A Survey of Visual and Interactive Methods for Air Traffic Control Data

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***Abstract*—The StayCentered project at Technische Universität Chemnitz has the goal to improve the overall security of air traffic controllers. Therefore, we attempt to empirically comprehend the usual controller workspace and their dyadic team structure. Within this context, the following paper describes actual interfaces and visualization, discusses recent research within this field and outlines the project's intention.**

***Keywords*-Air traffic control; Data visualization; Collaborative work; Emotion recognition;**

I. Introduction

The work of air traffic controllers is best described as voiced interactions in front of the radar screen and in conjunction with the pilots aboard the aircraft within the controlled airspace. Since this work is essential for a speedy and secure travel through national airspace, redundancies are an important factor. The StayCentered project is focused on identifying human error potential by analyzing the presented information, the interaction between the two controllers responsible for any given airspace and the interface. The following paper describes current workspace at Deutsche Flugsicherung (DFS), reviews recent literature, and discusses possible enhancements.

II. State of the art in the field of application

Starting point for considerations are actual objectives, routines and tools in air traffic controllers workaday life at DFS.

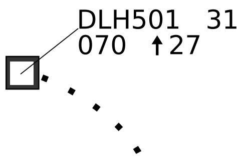
A. The workflow of an air-traffic-controller-dyad

Due to the need for redundancy, usually two controllers are responsible for any given airspace. Both have access to the identical radar information, weather reports and planned flights. In regards to the communication with the pilots, one controller (a) is voicing traffic commands over the radio, while the other (b) is coordinating the acceptance or handover of flights from or to other sectors. This is necessary, since each sector has their individual operation of flight-levels and is generally only accepting flights within a certain flight-level threshold in order to keep a smooth vertical alignment between adjacent flights. While arranging the handovers, controller (b) is also responsible to verify the communication between controller (a) and the pilots and to intervene if necessary. Therefore, the division of responsibilities is depending on a good internal communication as well as a transparent work situation.

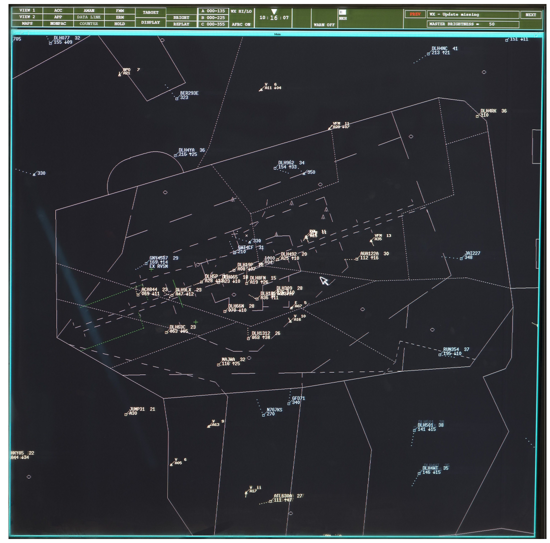
B. The standard layout of an air-traffic-controller's workspace

Actually there are three different workspace designs in use at the DFS. The basic setup beyond all systems is a number of screens arranged around the main radar screen. The radar allows for tracking of aircraft near to and within the controller's sector of responsibility. Each aircraft is represented by a small square that is followed by some dots representing recent flight history (Fig. 1b). History gives a clue to actual direction and speed.The aircraft is accompanied by a label, that shows at least call sign, altitude (flight level), ground speed and rate of climb/descent. Information within the label can be adapted by the controller (e.g. adding indicated airspeed, aircraft type or category of wake turbulence). Aircraft representations colored in gaudy yellow or red indicate conflict situations or emergencies, otherwise they are colored according to several filters. The background image on radar screen shows at least sector lines and optional information on position of radio beacons, meteorologic disturbances or closed airspace. Aircraft's direction vector (a function of time adopting constant ground speed and direction) or the closest point between two direction vectors may also be shown. Input devices for this are a touchscreen and a conventional mouse. Secondary screens display additional information, such as meteorological data (Fig. 1a). The most often used interactional device for the organization of the air traffic is either the paper based flight strip or its digital representation, accessed through a digitizer-pen on a touch screen. During first unstructured interviews, controllers at DFS pointed out, that they enjoy new ways of communication and data consistency between digital flight strips and the system. At the same time they are missing peripheral recognition of actions by the supporting member of the dyad. That is because every controller has his own display and materiality of the interaction is missing.

