearance with no delay. Having thermal/infrared vision and virtual labels in a control tower can increase the ATCo's situational awareness, especially in low visibility. It is also bene cial for safety and e ciency concerns. However, if there are several aircraft near each other, the amount of labels could confuse the controller and cause dangerous situations.

Figure 3: The immersive environement for the Remote Tower concept.

Scenario: Sound location It is 2pm. There are several small (e.g. VFR, Visual Flight Rules) and large (e.g. IFR, Instrument Flight Rules) aircraft in the airspace. A new aircraft enters the airspace and contacts the tower. The ATCo now knows the approximate position of the aircraft, but is unable to obtain visual contact because there are other aircraft in the same direction. A candidate solution is to use a sound location system. The RT has a surround system which reproduces any sound from an airport at its actual location. For example, if an aircraft that is contacting the tower is situated to the left of the controller, its emitting sound will come from the left. The system also indicates the distance from the airport by modulating the speech of the pilots that are further away. This allows the ATCo to distinguish the location of the

aircraft and to obtain visual contact. The surround system gives the ATCos additional information about the aircraft's position, which in turn can increase working speed. Spotting an aircraft from a tower can be di cult, even in good weather, but the help of the sound system may allow aircraft to be identi ed faster.

Immersive environment Implementation for ATC
The previous scenarios give a suitable overview of potential usage of immersive environment for ATC. In this section, we detail the implementation of our working prototype (Figure 3). In this prototype, the user wears an Oculus Rift [1] HMD and is immersed in a 360-degree visual environment of a selected air eld. The user changes point of view on the eld with a vertical mid-air gesture. An horizontal mid-air gesture changes the visualisation to an infrared light source view (for low visibility cases). When the user gazes at an aircraft, the system displays the corresponding information (e.g aircraft name, company). The 360 views use 8 images mapped on a sky box. Hand gestures are tracked with a Leapmotion [2], and we used the Unity [3] game engine to integrate the HMD and 3D immersion.

Naturally, due to the prototypical nature of our current RT implementation, e cient interactions and visualisation techniques need to be explored and tested. However, this RT prototype helps us to better grasp how new interactions can leverage user activity in a Remote Tower. Several Air Tra c Controllers experimented this environment with simulated tra c, and they all agree that this prototype is an interesting proof of concept. This

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[1]www.oculus.com
[2]www.leapmotion.com
[3]unity3d.com

prototype is the rst step towards more advanced features to support immersion for the Remote Tower concept.

Immersive Analysis of air tra c data

In the previous section we presented scenarios with immersive solutions for real time ATC. In the following, we discuss immersive solutions for o -line tra c analysis. ATC/M analysts deal with big records of air tra c data; for instance one day of recorded tra c over France (Figure 4). The analysts particular interests are the understanding of non nominal situations. In the following we present a scenario where tra c was abnormal, and how analysts to collaborate from distant sites to understand how the tra c was handled in those conditions.

Unusual stack formation due to degraded weather

London-Brussels-Frankfurt-Milan-Paris form the \core area" where high density of aircraft occurs in di erent tra c volumes. A group of Air Tra c Managers visualize tra c data that corresponds to a particular day where ATCos rerouted a set of aircraft (Figure 4), leading one of the pilots to decide to land in Paris instead of Brussels. Using a visualisation of tra c density, the analysts nd that around 1 AM an abnormal peak of density occurred in the Reims sector (north east of France). After a search of meteorological data records, the analysts discovered that the weather conditions were severely degraded and aircraft could not land in Brussels since the air eld was closed. The experts then extract the tra c data which correspond to this area and at this time of the day and visualize the trajectories. They observe the formation of a stack of aircraft in the Reims Area (green trajectories Figure 5 (2) and (3), showing a pile of aircraft ying in circle on top of each other): aircraft were put on hold before either landing in Paris or Brussels. With a visual analysis, the experts discover that the plane that landed in

Paris instead of Brussels was put on hold in this stack, and took the decision to land in Paris. This type of situation can occur when an aircraft runs out of fuel and cannot wait any longer in an holding stack. It is relevant for the group of experts to understand how and why the pilot took this decision. Hence the analysts need to get in touch with the ATC Center in Reims in order to collaborate with them to understand how this stack was handled in such a situation.

Immersive & Collaborative Trajectories Visualisation

The previous scenario illustrates the need for collaborative and immersive aircraft trajectories visualisation to support common understanding, share expertise and report situations from distant sites. Typically, this scenario is supported with 2D visualisation tools to show 3D aircraft trajectories, combined with video conferencing systems to share insights from distant sites. This communication support is not optimal for viewers when presenters navigate in the visualisation (e.g. when they perform pan and zoom operations), and describe and point at 3D data with 2D visualisations. We strongly hypothesise that the use of immersive technologies similiar to the ones used in the Remote Tower (HMDs, hand tracking devices) will improve collaboration by enhancing spatial cognition and situational awareness by providing spatial a ordances to analyse copius 3D trajectories.

