A SEMI-IMMERSIVE SYNTHETIC ENVIRONMENT FOR COOPERATIVE AIR TRAFFIC CONTROL

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Abstract

Nowadays many software applications in Air Traffic Control manage ATC data in bi-dimensional maps, so the modern workstations interfaces in some extent lack of interactivity and require the interpretation of large amount of data presented in very synthetic or symbolic way. In this paper a new interface for real 3D ATC data visualization and interaction is presented; it exploits a Virtual Reality immersive technique to give the operator an intuitive tool for managing air traffic approaching airports in crowded areas.

ATC-VR is a smart computer-human interface developed to allow the operator to keep all variables under control on a Virtual Reality desk. Using stereoscopic glasses and 3-D pointing devices the operator can "fly through" a scenery, in which a "tactical" situation is represented superimposing a realistic rendering of the landscape, aircrafts flying in the area and big amount of graphical information concerning flight paths, constraints, predicted under-separations, weather conditions, etc.

Interacting with the 3-D graphical representations, the operator can manage the traffic while the software acts as a supervisor allowing only actions which are compatible with the constrains.

This kind of interface allows also multiple operators co-operating at the same time in directing the air traffic.

1 Introduction

Safety issues related to the rapid growth of flight traffic in congested areas highly stimulate research activities on how to improve Air Traffic Control software and tools.

Traffic managers use many information about the traffic flows when making decisions: these are metering to avoid exceeding airport capacity, load balancing between various areas, assigning departure times. These information come from several sources as plan view displays, aircraft situation displays, operational personnel and flight strips. Coordination with Terminal, Center and Tower operators is a key issue for Traffic Managers to ensure a correct balance between traffic demand and system capacity [1-13].

Automation tools are being progressively introduced to help the operators in making critical decisions; these pertain sequencing and scheduling of arrival traffic, governing the descent phase and managing the final approach spacing.

In many scientific fields Virtual Reality (VR) [14][15] has been proved to be a greatly effective enhancement, in particular in augmented visualization and better representation; applications range from Virtual Prototyping (for example for aeronautical and mechanical assembly manipulation and visualization), to navigation in geographic scenarios (GIS – Geographic Information System) in order to control strategic and tactical situations during real or simulated conflicts.

This seems well suited for a new approach to Air Traffic Control (ATC) workstations. Traditional radar consoles use bi-dimensional maps as interfaces with the operator. This implies an high level of abstraction in the representation of all the information apart from the horizontal co-ordinates. The task of the operator results rather stressing, owing to the high level of concentration required to maintain a detailed awareness of the situation while interpreting symbolic data. Dedicated workstations, used for automatic traffic management, represent traffic flow on configurable moving timelines. Tags and color coding are used in graphical representations which require proper training and may be not easy to use.

In this paper an original software tool for Air Traffic Control data 3D visualization and interaction will be presented, exploiting semi-immersive capabilities of a Virtual Reality Desk (VRDD) completely designed and developed at the University of Bologna. The main idea is that using a VR interface, implemented using a VRDD with stereoscopic glasses and 3-D pointing devices, it is possible to give the operator the feeling of flying over the controlled area, changing its point of view according the needs of monitoring large scale scenarios or focusing the attention in smaller areas where problems may arise. Aircrafts flying can be represented more realistically together with their actual or predicted flight paths and related flight corridors. Furthermore constraints or danger zones in the air-space may be evidenced.

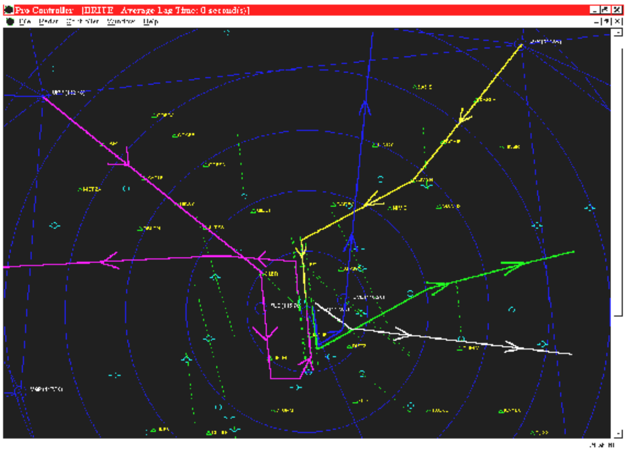

Fig. 1. Traditional Air Traffic Control software interface.

