The future of Air Traffic Control?

- Digitalizing the mental image

Georg Abadir, David Karlsson, Fanny Molander, Maja Schylström,
Helena Tjusberg, Kristina Vegelius
Linköping University 2010

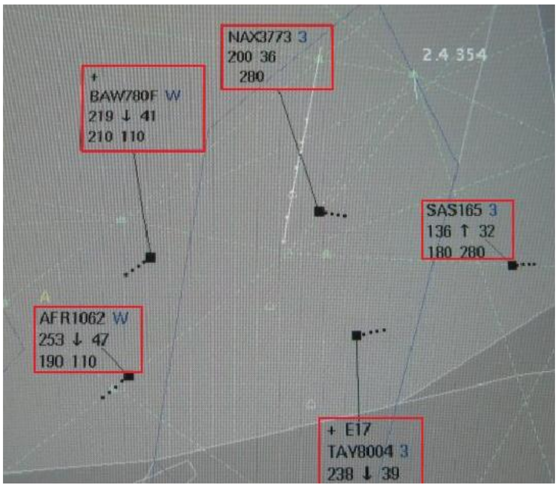
A study consisting of three parts examined the difference between a two dimensional and a three dimensional interface for use in air traffic control. Earlier research within the area was evaluated, controllers and subjects were interviewed, and a test was designed to examine perceptual differences. The results showed a clear difference regarding complexity in the interfaces. The study suggests areas for continued research as well as improvements to be made in the 3D interface.

Introduction

It is expected that the current air traffic management system in Europe will suffer serious bottlenecks as soon as 2020. This will make an expansion of the air traffic unfeasible unless something drastic is devised. (Norrköping Science Park, 2008)

Todays ATCs, air traffic controllers, work with a similar 2D radar display that has been in use for several decades. Due to technical limitations the development of 3D systems for ATC, air traffic control, use has only just begun, although it has been debated since the 1970s (Josefsson, 2010).

The main task for the ATCs is to avoid infractions of minimum separation. In order to do this they have access to working tools mainly consisting of a two dimensional radar display (picture 1), a radio and flight progress strips. ATCs stationed in towers control both the area around the airport and the *control zone*, a small airspace within sight, which makes the radar display less important in their daily work. However, at control centres the display is essential in order for the ATCs to oversee the *terminal area*, between 500 meters and 3000 meters feet above sea level. The Swedish airspace above 3000 meters is monitored from two larger control centres (ÖKC, 2010).



Picture 1: 2D radar display (Red rectangles added by the authors.)

Air traffic visualization 3D

In 2001, EUROCONTROL and C-research at Linköping University commenced a collaboration in a project called ATV3D. The purpose was “developing experimental software systems for the visualization of real-time air traffic control information, real or simulated, and conduct experiments to determine the potential value of three dimensional representations for controllers". (EUROCONTROL & Linköping University, 2009)

The purpose of this study is to contribute to the ATV3D project through a comparison of the current 2D interface and a 3D interface, which is one of the prototypes under development. Through a combination of qualitative and quantitative methods the general attitude towards the interfaces was examined along with perceptual advantages and disadvantages concerning a 3D system within ATC. The questions we aimed to answer were:

- What advantages and disadvantages are there with a 2D and a 3D interface, concerning receiving information and making decisions based on it?
- In which areas would the use of the 3D system be suitable?
- Which improvements could be made on the 3D interface?

