3D Visualization and 3D and Voice Interaction in Air Traffic Management

Marcus Lange, Jonas Hjalmarsson, Matthew Cooper*, Anders Ynnerman

Norrköping Visualization and Interaction Studio, Linköpings Universitet, Norrköping, Sweden

Vu Duong

Experimental Research Centre, Eurocontrol, Brétigny-sûr-Orge, France

Abstract

This paper describes the implementation of a 3D VR system for real time visual representation and manipulation of data in air traffic management and control. The system has been designed and implemented in collaboration with experts in the Eurocontrol Centre for research and development in air traffic control and is currently undergoing evaluation by air traffic control staff.

The system will enable us to determine what benefit, in terms of enhanced understanding and clarity of perception, such 3D displays, combined with enhanced information presentation, can provide to the controller. It is hoped that improvements in this area will permit more efficient and safe management of more aircraft over a wider airspace. Interaction schemes have initially been centred around the use of 3D interactors such as a 3D pointer but we have recently implemented a scheme for voice recognition which allows the user access to a much wider range of commands and actions without recourse to a static keyboard or complex button combinations. The exploitation of carefully selected voice controls frees the user to work within the VR environment using little or no hand-based interaction.

We intend to continue development of this system and expect that it will form an evaluation test bed for a wide range of new VR, 3D and other interaction technologies within this application area in the future.

CR Categories: I3.7 [Three-Dimensional Graphics and Realism]: Virtual Reality, J7 [Computer in Other Systems]: Command and control,

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*e-mail:matco@itn.liu.se

1. INTRODUCTION

The management of air traffic across the wide areas used in international air traffic routes is a large and growing problem with the ever increasing numbers of passengers and flights in operation. The systems used for air traffic management, however, are only adopting new technologies quite slowly with the modern controller being faced with a remarkably similar working environment to that which has been in use for more than 30 years. Despite the fact that the management of air traffic is obviously a three dimensional problem and despite long discussions[1][5] of what benefits might be gained from its use, to date no use of 3D displays has been made in production tools for commercial air traffic management. This results in a system where the controller, being provided with only a 2D representation of the data, must construct and hold the 3D model in their head: a difficult task with a large number of active aircraft spread across the wide airspace which they must manage.

This paper describes an ongoing collaborative development between the Norrköping Visualization and Interaction Studio and the Innovative Research group at the Eurocontrol research centre. The projects seeks to explore the application and benefits of 3D (stereo) VR display and interaction technologies with a view to determining the qualities required to produce an effective 3D information visualization environment for the air traffic controller. The currently implemented system, targeted at semi-immersive displays such as workbench displays and VR theatres, makes use of VR techniques to provide an environment within which an air traffic controller can observe and monitor a large number of aircraft over a wide area, being kept aware of the many complex factors about their planned routes which may affect the future planning of the flight paths, and can use 3D interaction methods to select and re-route aircraft interactively as the data are updated in real time.

The recent addition of voice control to the system has opened up the possibility of reducing the number of commands which must be mapped into the 3D interaction devices, the number of which is so high after two years of development that the user must frequently make use of a keyboard to be able to control the whole system. The voice control is now capable of controlling all features of the system with the exception of some of the more complex navigational tasks and for selecting aircraft and performing routing operations on them. For these tasks a 3D wand remains the interaction method of choice.

2. DESIGN AND IMPLEMENTATION

To provide an effective test-bed for 3D VR interaction and visualization in air traffic management we have developed a system which can provide a controller with a 3D environment showing all of the aircraft active in the controller's particular region of interest and those whose routes will take them through it during their flight time. The system is based around Stockholm's Arlanda airport which is a medium capacity airport supporting regional, national and some international air traffic. The flight information which we have obtained provides us with a complete set of inbound and outbound flights for Arlanda across approximately 60 minutes of a weekday morning and includes a range of different aircraft types and flight distances.

2.1 The visualization problem

Aside from the problem of the number of aircraft which are active in the airspace, each flight present in the display is affected by a large number of associated factors which control the behaviour of the aircraft and define the way in which the controller will manage the flight. This information includes such factors as the aircraft type, its current airspeed and altitude, the extent of its vortex wake and how it will be affected by those of the other aircraft preceding it, its take off and expected landing times, the name of the airline who operate this aircraft and its flight number. External information such as weather data, both forecast and reported, can also be extremely important when controllers wish to make routing decisions for the aircraft under their control.

