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3D Stereo displays for Air Traffic Control: a multidisciplinary framework and some results

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Abstract

The Virtual Sky project attempts to investigate the applicability of three-dimensional stereoscopic display for Air Traffic Control. This investigation is quite complex in that it requires several disciplines to be studied in parallel. For instance, we decided to use a multidisciplinary approach, which is made of three related components: "Visualization", "Interaction" and "Human Factors". This paper describes the framework of the investigation and provides the analysis' details for each component involved. Moreover, we present some preliminary results involving Air Traffic Controllers and entailing their training with a special Interaction device.

Keywords
Air Traffic Control, 3D Stereoscopic Visualization, Interaction, Human Factors.

I. INTRODUCTION

Air Traffic Control (ATC) deals with traffic organization such that safety is maintained despite the traffic complexity within a defined limited so-called *Capacity*. Growth in air traffic demand of an average of 5-6% per year in Europe and in the US requires that the theoretical Capacity of each control centers be increased in order to be able to accommodate more aircraft in the air without jeopardizing the safety of air traffic. Consequently, controllers are exposed to the challenge of being more and more efficient, not only in the maintenance of safety of flights but also the in the management of flight operations to reduce the complexity of the encounters.

The most important task of Air Traffic Controllers (ATCo) is the maintenance of aircraft separation. The term "separation" refers to the safety distance that has to be kept both vertically and horizontally between aircraft (a/c) thus to avoid eventual collision. These safety distances are called *vertical* and *lateral separation minima*[1].

In the current practices, controllers carefully monitor the traffic displayed on the Radar monitor, a plane view display showing the aircraft tracks each of which is accompanied with a data block sometimes called *Label*. This data block reports, at least, the identity of the aircraft, referred to as *Call-sign*; its flying altitude in terms of *Flight Level*; its speed, and rate of climb or descent. Controllers rely on the information made available to them through the Radar display, and on the information concerning the flight plan of each aircraft (that is also displayed on the same screen, usually in a dedicated window), to maintain separations between aircraft by giving orders to pilots to make evasive actions if two or more aircraft infringe the separation minima.

The way information is displayed in current radar displays is a critical issue, since controllers have to use efficiently use that information to perform their tasks. Actually, the complexity of controllers' working conditions goes beyond visualization problems. For instance, in high-density traffic situation, not only the monitoring workload is increased but also the amount of verbal communications (and the operational procedures) augment. Yet, visualization remains a major issue for ATC: current radar screens display not only aircraft tracks and labels but also other flight related information such as flight plans, airspace (sectors, routes and beacons) as well as the interfaces of all decision support tools that attempt to assist controllers in their tasks.

Yet, in the current two-dimensional (2D) Radar displays, controllers often report the problem of the "cluttered picture" (or "Christmas tree") referring to radar display encumbered with too much information represented by too many graphical objects. The visual clutter is often perceived as disturbing, distracting and a cause of detriment to the monitoring tasks.

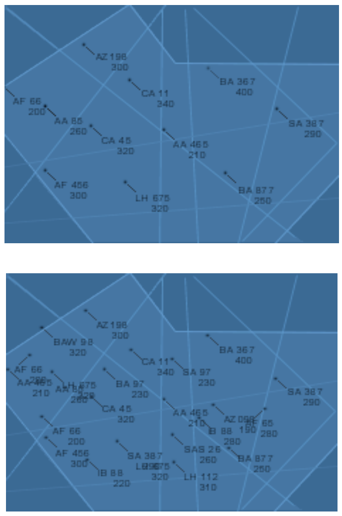


Figure 1: Low and high traffic density

Figure 1 shows a generic sector with two levels of traffic density, the first one with low traffic and the second one with high traffic. It is obvious that the control tasks are more critical in the second situation. Considering the increasing amount of information made available, traditional 2D radar representations might be overloaded.

[1] Several rules are applied depending on the circumstances and contexts. The International Civil Aviation Organization (ICAO) defines this set of operational rules.

A possible solution to overcome such problems could be the use of three-dimensional (3D) stereoscopic displays. This technology might represent a solution to the visualization problem described, because it takes advantage of the depth as an extra dimension to display the data. However, the actual applicability of the 3D stereo technology has to be studied.

In order to do this, we propose to use a multidisciplinary framework for the empirical analysis of the applicability of 3D stereoscopic displays to ATC.

II. THE RESEARCH FRAMEWORK

The research framework comprises three inter-related components (cf. Fig. 2).

The first component deals with the Visualization, the study and definition of how ATC objects should be graphically represented in a 3D stereo display. Examples of the studies include the representations of domain knowledge and decision support information such as flight plans, trajectories, and safety related information.

For each visualized object, not only the trade-off between the degree of realism of the 3D models, and the associated computational costs shall be evaluated; but also the pertinence of the representation with respect to controllers' behaviors in the execution of their tasks (e.g. use of colors, use of 2D elements as text, etc.).