The evaluated 3D interface has been available as video recordings in the study. In reality, there are many different possibilities for visualization in the system. The user is able to choose which information is displayed, and the angle and distance from which the situation is presented. (ÖKC, 2010)

2D vs. 3D

In a study by Tavanti and Cooper (2009), ATC trainees that were interviewed regarding a 3D interface for ATC were in general positive to the interface. Furthermore they thought that the 3D interface should be used for training purposes. Tavanti and Cooper (2009) hypothesize that the 3D interface can contribute to giving the trainees a more natural view of the spatio-temporal relationships concerning air traffic. (Tavanti & Cooper, 2009)

Cockburn and McKenzie (2002) investigated how the spatial memory is influenced by 2D and 3D through placing, organizing and localizing homepages on a previously empty display. Not only was the 2D interface perceived as less cluttered, but locating homepages in it was also faster than in 3D. (Cockburn & McKenzie, 2002)

The results of a study regarding identifying the shape and determining the relative position of two objects show that 3D perspective is sometimes superior 2D and vice versa. 2D was to prefer when determining relative position. (St John *et al.*, 2001)

Studies conducted by Dalgarno and Harper (2004) indicate that interactive 3D environments, in comparison to animations and film, enhance the spatial learning provided there are authentic tasks to perform. This is supported by the results of a study conducted by Sturz *et al.* (2009) which showed that subjects with a lot of experience of video games performed better than others regarding tasks in a 3D interface on a computer screen.

Cognitive functions

In this section theories regarding cognitive functions that affect the work of ATCs are presented as Shorrok (2007) refers to several publications where it is found that perception is involved in most of the accidents concerning ATC. Among them a review which showed that attention and memory related mistakes were the most common among ATCs (ibid.). The following section is based on Cognitive Psychology by Robert J. Sternberg (2006), if nothing else is stated.

The working memory allows the controller to integrate perceptual input from the radar display and the strips, with auditory input from radio communication; this is done simultaneously with processing the information and converting it into tactical and strategical decisions. Since a controller has to anticipate and avoid situations that might result in an infraction of minimum separation, their working memory has to perform several controlled processes, including timetabling of actions. (Esgate, 2005)

Visual perception is not only perceiving stimuli, but also interpreting and creating a mental representation of it. The concept of perceptual constancy is applied in order to perceive an object as invariant even though the proximal sensation changes. Rather than perceiving an approaching object as larger, the distance to it seems to be decreasing as the image of it enlarges on the retina.

There are two types of cues for depth vision, namely monocular and binocular. In order to represent the physical environment, cognitive maps with a special focus on spatial relations are constructed. According to the eye movement theory (Thorndyke, 1981), a distance is estimated based on the time required to move the eye from start to stop. If landmarks are placed along the path, the distance seems longer due to the increased time usage (ibid.).

Perception and attention are closely connected. As the brain only manages to handle a limited amount of stimuli at a time, focus must be placed at a certain stimulus. The similarity theory states that the higher amount of variety and details the background consists of, the harder it is to distinguish a specific stimulus.

Some processes require a lot of attention and must be executed sequentially, these are called controlled processes. As opposed to controlled, automatic processes are executed unconsciously and can be performed parallelly. With a great deal of practice, some controlled processes can become automated. Through enough training, ATCs learn to transform the flight levels into conceptual knowledge (Tavanti & Cooper, 2009); thus the process of creating a mental image changes from being controlled to automatic.

Situation awareness

According to Stanton *et al*. (2010) the use of technical aids influences the SA, situation awareness. Endsley (1988, p. 792) defines SA as “the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”.