For that purpose, we developed a prototype for collaborative aircraft trajectory visualisation that allows multiple users to analyse together a large quantity of aircraft trajectories using HMDs and hand tracking devices. As a collaborative platform for immersive big data visualisation, we identi ed the following design requirements:
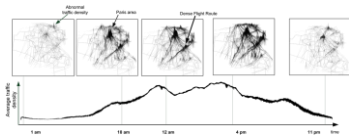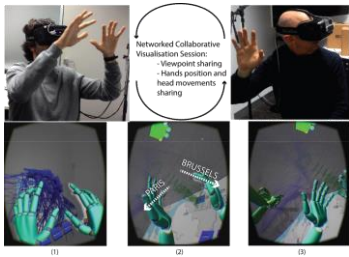

Figure 4: visualisation of density of one day of air tra c over France (500,000 multidimensional data points). The upper geographical visualisations show accumulated aircraft trajectories at di erent time of day (longitude and latitude are mapped to the X and Y axis). The lower visualisation is a density curve which shows the relative peaks of tra c.

RQ1 Immersive visualisation Users are visually immersed in the trajectory visualisations (stereo vision, head-tracking, change of point of view and position).

RQ2 Position indication and interactive rendez-vous The system indicates users' positions, and users can invite each other to share point of view.

RQ3 Pointing and Gaze The system supports users' pointing and gaze sharing to augment the sense of presence.

RQ4 Filtering The users can lter trajectories of interest (e.g. time ltering).

RQ5 Collaboration Users can connect from di erent geographical sites.

To address these requirements, we created a networked Unity application that enables a connection between two users from remote sites (RQ5, Figure 5, top). Each user on each site uses an Oculus Rift that delivers an immersive visualisation experience with stereo vision and head-tracking (RQ1, Figure 5, top). The hands and ngers of the users are tracked with a Leap Motion device (RQ3), and users view a high- delity feedback of the movement and position of their own hands in the Oculus Rift (Figure 5 (1)). Users can change their viewpoint by leaning and rotating their heads with the help of the head-tracking of the Oculus Rift. Users can navigate in the visualisation using a combination of gaze direction and the use of a game pad (RQ2). We developed a rendezvous interaction that allows each user to send their location in the virtual environment. The distant user receives a noti cation: an incoming message in their eld of view. We developed basic ltering operations such that users can replay the tra c with the game pad (time ltering) and change the opacity of the trajectories (visual ltering to reduce clutter) (RQ4). The head and hand positions and rotations of each users are sent over the network

using socket communication. Oral communication is supported with VOIP clients such as Skype or Zoom.

This platform is a rst prototype that aims to improve communication between remotely located ATC experts. With this novel and visually immersive prototype, the groups of experts from the previous stack formation scenario can connect with experts in Reims and run a collaborative visualisation session (Figure 5, top). The users start with an overview of the tra c (Figure 5 (1)). The expert in Reims navigates to the stack and sends a virtual rendezvous to share the relevant point of view to the distant user. Once the two users are at the same position in the virtual environment, the expert explains the formation of the stack with the use of his hands in the 3D environment. The expert explains how the planes were managed in this stack and how they were sequenced for landing in Paris and Brussels (Figure 5 (2), the green stack of aircraft trajectories). During the session, the two users are immersed in the three dimensional tra c trajectories and bene t from the a ordances that the system o ers. They can directly point at 3D trajectories with their hands and analyze the data collaboratively (Figure 5 (3)).

Conclusion And Future work

In this paper we exposed real-time and o -line ATC/M scenarios and how those activities can be supported with the use of di erent immersive solutions. In particular, we showed two immersive ATC/M prototypes for control and data data analysis. We introduced the Remote Tower, where the user can grasp the potential of an immersive environment to ful ll ATC tasks. This technique is promising but work remains to develop new interactions and visualisation techniques and to validate them. We also presented an early collaborative and immersive

Figure 5: Top: Two remote users using the collaborative visualisation platform. Each user wears an Oculus Rift DK2 head-mounted display, equipped with a Leap Motion device that enables hand tracking. Bottom: Visual representation of the remote collaborative session in the Unity client. The session starts with an overview of the data set (1), here we have a day of air tra c data over France. An expert sends a rendezvous position to the other viewer and explains how the stack was formed and handled (2). The two participants share the same virtual space, discuss orally via VOIP and can describe and show particular spatial arrangements of trajectories directly with their hands (green and blue hands (3))

prototype tool which enables experts to collaborate from distant sites with the use of HMDs and hand tracking devices. We believe that this type of platform will reduce users' cognitive e orts when collaboratively analyzing trajectories, and improve their work ow and comprehension of tra c (a recent study showed the bene ts of collaboration with head mounted displays [2]). However, further work is needed to re ne the design, evaluate and validate this platform with expert users.

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