The second component refers to the Interaction and investigates the appropriateness of interaction methods and devices with a stereoscopic display. The goal of this component is to define a model for creating an interaction metaphor that is compliant with controllers' requirements and needs.

The third component involves the Human Factors, the domain that deals with final users' needs, abilities, and performance with a system. The goal of this research component is to perform the users' evaluations using both quantitative and qualitative measures.

In 3D stereo environments, the issues of visualization representation, interactions and users' perception and cognition, are interrelated. The choice of displaying objects and the way to display them certainly influence final users' performance. For instance, in 3D stereo environments 3D tracking and selecting devices supersede the basic interaction technologies of 2D interfaces and the performance of the final users can be entirely different. We believe that the integration of these different aspects is very important for an effective research approach.

In order to get the richest results, all these aspects should be investigated in parallel. For every solution or new idea elaborated, an evaluation has to be conducted. This approach ensures that the progress in the study is compliant with actual users' requirements, thus to avoid the implementation of unusable and ineffective displays.

The following sections will describe more in detail two components, the "Visualization" and the "Interaction". In the "Human Factors" section some preliminary results entailing controllers' interaction with the 3D stereo display are presented. The work is summed up in the conclusions.

III. 3D VISUALIZATION IN ATC

The 3D visualization contents two major areas: modeling and representation. The modeling refers to creation and construction of 3D objects based on geometric primitive objects and flexible scripting language; the representation refers to the rendering of the 3D models created.

The objective of this framework component is the conviviality of 3D stereoscopic visualization in ATC. In other words, all traffic and decision support information should be represented to controllers in such a manner that the tasks are efficiently assisted [3]. Of course, the trade-off between a chosen representation and its related computational costs has to be considered. In fact, if a detailed representation of 3D objects is provided, the computational performance will decrease. Moreover, the users have to interact with the objects displayed; the interaction and the real-time manipulation may also cause an additional computational cost that affects the system's performance.

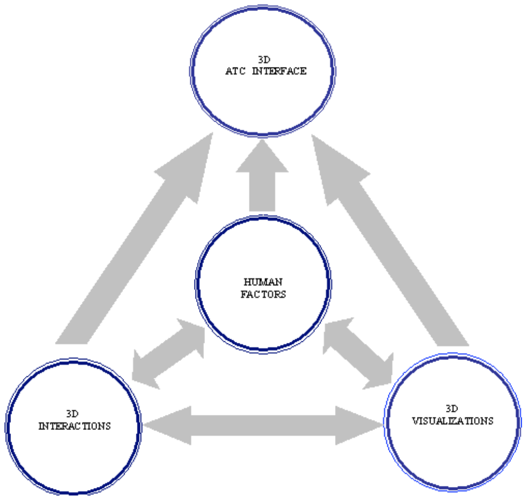


Figure 2: Research framework

In order to avoid an excessive computational cost, objects have to be displayed with different degrees of details [1] according to their importance for importance for controllers' activity. It is necessary to provide a model according to which ATC objects should be classified in compliance with their rationale and properties. Thus, the following classification is proposed (cf. Fig.3).

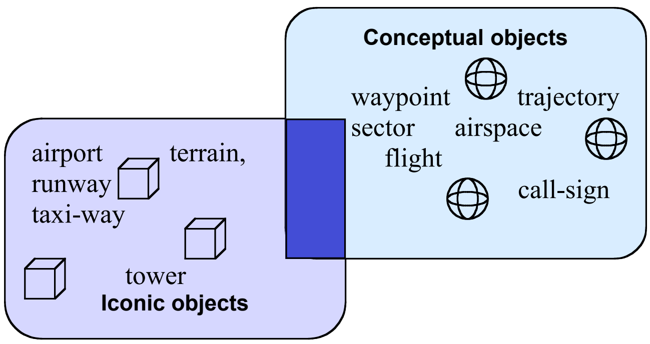


Figure 3: ATC Object Classification

A first type of objects is called *physical*. The representation of physical objects is iconic; that is, they have to be similar to the "real" physical objects existing in reality (e.g. aircraft, airport, terrain or weather information, etc.). This type of 3D objects can be rather complex to be modeled and they require a high degree of detail in the 3D representation. This type of objects is also *manipulation dependent.* This means that manipulations and interactions done by the users upon the objects determine a physical modification of the 3D objects'.

A second type of objects is called conceptual. Their representation is not iconic, since in real world they do not have a physical referent (e.g. the airspace, the sectors, the aircraft trajectories, routes, etc.). The modeling of this type of objects is not constrained by similarity issues and it implies a certain degree of flexibility. By definition this type of objects are *manipulation independent*, so, the actions of the users have no or little "physical impact" on their 3D representation.