(a)



(b)



(c)

Figure 1. Radar Screen (a) An air traffic controller dyad [1] is composed of an executive (left) and a planner (right) (b) Aircraft Representation with callsign, groundspeed, flight level and rate of climb/descent (c) Radar Screen at Deutsche Flugsicherung [1]

III. Related work on air traffic controller's workspace

Main tools structuring air traffic controller's working process are the representation of current situation within airspace (radar visualization), communication tools (telephone and radio) as well as an organizational tool (flight strips or the like). Situational representation and organizational tools are ongoing subjects in research.

A. Flight Strips

Replacement of paper flight strips has been discussed intensively. Mac Kay [2] highlights the importance of flight strips within air traffic controlling. They take advantage of visual and tactile memory, they are flexible, reliable and support cooperative work due to their physical presence and visual forms of interaction.

In order to benefit from physical flight strips and digital communication structures new interfaces have been developed. Hurter et al. [3], [4] propose Strip'TIC (Stripping Tangible Interface for Controllers). Paper strips are tracked and the system can highlight information through a projection onto them. Anoto Digital pen is used for any given interaction, so that information written on a paper strip is also digitally available (Fig. 2a). Witzke et al. [5] presented within their thesis e-ink flight strips. Thus combining benefits from both, the physical and the digital, worlds (Fig. 2b).

B. Radar Visualization

Concerning radar and adjacent information visualizations there is an ongoing discussion about the benefits of 3D views.

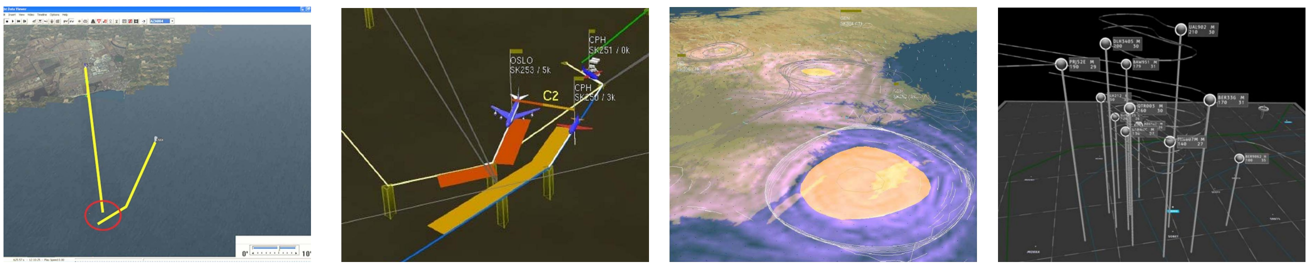
Tavanti et al. [6] tested controllers performance and accuracy regarding the identification of critical flight levels. Controllers using the 2D view performed as accurate as those using the 3D stereoscopic view, however latter performed at a faster pace. Beside the task about identifying relative altitudes of aircraft, Burnett and Barfield [7] asked controllers to resolve conflicts and to reconstruct the presented situation. Results showed only little differences in performance between plan view and perspective view, merely altitude tasks showed better performance on perspective view. These experiments considered 2D plan views, that encode the altitude textually. Consideration of graphical encoding was neglected. Also Smallman et al. [8] argue that a 3D view is not as important as the availability of information and that well designed 2D displays that use graphical encoding are capable of obtaining the same benefits.