In the existing air traffic control scenario, with which we are all familiar from films and documentaries, the air traffic controller is presented with a limited amount of information through a text block attached to glyph 'blips' on a 2D radar display. Thus the sum of information to which the controller has immediate access will typically be the flight number, position, direction, speed and altitude. All other information is likely to be provided through another source, either a separate computer display or even on paper.

Within our immersive VR environment we wish to present all of this information within the scene with no recourse required to external information sources. To force the user to switch from the immersive display to a separate information source would both be time consuming, taking their attention away from the active flights over which they are watching, and would damage the sense of presence which such VR systems as this can engender and from which we hope to benefit through an enhanced sense of awareness of the 3D scene. Thus all of the required information must be attached to the aircraft in a manner which makes it clear and easy for the controller to interpret with a minimum of searching required.

2.2 Visual information representations

The 3D environment that we have developed represents the aircraft as easily recognizable 3D geometries for the different aircraft types and we have attempted to map airline liveries onto the models, where possible, to provide information about the airline. Flight paths are indicated by colour-coded tubes connecting waypoint 'posts' which indicate the real and virtual waypoints which the aircraft are instructed to fly past or through. The waypoints also have an associated altitude defined as a flight level (1000 foot intervals). This three dimensional information, using models which have been scaled up enormously from their real-world size, provides useful depth cueing information to the controller and makes the aircraft models (and hence their types) visible when the controller is looking at the scene in a global overview.

To assist in conflict avoidance and resolution the controller is provided with the facility to display information about each aircraft's position at a future time. The future position, at one minute intervals, is displayed using a colour-coded tube which precedes the aircraft as it moves and indicates its planned route through branches and joins in the trajectory network.

Height information regarding the planned altitude for each flight at each waypoint is included using colour-coding on the waypoint posts and using a translucent 'curtain' below the flight paths to make the individual flight levels visible to the user. We have also experimented with displaying the actual current altitude of each flight using a colour component attached to some element of the 3D structure of the aircraft, typically the wings and, perhaps, the tailplane but the number of flight levels and hence the number of distinct colours required makes it difficult to make this information sufficiently apparent. At present some additional information is attached to the aircraft as a text tag which conveys the flight number and current altitude but it is intended to explore other ways to include this information in the future.

A close up view of the active system, showing all of the features described above is shown in Figure 1.

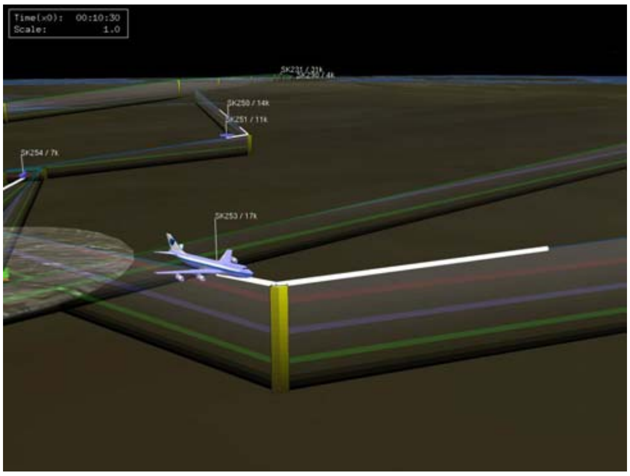

Figure 1: Close up view showing aircraft models, flight path information and estimated future flight positions.

2.3 Navigation and orientation

To provide usable navigation and orientation information for the controller we have included a limited amount of geographical information in the scene. The local terrain is represented as a three dimensional surface based on a 1km resolution map obtained from the US Geographical Information Survey. No attempt to make the map photorealistic has been made since this would provide useful information to the controller. Instead a simple colour map based on height has been included to highlight major orientation features such as water and substantial hills and mountains. The region of the terrain around Arlanda is quite flat so the map typically shows up as a relatively uniform green colour but the coastline is distinctive and provides excellent orientation information for the controller as they move their viewpoint across the scene.

