Visualization of uncertainty for Air Traffic Controllers

Christophe Hurter, Serge Roux, Stéphane Conversy, Jean-Paul Imbert

Visualization of Uncertainty for Air Traffic Controllers

Christophe Hurter, Serge Roux, Stéphane Conversy, Jean-Paul Imbert

Abstract— The goal of Air Traffic Controllers (ATCo) is to maximize both safety and capacity, so as to accept all flights without compromising the life of the passengers or creating delays. Because air traffic is expected to double by 2030, new IT systems must be developed to manage this traffic increase while maintaining or improving safety. ATCo radar screen displays past, current, and future aircraft position that contains uncertainty without displaying it. Uncertainty is mentally integrated by ATCo when assessing the future aircraft position. In this paper, we give some information regarding the radar data uncertainty and we propose new designs to display future aircraft positions more accurately with their uncertainty.

Index Terms—Uncertainty visualization, Air Traffic Controller, InfoVis

INTRODUCTION

The goal of Air Traffic Controllers (ATCo) is to maximize both safety and capacity, so as to accept all flights without compromising the life of the passengers or creating delays. Because air traffic is expected to double by 2030, new IT systems must be developed to manage this traffic increase while maintaining or improving safety.

In order to monitor actual traffic, Air Traffic Controllers (ATCo) use radar screens which display aircraft positions (Figure 1). The radar screen displays the past and current aircraft position with the comet design [3]. These radar screens display data from the IT system called STR (Système de Traitement Radar). This IT system merges radar stations data to update tracks associated to aircraft. The data merging process is complex and generates uncertainties due to radar and tracking accuracy. In reality, radar visualizations hide these uncertainties and display the aircraft locations as if they were the actual locations.

In order to avoid collisions, proximity warnings, and to optimize aircraft flow, ATCo give order to aircraft. For instance, to keep a safe distance between two aircraft, ATCo can ask the pilot to steer 10 degrees left. The radar screen will then display the steering aircraft when the pilot has decided to turn. ATCo have very limited tool to assess the future aircraft position and its uncertainty. They use aircraft current speed (displayed in the first row of its label), its altitude (displayed in the last row of the label). They can also display the speed vector that shows the future aircraft position if it keeps the same speed and direction, but again without its uncertainty. They also can measure distances in Nautical mile (Nm) by selecting points with the mouse pointer on the radar screen.

As previously explained, ATCo use the past, current, and future aircraft position that contains uncertainty without displaying it. Even if it is not displayed, ATCo estimate this uncertainty. Therefore we believe that uncertainty visualization (data externalization) is a tool that will help ATCo to improve their efficiency while maintaining their safety level. In this paper, we investigate new radar visualizations that display the data uncertainty through new designs.

The remainder of the paper is as follows:

- *C. Hurter is with DGAC/DTI R&D, ENAC and the University of Toulouse, France E-Mail: christophe.hurter@aviation-civile.gouv.fr.*
- *S. Roux is with DGAC/DTI R&D, France E-Mail: serge.roux@aviation-civile.gouv.fr.*
- *S. Conversy is with ENAC and the University of Toulouse, France E-Mail: conversy@enac.fr.*
- *JP. Imbert is with DGAC/DTI R&D, ENAC and the University of Toulouse, France E-Mail: jean-paul.imbert@aviation-civile.gouv.fr.*

Manuscript received 31 March 2011; accepted 1 August 2011; posted online 23 October 2011; mailed on 14 October 2011.
For information on obtaining reprints of this article, please send *email to: tvcg@computer.org.*

We first detail the uncertainty while computing current aircraft positions. Secondly we detail our new designs that show uncertainty. And finally, we conclude this short paper with a discussion on the usefulness of uncertainty visualization for ATCo.

1 UNCERTAINTY IN RADAR POSITION COMPUTATION

Given the limited space in this document, this section gives simplified information regarding the uncertainty of aircraft position computation. Nevertheless, we attempt to answer this question: what are the uncertainty margins in pixels and millimeters of the displayed aircraft on radar screens. In order to compute the following data, we used the standard radar screen of 1600*2560 pixels, 640mm wide, 400mm high, with the typical zoom ratio that displays one sector and its surroundings which cover the whole screen area. This zoom ratio allows the display of 22 pixels per Nm.

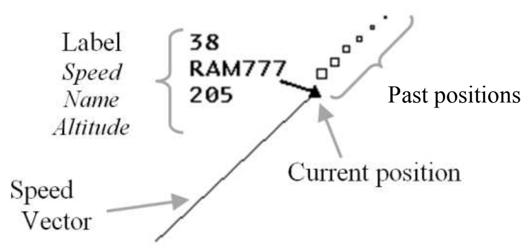

Figure 1: radar comet

1.1 Uncertainty related to the screen refresh

Each track (which corresponds to one aircraft) is updated every 4 seconds. Considering the worst case scenario, when an aircraft flight at a maximum speed of 500 Kt (knots, 900km/h), the error will be 0.55 Nm (1 km), i.e. 12 pixels on the radar screen (3 mm). This error corresponds to the distance that one aircraft fly during 4 seconds. ATCo must maintain a minimum safe distance of 5 Nm between aircraft otherwise they have to report the situation to aviation authorities. This mandatory safety distance is 10 times greater than the uncertainty due to the screen refresh rate.

1.2 Uncertainty related to the radar tracking system

Information in this section is extracted from internal documentation regarding the evaluation of radar over France [1] [2]. This process happens regularly to monitor the French radar tracking system (STR). For the purpose of clarity, the following uncertainty computations are basic. This section only gives order of magnitude of these uncertainties.