The combination of the scenery representation with symbols, graphics entities like lines, surfaces, volumes, organized in different layers, selectable by the operator, results in an augmented perception of the situation. This arrangement gives the operator a better situation awareness and a more instinctive control of the Air Traffic and enhanced prediction capability. This results in a lighter work-load than the one involved by more traditional ATC workstations.

The variety of the situations, points of views, choices and representation gives a less static and stressing environment than the conventional one.

2 VRDD (Virtual Reality Design Desk)

In this paragraph a short description of the hardware and software tools used is given.

2.1 Semi-Immersive Virtual Reality Desk

Nowadays semi-immersive applications represent one of the most interesting and cost-effective solutions for Virtual Reality. These allow not only enhanced visualization of tridimensional models, but also improved interactivity for design and 3D modeling, providing an important tool for engineers, industrial designers and researchers working with high performance visual computing environments.

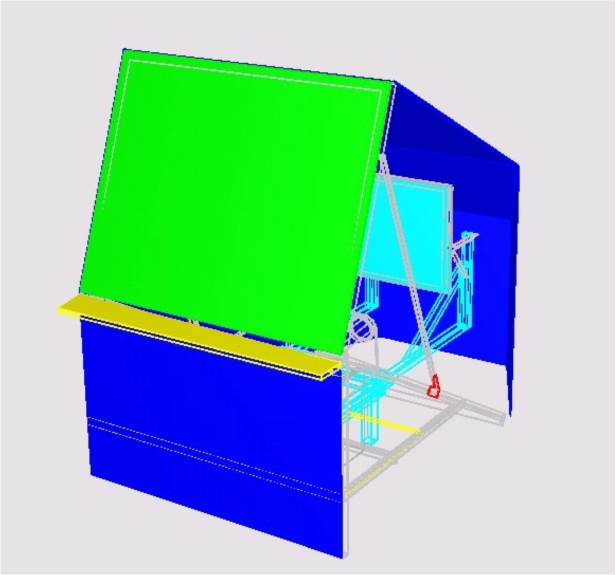

Fig. 2. VRDD at a glance.

The interface here presented is based on a VRDD. In Fig. 2 and 3 it is shown the layout of

VRDD, consisting of a rear-projected translucent screen, yielding clear view of computer generated images in a dark room.

To reduce the size of the equipment, a mirror is used. The 3D immersive effect relies on stereoscopic view, obtained by VR environment synchronized shutter glasses.

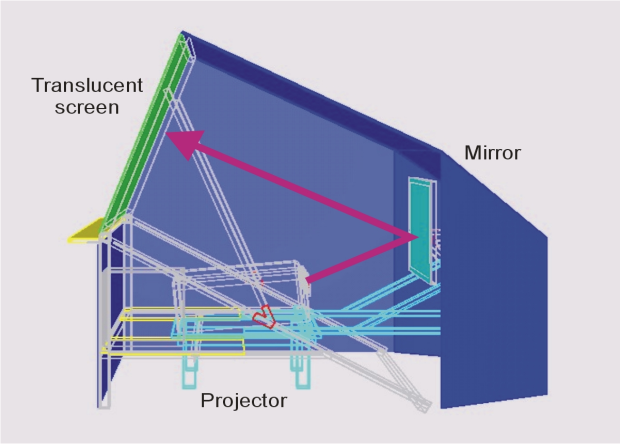

Fig. 3. VRDD rear projection layout.

The VR based visualization and design desk has been employed for ATC-VR development and test. As well as development phase, VRDD has been proved to be mostly helpful in the every-day use of the application final release, due also to a multi-user capability. Unlike fully-immersive environment (i.e. headgear based solutions), semi-immersive VR systems may share the same 3D model with multiple user-viewers. A collaborative viewing represents a key point and a winning advantage in monitoring and controlling systems, like Air Traffic Control.

VRDD software is powered by an SGI Visual Workstation 320 equipped with a Pentium III 500 Mhz and 256 Mb of RAM memory.