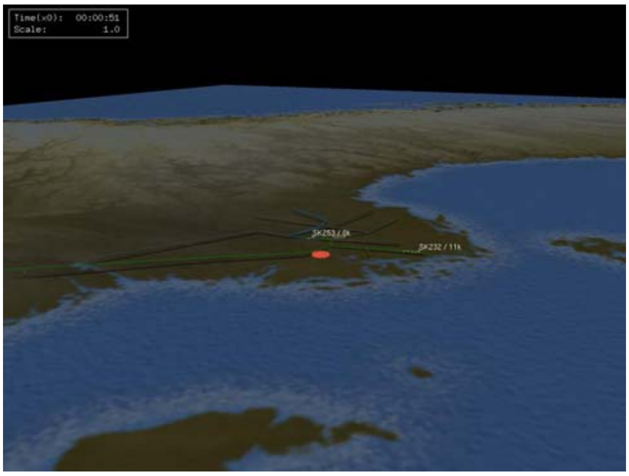

Figure 2: 3D geography over Scandinavia, coloured by height

Terrain of an altitude of approximately 1800 feet or above is coloured white and hence stands out distinctively against the green lower terrain as well as providing the obvious height cue of 'snow-capped peaks'.

2.4 Weather information

Through contacts at the Swedish Meteorological and Hydrological Institute (SMHI), the organization which is responsible for all weather forecast information across Sweden, data sets have been obtained which are similar to those provided to the Swedish Civil Aviation Authority for use by air traffic controllers. This information takes the form of geographically located weather forecast data giving the probability of certain weather conditions at each point in a grid across the region and with respect to altitude by flight levels. This information includes such features as predicted turbulence and icing dangers at the grid points and across a range of altitudes. We have incorporated this information within the 3D environment using the original grid cells and altitudes marking zones with significant risk (higher than a user-defined threshold) of these phenomena occurring. The danger zones are then represented in the display as translucent coloured blocks using textured surfaces to distinguish between the icing warnings (uniform blue) and turbulence warnings (patterned, white). These are clearly visible in the scene shown in Figure 3.

Other weather information has been incorporated during the most recent development phase with method for the representation of air pressure and wind speed being included through the use of pressure isobars (both as a single 2D layer and as a 3D isobar structure) and the inclusion of animated stream-particles (stream-line segments) which show wind speed and direction. Other, simpler representations of pressure and wind speed using cutting planes and vector plots have also been explored. Finally, to show air movement, we have introduced a method based on line integral convolution[8] (LIC) on a per-plane basis to show areas of strong air movement which the controller may wish to avoid. These weather representations are shown in Figure 3.

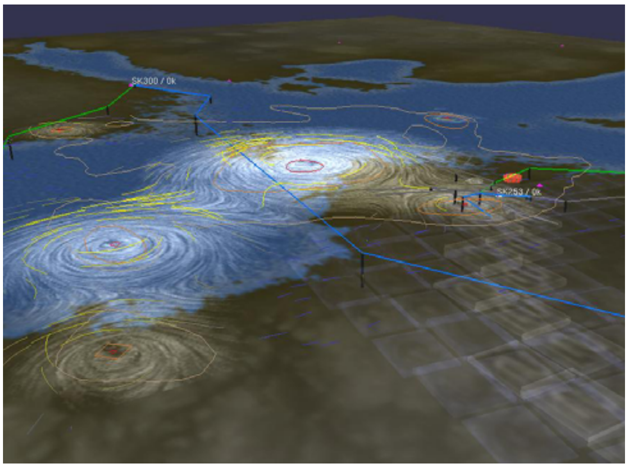

Figure 3: Weather representations in the current application showing pressure, stream particles and LIC representation of air movement throughout the supplied forecast data.

All weather information can be updated during execution of the application with updates in real time as new measured and forecasts data become available.

2.5 Interaction mechanisms

Within the workbench environment we make use of 3D interaction devices both to navigate in the scene and to select and manipulate flight information within the scene. The user's viewpoint is typically centred on a point of interest (initially located at the airport) but can be updated to centre around any position by simply pointing and clicking using a 3D wand pointer. The same wand device can then be used to control rotation of the camera around the view centre in two degrees of freedom and zooming of the view. The wand device can also be used to expand the height scale to emphasize the height of the 3D objects such as flight paths and weather information. In the latest version of the system this 3D interaction is supplemented by a powerful and flexible voice recognition system based on a discrete command set allowing the user to mix 3D interaction and voice control of the specific features of the system at will.