For example, zooming on an aircraft trajectory does not necessarily require an increase of the thickness of the trajectory; but the distance between the waypoints within the trajectory will increase. Conceptual objects are essential for controllers' activities therefore their representation has to be very accurate [8].

The suitability of the 3D visualizations proposed has also to be evaluated with the controllers, so as to assess the appropriate levels of detail of the representations and to identify which are the most appropriate ways to display ATC objects.

IV. 3D Interaction Issues in ATC

The interaction with 2D interfaces is nowadays standardized with the WIMP paradigm (Windows, Icons, Menu and Pointer). However, 3D stereoscopic displays may require replacing the mouse and keyboard-based interactions with *ad-hoc* 3D input devices, like the wand (a tracked device composed of a single joystick for navigation and some buttons for control), the tracked glove, or haptic devices. Yet, in the 3D ATC domain, no standard interaction techniques have been introduced.

Therefore, the main objective of the "Interaction component" is to find an interaction model (and some interaction techniques) that allows controllers to interact effectively with ATC 3D objects.

Within the domain of 3D and ATC, some work has already been done. For instance, Persiani and Liverani [7] developed the "ATC-VR", a new interface for 3D ATC data visualization and interaction. The ATC-VR uses a Virtual Reality environment to give the controller an intuitive tool for managing air traffic approaching airports in high-density areas. The ATC-VR uses stereoscopic glasses, a 3D pointing device and the pinch glove to interact with 3D graphical representations. The pinch glove is a discrete-input device; the user can pinch two or more fingers to signal an event. Basic interaction tasks like the objects' selection and manipulation have been implemented on pinch glove and 3D pointing device. Zeltzer and Drucker [9] developed a mission planner using a virtual environment system. Users can interact directly with 3D objects like aircraft, terrain, threats and targets by using voice and gesture recognition. Also for this application, the pinch glove is used as 3D input device.

However, the previous investigations used *ad-hoc* 3D interactions, and they do not propose guidelines or a systematic model describing the possible interaction with 3D ATC objects.

A basis to start modeling the possible interactions with 3D ATC objects is given by Bowman [2] who classified the interactions with 3D displays into three basic forms: navigation, selection and manipulation. Since the users interact with the 3D objects it is also necessary that -in our model- both the interaction and the objects' visualization to be taken into account. In Fig. 4, the relation between the 3D interaction and visualization is graphically displayed. It was above described that 3D ATC objects can be classified into two types, physical and conceptual. Controllers may need to navigate within the 3D space and to select and manipulate those objects' types.

The *link* between the 3D ATC objects and the possible actions that users may perform on them is provided by the interaction inputs, which could be represented by two devices largely used for 3D interaction, namely the Haptic

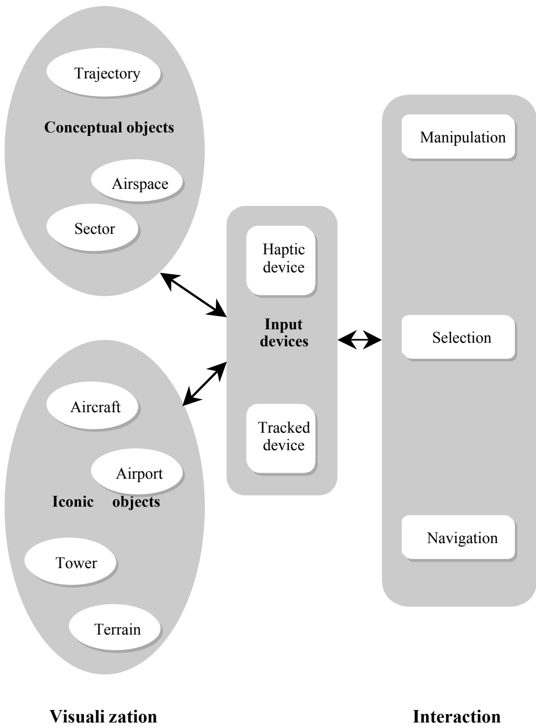


Figure 4: Object Modeling - Interaction Relation

and the Tracked device. For the Virtual Sky project, the interaction equipment available is an Intersense [11] Tracked Wand, with which the users can interact with 3D objects thank to a red ray visualized in the screen display. In order to get some preliminary results and to get our users acquainted with the new interaction device, a training session with some former operational controller working at EEC was organized. The results of the training sessions are presented in the following section.

V. Human Factors & 3D interaction

The method that we used for the training sessions takes inspiration from the user centered design approach [6]. According to this approach, the users (and not the applications) are at the center of the design. Thus, the design process has to take into consideration the end-users' activities, abilities and needs.