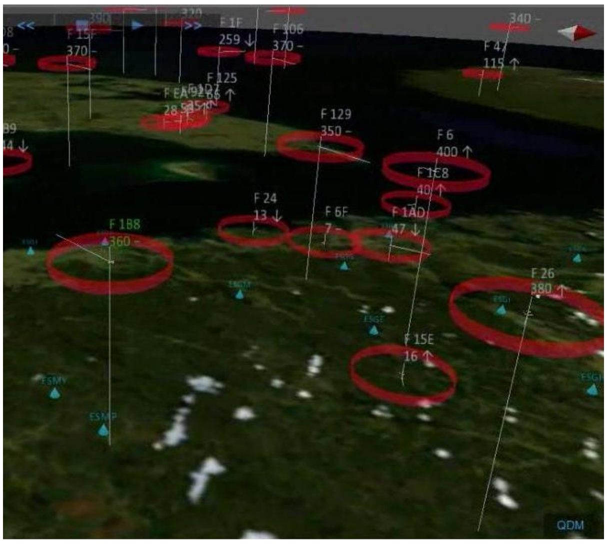
Stanton *et al*. (2010) describe a previous study which showed that the more aids used, the worse the subjects’ performances were. Stanton *et al*. (2010) claim that the results obviously are due to the subjects not having to keep all of the information in mind while using the aids available. Furthermore they suggest three different approaches of describing and analysing SA: *the psychological, the engineering* and *the system ergonomics*. When using the engineering approach, SA is placed in the environment and represented by artefacts and objects used, whilst in the system ergonomics approach, the focus is on the interaction between the agents and the artefacts in the system. The psychological approach describes SA as only existing within the human mind. The most common way of describing SA from a psychological point of view is probably Endsley’s three level model (Endsley & Garland, 2000). Stanton *et al.* (2010) argue that there is a problem with models such as Endsley’s since they are difficult to use when explaining behaviour outside the area of analysis. Moreover they say that different agent’s pre-existing information will be connected with additional information, thereby creating individual schemas for each agent, even if they all have access to the same information. (Stanton *et al*., 2010)

Salmon *et al*. (2010) claim that in order to support compatible SA in a group, tools have to be designed based on each of the agents’ needs. In that way the tools will mediate the accurate information, at the accurate time and to the accurate agent in the system. Displays and interfaces should therefore only present the information necessary for the agent in question and thereby eliminate the access to redundant tools and functions. (Salmon *et al*., 2010)

Method

To capture as many different angles as possible in the study, a combination of qualitative and quantitative methods was used. By visiting two control towers and one control centre, fundamental background information about ATC and the two dimensional radar system was acquired. During the interviews, the ATCs were shown video recordings of the 3D interface and were asked to share their thoughts about it. Three ATCs and one intern also participated in the test that was specifically designed to examine the difference in perceptual experience between the 2D and 3D interfaces. Their results were processed separately from the test group which consisted of students at Linköping University.

The test consisted of three parts where the first concerned questions about the subject's previous experience, whereas the second part was divided into two minor perceptual tasks, and the third part regarded distance assessment between aircraft in snapshots from the 2D and 3D interfaces. Three snapshots from each interface were used in the test. At the end of the test, the subjects received questions about their certainty of their answers, how they had solved the tasks and what information they had focused on the most.



Picture 2: Snapshot 1, in 3D (Cropped version)

Results and discussion

The quantitative results showed that significantly more time was required to give a correct response on snapshot 1, in 3D, (picture 2) than an incorrect. The opposite, although not as obvious, was noticed regarding the answers on the 2D images. We believe that the search, that is performed to find the correct answer in the 3D images, is more extensive than for 2D, and therefore requires more time. Similar results have been presented by Cockburn and McKenzie (2002) in a study concerning localisation in 2D and 3D. This disparity suggests that subjects giving the wrong answer in snapshot 1, in 3D, did not spend the time required to solve the task. We find this to be a negative aspect in the 3D-system as ATCs are expected to have the ability of making quick decisions.

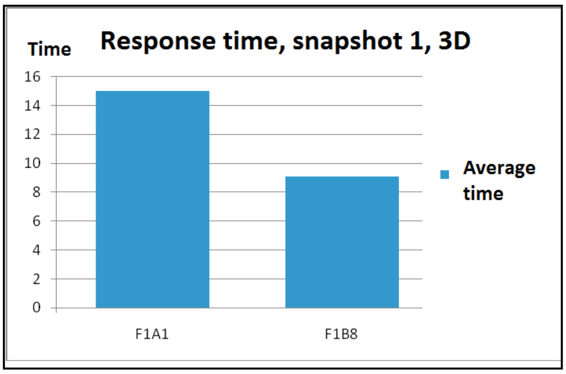


Figure 3: Average response time in snapshot 1, 3D

Subjects with experience from computer games generally performed better than others in 3D. This can be explained by them having general experience within the domain, which according to previous studies (Dalgarno & Harper, 2004; Sturz *et al*., 2009) enhances their ability in performing specific tasks within the same domain.