Once an appropriate viewpoint has been found, the user is able to select and manipulate the planned flight path of an individual aircraft. To overcome the frequent problems with overlapping flight paths, where different aircraft will share waypoints and paths between pairs of waypoints, the selection has been made on the basis of a specific flight. The controller selects the flight of interest using the wand pointer. This automatically highlights the flight path of that aircraft and renders the waypoints making up that path selectable by the user. The controller can then either move the selected waypoint or can insert and position a new waypoint between two existing waypoints.

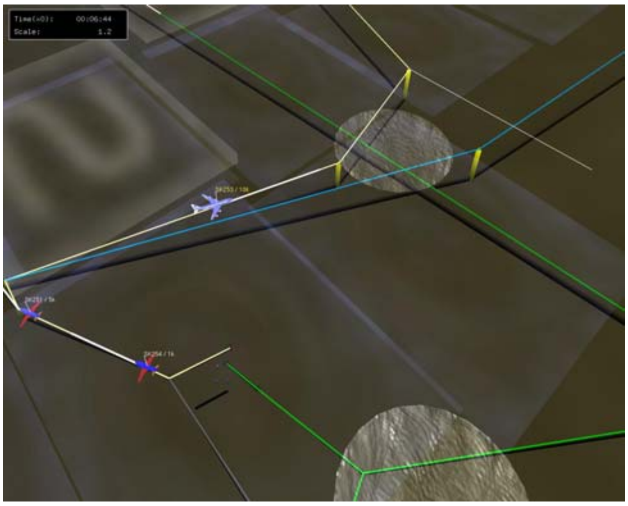

Figure 4: Having selected a flight, the 747 in the centre of the view, the user then selects the waypoint to reroute the aircraft.

The movement of a waypoint or the insertion of a new waypoint corresponds to the creation of a new 'virtual' waypoint, which is to say one which does not correspond to a real physical radio transmitter, and positioning it. This is a common practice in modern aviation. The positioning of the new waypoint, in all three dimensions, is carried out using the wand pointer before the waypoint is finally released. To aid the controller in selection the selectable objects: aircraft and the currently selectable waypoints, exhibit a strong localized 'gravity' which snaps the pointer to the object.

2.6 Implementation and performance

The program has been implemented using OpenGL for the rendering and CAVELib for the management of viewports and handling input from the keyboard and head and wand tracking devices. The flexibility of both these APIs makes the system extremely portable across platforms and the majority of the development has been carried out on Linux-based PC's while the system is targeted towards the semi-immersive workbench and VR theatre installations driven by an Onyx2 multi-pipe system.

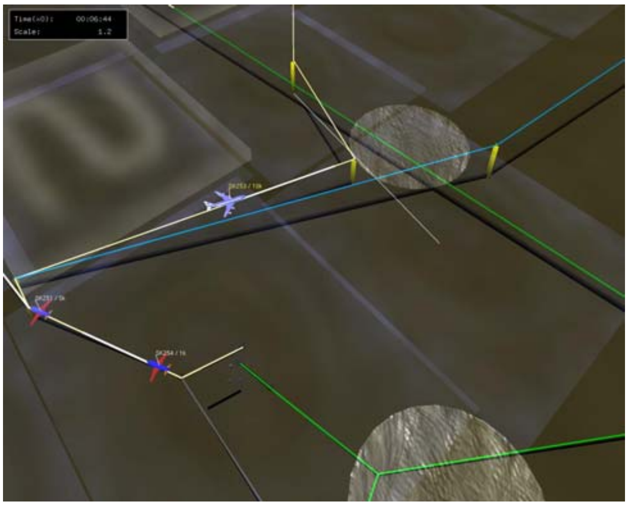

Figure 5: The selected waypoint is interactively rerouted such that the flight path bypasses the reported region of turbulence.