1.2.1 Aircraft latitude and longitude position uncertainty

Given that typically 0.1% of displayed positions have an error greater than 0.15 Nm, this error represents 3 pixels on the radar screen.

1.2.2 Aircraft speed uncertainty

Typically 0.1 % of speed plots have an error > 20 Kt. The aircraft speed, which is displayed with the speed vector, shows at its end the future aircraft position in 3 minutes if the aircraft keeps the same heading and speed. This error corresponds to 1 Nm (3 minutes flight duration) on the radar screen, 22 pixels, 5 millimeters. The radar screen does not display the speed uncertainty.

1.2.3 Aircraft heading uncertainty

Typically 0.1% of heading plots have an error of 10 degrees when flying straight, which corresponds to 4 Nm (500Kt speed, 3 min flight duration), 88 pixels, 22 millimeters. When steering, 0.1% of heading plots have an error of 40 degrees which corresponds to 17 Nm (500Kt, 3 min), 376 pixels, 93 mm. This uncertainty is by far the most important one, but most aircraft are flying straight and the current aircraft heading is less important that its actual location.

1.3 Summary of radar screen uncertainty

The following table contains the summary of the uncertainty of the radar tracking systems and their impact on the ATCo's radar screen.

Uncertainty of current position	value	Pixels	Screen distance
Refresh rate	0.55 Nm	12	3 mm
Position (Lat/Long)	0.15 Nm	3	1 mm
Uncertainty of extrapolated position			
Speed	1Nm	22	5 mm
Heading (straight)	4 Nm	88	22 mm
Heading (steering)	17 Nm	376	93 mm

This table shows that the uncertainties (for 0.1% of displayed positions) impact very little on the displayed aircraft location. Since the size of the symbol that depicts the current aircraft position is 14 pixels wide, it roughly represents the position uncertainty.
This uncertainty is important regarding the extrapolated positions, especially when steering. But ATCo use the speed vector to assess minimum crossing distance only when aircraft are flying straight.

2 PROSPECTIVE DESIGNS FOR ATCO

In this section, we will detail new designs that display radar data with their uncertainties. As previously explained, positions uncertainty, is roughly embedded in the square that represents the current aircraft position. However, the uncertainty of aircraft extrapolated position (speed vector) is not visible. Therefore we propose new designs that display uncertainty of extrapolated positions, one with a curved speed vector, and one with a parrot scale.

2.1 Curved speed vector

The curved speed vector shows the user that the aircraft is actually turning. The animation speed gives him an indication of the turn rate. A speed vector with a small curvature will show a slow turn. Furthermore, with this new design ATCo can see a more realistic future aircraft position compared to the straight speed vector.

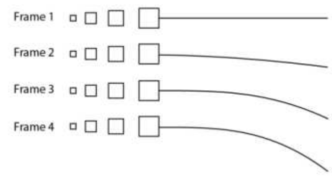

Figure 2: curved speed vector.

2.2 Parrot scale design

This design displays future aircraft positions as dots. We connect dots of two aircraft's future positions if they correspond at the same time. We also added the minimum crossing distance (the yellow shape) and its location (the pink line). This design is animated; hence it shows how the crossing will evolve (Figure 3).
This parrot design is impaired by the ladder that uses tamed parrot to climb in their cage. While this design is very accurate, it is very dense; it displays a lot of visual features, and is limited to two aircraft. But it enables ATCos to assess and forecast aircraft crossing.

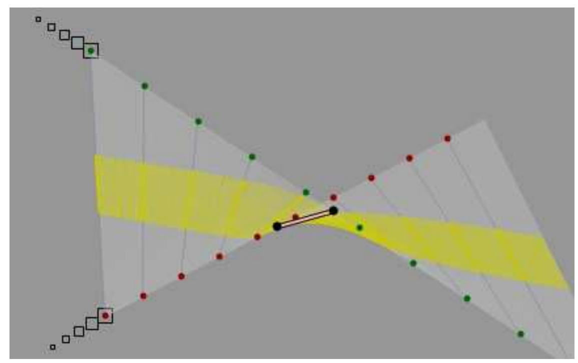

Figure 3: parrot scale design.

3 PERSPECTIVES AND CONCLUSION

As explained in this paper, uncertainty data is not displayed on the radar screen. Some data uncertainty is explicit, like the aircraft location that is embedded in the design of the current aircraft location. Others are mentally integrated by ATCo when assessing the future aircraft position. Radar screen design is a balance between accurate displayed information and cognitive workload to retrieve data. Complex designs with the visualization of uncertainty may spoil the radar screen and thus hinder the proximity detection and the safety level.
We identified that ATCo need new tools to display future aircraft positions more accurately with their uncertainty. Therefore we have created new designs: curved speed vector, and parrot scale.
In the future, we plan to assess these designs with simulated traffic and ATCo in order to validate their usefulness.

REFERENCES

[1] DTI/DSO/IDV Evaluation de l'image en-route VISPRI du CRNA Ouest (chaine de surveillance ARTAS virtualisé + EXSA + ODS) et du déport TMA de Deauville. Internal documentation n° DTI/DSO/1108283/IVD

[2] DTI/DSO/IDV MCO DACOTA Toulouse - Evaluation rapide DACOTA 6.1.3.2 sans PSR. Internal documentation n° DTI/DSO/1108829/IVD.

[3] Hurter, C., Conversy, S., Vinot, J.L. Temporal data visualizations of Air Traffic Controllers. CHI 09 Interacting with temporal data workshop. Boston USA.

[4] J.J. Gibson, The Ecological Approach to Visual Perception. Houghton Mifflin, Boston. 1979.