ATV3D for example is a 3D stereoscopic interface for ATC [9]. Within this, researchers had a closer look at interactive resolution of conflicts [10] and 3D weather visualizations [11] (Fig. 3). Another 3D stereoscopic ATC system was developed by Bagassi et al. [12]. They presented two visualizations of aircraft's future trajectories within a photorealistic 3D environment with cones as symbols for aircraft (Fig. 3). Bergner and Schmand [13] examined advantages of a 3D stereoscopic view showing current situation in holding patterns (Fig. 3). However, they also noted that today's stereoscopic equipment isn't yet practicable for using it over the duration of a whole work shift.

Palmer et al. showed, that a 2D plan view display showing aircraft icons, whose size and contrast correlate to the aircraft's altitude, improves potential conflict detection [14].

(a) (b)

Figure 2. Augmented Flightstrips (a) paper strips extended by projection [4] (b) e-ink paper strips [5]



(a) (b) (c) (d)

Figure 3. 3D stereoscopic visualizations for air traffic control (a) prediction lines for future aircraft trajectories [12], (b) visualization for conflict resolution [10] (c) weather visualization [11] (d) holding pattern in 3d [13]

Using color coding instead of gray scale contrast, enhances conflict detection accuracy even further, although perception of perspective appears to be less distinct [15]. Hurter et al. [16] characterized and compared four designs of aircraft's recent history (comet). Comet representations without holes have better occlusion resistance. Each design indicates speed through its length but only classical (ODS) and RadarGL design's curvature indicate an aircraft's tendency.

IV. "'StayCentered"' project context

To adequately support the air traffic controller dyad, the upcoming system is supposed to offer assistance to the controllers as well as to their supervisor. It should identify possibly upcoming stressful developments within the airspace and offer assistance by reevaluating the sector borders or by recommending to call in additional controllers and alongside automation strategies [17] to reduce cognitive stress levels.

A. *Psychological view on air-traffic-controllers*

From the perspective of the cognitive sciences, the empirical examination of air traffic controllers in general is very fruitful. In order to incorporate the many different information available to one coherent situation of an airspace, the mental representational capabilities have a strong impact. Various models are available to describe the mental workflow as well as the capabilities of air traffic controllers (e.g. [18],[19]). However, the main research question within the current project of StayCentered is to develop a mental and emotional model of the controller dyad in front of the radar screens. Therefore, sensory equipment will be implemented in order to record and infer situational arousal, facial action coding, body posture, vocal properties and eye movement as well as pupil dilation. Since the air traffic controllers rely heavily on their working memory capacity [20] in order to calculate a certain flight path and possible interruptions, a key factor to measure will be the ongoing cognitive load during usual traffic procedures. Within the context of this specialized group of people and their unique tasks, the measurement of brain functions is limited by keeping it as non-invasive as possible. Therefore, the use of eye-tracking data seems to be a valuable and reliable tool for the measurement of cognitive load itself [21] as well as the detection of ongoing problem solving [22]. Additionally, the detection of pupil dilation seems to be linked to ongoing cognitive load as well [23] and is therefore collected alongside eye-movement.

B. *Interfaces*

Within the described context interface, design is not just about generating a suitable visualization on and interaction with data already available at actual systems. Moreover it is about adapting the controller's interface to the situation as it is appreciated by the mental and emotional model. Enhancing controller's situation awareness and keeping their mental workload on an adequate level. Interfaces should allow for good and fast communication and for a transparent work situation, and thus supporting cooperative work within the dyadic team.

V. Conclusion

We have delivered an insight into today's air traffic controllers workspace at Deutsche Flugsicherung. Recent research within the field reveals two trends. One discussing the need of paper flight strips and the other one discussing 2 and 3D radar visualizations. The StayCentered project at Technische Universität Chemnitz tries to develop a mental and emotional model of the controller dyad in front of the radar screens and adapting the controller's interface according to the models output. Thus enhancing contoller's situational awareness and supporting cooperative work within the dyadic team.

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