To make use of multiprocessing on the Onyx2, the system is implemented with each major functionality allocated to a separate process as shown in Figure 6. Keyboard input is handled through the application process and tracked objects (head and wand) are handled through the existing tracking management process. The 'Update' process controls the execution of the simulation, updating the positions of the objects within the scene. The 'Server' process is used to receive user input managing the representation of objects in the scene such as height colour-map information and other display settings. This originates from one or more text, graphical or voice clients, typically running on separate computers. The 'Sync' process ensures that the other processes act in a synchronized manner. The 'Draw' process(es) perform the rendering with one process required for each graphics pipe used in the current display.

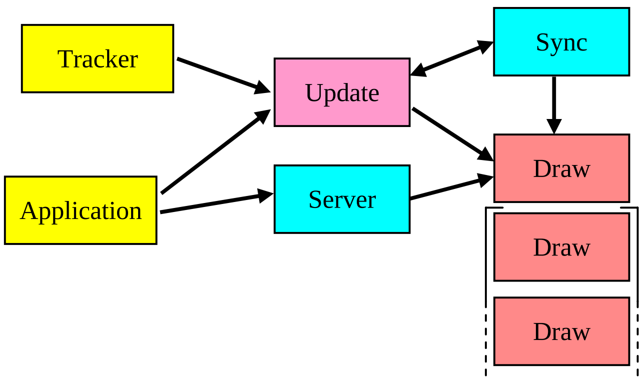

Figure 6: Process structure of the implemented system

Vertex arrays are used for most of the geometric objects in the scene. Many of the objects are also double buffered which allows coherent access by the various processes to the shared memory. 'Lightwave' object support is provided to permit the loading of the complex 3D objects such as the aircraft models. The Lightwave objects include the facility to display additional information such as the current flight level by attaching colour information to certain parts of the aircraft such as the wings or tailplane. Rendering callback functions can also be defined for each individual model.

Each segment of a flight's planned route requires one quad for each 'curtain' segment and a GL line for the tube. The waypoints themselves are displayed using 3 quads per waypoint. Colour data to display height information on the curtains and waypoints is included through 1D textures. In the flight data set in the current work this produces a scene including approximately 1000 quads for the flight path information. The static terrain map used in the current scene comprises 4000 triangles.

On the Onyx2 system, driving either the Barco workbench through a single pipe or the three projector VR theatre through three pipes, the system typically gives a frame rate of approximately 20-25 frames per second. Recent experiments with a Linux based PC (Compaq 2.2GHz P4 with an NVidia Quadro4-900XGL graphics card) driving the Barco workbench has given rendering rates of approximately 40 frames per second.

2.7 VOICE RECOGNITION

The voice recognition system has been implemented using a small program developed using the Microsoft Speech Application Programming interface (SAPI) which provides facilities for the development of applications using discrete voice pattern recognition system. SAPI has been developed from the voice recognition research and development of Lernout and Hauspie which was acquired in a strategic partnership by Microsoft in 2000.

The voice recognition program we have implemented executes on a separate PC system and communicates with the main application using TCP sockets and sends simple text commands to control the features of the application. The voice command set available to the user, currently some 90 commands, has been carefully chosen to minimize the likelihood of misrecognition and, with careful training of the voice system and careful setup of the microphone headset and sound levels recognition rates of well over 95% have been routinely achieved making for a very relaxed working environment for the controller without recourse to a keyboard which has been essential until now.

The controller can use the voice system to switch on and off all of the visual display features of the system and to control some of the simpler navigation using command to rotate, elevate and zoom the camera as well as to focus on specific flights. The voice command "focus on flight S K 2 3 1", for example will cause the camera to smoothly move to the specific flight adopting a standard view on the flight selected. More complex navigational and interaction tasks such as selecting a flight and manipulating the waypoints defining its planned flight path still, however, rely on the use of a 3D wand. We are currently exploring methods and commands which might make even these functions available through the voice interaction system.

3. EVALUATION

Having developed and delivered the software system described here, it is currently undergoing evaluation with air traffic control staff at the Eurocontrol experimental research centre. These evaluations cover a range of properties of the system. Initially evaluations of the overall system are being performed which concentrate upon the reaction of the controllers to the 3D system and how clear and understandable are the visualization features which we have incorporated. This will provide us with guidelines for initial work to refine the system over the coming years.