Following this approach, we tried to have some preliminary feedback from the controllers about the 3D stereo equipment, during a special training session. The sessions had three main goals, first allow controllers to become familiar with the stereo equipment; second, to discover possible interaction problems; third, to carry out some interviews in order to identified some ATC activities that could benefit from the functionalities of the 3D stereo technology. Nine formerly operational controllers took part to the study.

VI. Training Sessions' Equipment

For this training the 3D stereo equipment available at Eurcoontrol was used, which was composed of a BARCO [10] projection system BARON 900 (136cmx102cm, resolution 970x720 with 120Hz frequency) displaying stereoscopic 3D scenes with geometric objects.

The 3D scenes were written in C++ with Open Inventor version 3.11 and CAVELib version 3.0.1 and ran on a Silicon Graphics' station Onyx2 with 512 Mbytes RAM. Controllers were using Stereographics Crystal Eyes glasses (110 Hz refresh rate) equipped with Intersense tracking system IS-900 VWT. The interaction device was an Intersense Tracked Wand with button and joystick.

VII. Methods and Some Results

The controllers were sitting in front of the BARCO monitor (at a distance of approximately 150 cm); they were instructed on the basic interaction functionalities of the devices and then they were required to freely move simple geometric objects. As previously described, the interaction device was a Tracked Wand from which a red ray (a simple straight line) emanates.

Controllers could move the wand to point the ray towards a certain object. The selection of the object was then determined by the collision between the ray and the object. When a user wanted to select a target object (as example, the green rectangle depicted in Figure 5) occluded by other objects, the ray (colored in red in the Figure 5) intercepted all the objects lying within the same trajectory (cf. Figure 5) and this was causing more collisions to be detected. However, only one object at a time can be selected and it sometimes other than the target object was selected.

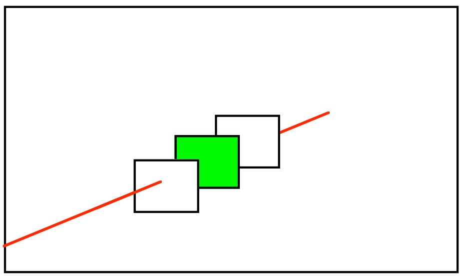
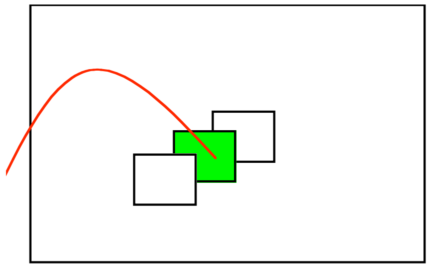


Figure 5: Selection problem, ambiguity of the collision detection

This problem emerged many times during the training with the controllers and caused some frustration. To overcome this technical problem, three new interaction metaphors were elaborated [4]; the first is called the Elastic Wand.

In the Elastic Wand the ray curvature should be adjustable. The basic principle of Elastic Wand is displayed in Fig. 6; like the Tracked Wand implemented in the current system, an end of the ray is fixed to Tracked Wand



and moves with it; but, differently from the current implementation, the ray could be curved according to the user needs, by simply interacting with a pin-like joystick placed at the center of the Wand, so that users can easily reach the desired objects. The other two interaction metaphors (the transparent sphere and the transparent cylinder) implement more sophisticated solutions, like transparent geometrical shapes and floating menus aiming to overcome the occluded objects problem.

Another problem encountered concerns the ergonomics of the interaction. At the beginning we did some informal checks with few controllers, who were asked to stand up in front of the monitor during the training session. They had to keep the Tracked Wand with their right hand and in order to properly move the pointing ray, several movements of the wrist and of the elbow were required. After few minutes of interaction, controllers reported to feel tiredness in the upper part of the right arm and in the elbow. To overcome this problem an armchair was placed in front of the monitor; thus controllers could sit down and to rest the elbow. Such solution was quite empirical, but it seemed efficient and controllers appreciated it; thus it was decided to use it during the following sessions.

After the training controllers went through a last interview. As explained in the previous section, we wanted to identify some ATC activities that could effectively make use of the 3D stereo technology; therefore it was necessary to have direct feedback from the controllers, who have the necessary operational knowledge to spot those activities. The preliminary results of the interviews reveal controllers cannot envision a 3D display for standard approach and en-route tasks, but that some specific activities could be supported by the stereo 3D, like: tower operations, training, stack management and the traffic allocation within sector.

VIII. Conclusions

The present study presented the research framework of the VirtualSky Project. Also, some preliminary results were presented. An important interaction problem was identified and three solutions were proposed: the idea of providing the Wand ray with an adjustable curvature and the use of transparent geometrical metaphors. The transparent cylinder solution was partially implemented and it will be further evaluated.

The other results of the study, suggest that the 3D stereo technology, could be beneficial but only for few ATC activities; however, in order to be more confident about those suggestions further evaluations and studies have to be performed with controllers.

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