In comparison between snapshot 2 and 3, in 3D, the difference is substantial in both performance and time. The average time used for the task in snapshot 2 was almost four times longer than in snapshot 3. Snapshot 2 contained more than thirty aircraft distributed over a larger and more detailed surface, whereas snapshot 3 only contained three aircraft on a smaller surface with fewer details. We believe these results are due to the first snapshot being cluttered, which possibly contributes to the eye movement phenomenon (Thorndyke, 1981). Both ATCs and subjects were of the opinion that the 3D interface generally contained too much information which according to the similarity theory, explained by Sternberg (2006), makes it more difficult to distinguish the important stimulus. This may further explain the time difference between snapshot 2 and 3, in 3D. The subjects mentioned that the 3D interface felt cluttered, although not having to deal with numbers was a positive aspect. The process in 2D, in which subjects had to perform arithmetic in order to establish the spatial relationship between aircraft, has shown to be automated with extensive training (Tavanti & Cooper, 2009). The ATCs interviewed argued that they have no difficulty visualizing the airspace mentally and therefore found 3D unnecessary for operative use. They also felt that the 3D system is being developed to solve non-existing problems. Earlier studies (St. John *et al*., 2001; Cockburn & McKenzie, 2002), concerning tasks that are relevant for ATCs, have also shown that subjects perform better with a 2D interface than with one in 3D.

One of the controllers interviewed thought that 3D might be helpful in the sense that controllers would be able to choose their preferred perspective, instead of everyone being shown the same one. We believe that this could be a small step towards the compatible design which Salmon *et al*. (2010) argue would support SA. However, another controller said that today's ATCs use different perspectives in their mental images, which is also confirmed in another study concerning the ATV3D-system (Tavanti & Cooper, 2009). As previously stated (Salmon *et al*., 2010), even though everyone receives identical information, they shape their own personal SA. Endsley's (1988) definition, and three step model (Endsley & Garland, 2000), of SA can be used to explain individual controller's internal processes. As previously mentioned, this model has been criticised (Stanton *et al*., 2010) for its inapplicability outside the human mind. Hence, for continued research, we suggest that the ATC system's SA as a whole to be evaluated using another approach, preferably the system-ergonomics (ibid.).

Recommendations

The most important problem with the 3D interface is that it is quite indistinct, meaning that the existing cues and tools are in need of being simplified. One possible improvement is to make a more apparent dissimilarity between the lines showing position and direction by giving them different colours or thickness. The background could also be improved by a simplification that helps decreasing the perceptual workload. Furthermore, some form of reference points would be helpful when judging distance. We find the red cylinders used to represent the minimum distance of separation contributing to making the image difficult to interpret. Hence, an exfoliation of the information presented could be made by removing the cylinders, from all aircraft except those at risk of infractions of minimum separation. The cylinders should, regardless of use, explicitly display which aircraft is positioned at a higher altitude.

Conclusions

What we consider being the positive aspects of 2D is that the interface is simple to understand and only contains meaningful information. We think that the fact that none of the interviewed ATCs mentioned any substantial disadvantages with the current system speaks for itself. Some ATCs even meant that the problem, which allegedly would be solved by 3D, does not exist. However, one disadvantage with the 2D system is that it requires a great amount of training in order to learn how to create the mental image of the airspace. The 3D interface could give a more direct understanding for the different dimensions. Disadvantages with 3D are, among others, that the interface is cluttered and contains too much information. In order to get a full picture of a certain situation in 3D, interaction is required from the user.