In the longer term more detailed examinations of the ability of controllers to work with the system will be carried out. These studies will concentrate on the effectiveness of the 3D representation in exploiting the facility of human spatial memory rather than conceptual memory within this application area. Previous studies [2][3][4] have indicated that there is a definite difference in the way in which a user responds to three dimensional representations of data compared with two dimensional. When combined with visible geographical references[6][7], three dimensional data might be expected to be more readily recalled when cued with geographical information than conceptual information cued by data. If successful it is hoped that a transition to incorporate 3D displays in air traffic control may provide both an efficient working environment and may actually allow the controllers to manage a larger number of aircraft scattered over a wider area of terrain and altitude without any reduction in their ability to stay in control of the situation and, consequently, without any reduction in safety for flights and their passengers.

The evaluation of the effectiveness of the system in accessing and exploiting human spatial memory will be carried out in a further collaboration between researchers at Eurocontrol and at the University of Uppsala, Sweden.

4. FUTURE WORK

4.1 Planned new features

Initial evaluation work has provided feedback about the display and the representation which we will incorporate in future versions of the system. Primarily users have asked for additional information regarding orientation and locations cues. In addition to these changes we plan to introduce a number of new features into the project in future development phases as part of the ongoing exploration of new technologies within air traffic control.

4.1.1 Conflict detection and resolution

The principal concern in air traffic management is the early detection and resolution of potential conflicts. The displayed 'look-ahead' which we have included in these early versions of the system, showing where an aircraft will be some minutes into the future, provides some assistance here but is of very limited use as the problem is much more complex than we are able to include from our limited data.

Other researchers, working with Eurocontrol, are developing probabilistic approaches to conflict prediction and resolution using models of flight behaviour and we hope to include this work in future versions of the software. These detected potential conflicts will require the addition of warnings using visual, text and possibly audio cues to draw the user's attention to them. The use of spatially located audio cues may prove very useful since the user can potentially have relocated the camera such that the warning may occur outside of their immediate field of view.

4.1.2 Haptic interaction

The behaviour of aircraft and how they are affected by changes in their routing is extremely complex and typically modelled by a very complex set of equations. Selection of routes over long distances to minimize energy consumption and provide efficient use of the air space is an extremely complex problem being routinely solved in air traffic planning. When controllers wish to make navigational changes to avoid weather disturbances or reroute a flight to avoid a potential future conflict they are unable to take these very complex factors into consideration but, instead, must reply upon their experience and training to minimize the negative effect they may have in making a change. Using haptic interaction would provide a simple means by which the controller could be made more aware of the reduction in energy efficiency which their changes would cause. Ultimately the haptic device could provide a hard-limit to changes made, thereby preventing the controller from making changes which place the aircraft in danger of having to declare a fuel-related emergency.

4.1.3 Display and Interaction at airport

The system which has been developed so far is primarily targeted towards the management of aircraft in the relatively open air spaces between airports. Different problems appear when one considers the task of marshalling aircraft in the immediate environment around the airport where flights are much closer together and must be vectored into 'stacks' where they then hold awaiting final approach, landing and, finally, on-ground control as they approach the terminals.

When used in the management of flights in the large scale view, the application makes use of large aircraft models. These structures provide depth cueing information from their relative apparent size as well as providing a base onto which additional information can be placed. The real world scale of the objects displayed, however, can be measured in kilometres or even tens of kilometres. When close to the airport these very large objects obviously become a substantial problem and so we will make use of a rescaled environment with different representations of the aircraft so that they can be clearly differentiated. This revised application is planned for a future development phase of the project once we have received feedback on our current application from the evaluation processes.

5. CONCLUSIONS

The system developed provides a comprehensive interface for the air traffic controller to view, interpret and interact with complex flight data and supporting information affecting the controller's actions. The effectiveness of the display and its value in terms of presenting information to controllers is still being assessed by air traffic control staff and the design is being refined in accordance with feedback from that evaluation as it is received.

The project has enabled the consideration of a number of potentially useful technologies in this interesting and essential application area. It will also provide an excellent test environment for other new methods and technologies and it is hoped to continue this development and explore the application of more VR technologies in the future.

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