We argue that the 3D interface requires more time concerning processing information and making a correct decision than the 2D interface. Therefore, we find the system appropriate for areas such as training and post incident analysis, where time is not an issue; particularly since it may help people without ATC training to visualize the airspace. Another conclusion, regarding areas of use, is that system is not suitable for operative use in its current state.

References

Information from an anonymous air traffic controller who work at Östgöta control centre is referenced as ÖKC, 2010.

Some pictures and explanations of the 2D radar displays were retrieved from a PowerPoint presentation by Törnvall at LFV and is referenced as Törnvall/LFV, 2000.

Published references

Cockburn, Andy & McKenzie, Bruce (2002) Evaluating the effectiveness of spatial memory in 2d and 3d physical and virtual environments. I *Proceedings of the SIGCHI conference on Human factors in computing systems: Changing our world, changing ourselves*; Minneapolis, Minnesota, USA 20-25 April 2002; pp. 203-210. New York, NY, USA: ACM

Dalgarno, Barney & Harper, Barry (2004) User control and task authenticity for spatial learning in 3D environments. *Australasian Journal of educational Technology*, 20(1), pp. 1-17

Endsley, Mica R. (1988) SITUATION AWARENESS GLOBAL ASSESSMENT TECHNIQUE (SAGAT). I *IEEE Proceedings of the National Aerospace and Electronics Conference*, pp. 789-795. University of Michigan Library

Endsley, Mica R. & Garland, Daniel J. (2000) *Situation awareness: analysis and measurement*. Mahwah, New Jersey, USA: Lawrence Erlbaum Associates Inc., Publishers

Esgate, Anthony & Groome, David (2005) *An Introduction to applied cognitive psychology*. Hove, England: Psychology Press

Salmon, Paul M., Stanton, Neville A., Walker, Guy H., Jenkins, Daniel P. & Rafferty, Laura (2010). Is it really better to share? distributed situation awareness and its implications for collaborative system design. *Theoretical Issues in Ergonomics Science*, 11(1/2), pp. 58-83.

St. John, Mark, Cowen, Michael B., Smallman, Harvey S. & Oonk, Heather M. (2001) The Use of 2D and 3D displays for shape-understanding vs relative-position tasks. *Human Factors* vol. 43, no. 1, pp. 79-81, Human factors and ergonomics society.

Stanton, Neville A. (2010). Situation awareness: Where have we been, where are we now and where are we going? Theoretical Issues in Ergonomics Science, 11(1/2), pp. 1-6

Sternberg, Robert J. (2006) Cognitive Psychology. Fifth edition, International Student Edition. Wadsworth, Cengage Learning.

Sturz, Bradley R., Bodily, Kent D., & Katz, Jeffrey S. (2004) Dissociation of Past and Present Experience in Problem Solving Using a Virtual Environment. CyberPsychology & Behavior. February 2009, 12(1), pp. 15-19

Tavanti, Monica & Cooper, Matthew (2009). Looking for the 3d picture: The spatio-temporal realm of student controllers. I Proceedings: Human Centered Design vol 5619; Minneapolis, USA 19-24 July 2009; pp. 1070-1079. Springer-verlag.

Thorndyke, Perry W. (1981) Distance estimation from cognitive maps. Cognitive Psychology, vol. 13, pp. 526-550.

Unpublished references

EUROCONTROL and Linköping University (last updated 2009). ATV3D OPEN SOURCE SOFTWARE. (Electronic) Available: <http://atv3d.sourceforge.net> (2010-05-31)

Josefsson, Billy (2010) ATCO, Senior Advisor ATM & Human Performance, Air Navigation Services Division, LFV. Personal correspondens.

Norrköping Science Park (last updated 2008). *Arbetsminne inom flyget*. (Electronic) Available: <http://www.nosp.se/tabid/3007/itemid/322/language/sv-SE/3D-fr-kat-arbetsminne-inom-flyget.aspx> (2010-05-31)