2.2 VRDD 3D stereo glasses

Stereoscopic viewing is the use of computer technology to recreate the way we naturally see depth — stereoscopically. Stereoscopic viewing describes how we use both eyes — each with a slightly different perspective — to perceive depth in a physical environment. Stereoscopic viewing delivers the most realistic visual representation possible of complex digital models, giving engineers and scientists the best possible understanding of three-dimensional information, and yielding levels of technical proficiency not available using a typical 3D view.

VRDD exploits Stereographics Crystal Eyes for shuttered stereovision (Fig. 4).

Fig. 4. Stereographics CrystalEyes.

2.3 VRDD spatial tracking

The tracking system is provided by a 3D spatial data-set from Polhemus Fastrak and fully integrated into the environment for user's head position and hand movements. Additionally a magnetic Stylus has been provided with push button capabilities and picking actions. Using a fixed transmitter as reference, this pencil-like system accurately computes position (x, y and z coordinates) and orientation (yaw, pitch and roll) of a tiny receiver contained in the stylus.

Fig. 5. Spatial tracking for head and both hands.

2.4 VRDD manipulation device

The manipulation system uses also cloth gloves with electrical sensors in each fingertip. Contact between any two or more digits completes a conductive path, and a complex variety of actions based on these simple "pinch" gestures can be programmed into applications.

The standard RS-232 serial interface allows the glove system to be used with virtually any workstation or personal computer.

Fig. 6. Manipulation gloves for object selection.

2.5 Software tools

Software is developed using an object-oriented 3D toolkit (Open Inventor®) offering a comprehensive solution to interactive graphics programming problems. It presents a programming model based on a 3D scene database that dramatically simplifies graphics programming. It includes a rich set of objects such as cubes, polygons, text, materials, cameras, lights, trackballs and handle boxes.

The file format used is the basis of Virtual Reality modeling Language (VRML) and complex scene-graphs can be created simply using a C/C++ API for manipulating nodes and components. A *node* is the basic building block used to create a 3D scene. An scene (referred to as a scene-graph) is an ordered collection of nodes. Each node specifies a set of fields (data elements contained within nodes) and associates a name with each field.

Nodes can represent shapes, attributes, cameras, lights, transformations and more. Some nodes (draggers, manipulators) respond directly to user input and are useful for creating direct 3D manipulation interfaces. Nodes can be named and instanced and fields from one node can be connected to fields of other nodes for database and program economy.

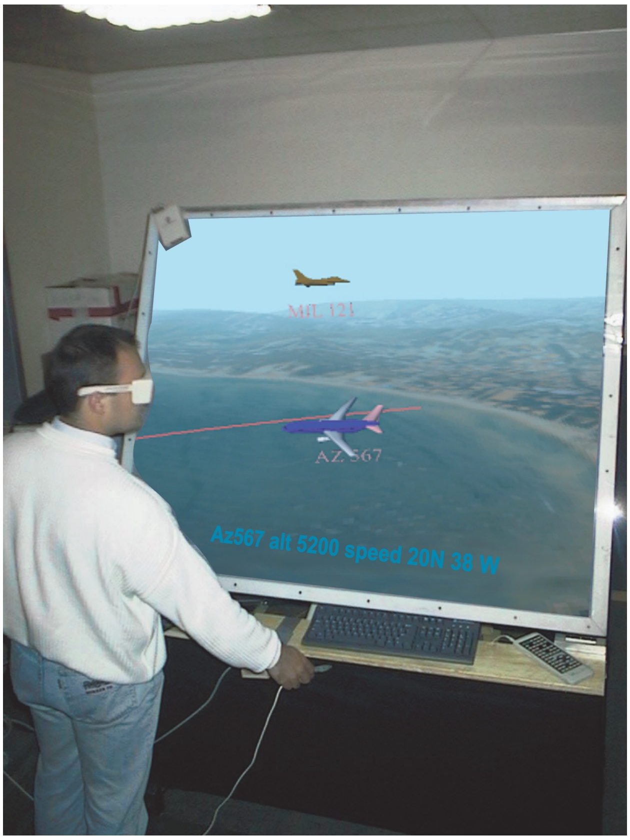

Fig. 7. An ATC-VR session.

A number of actions can be applied to the scene/node. These actions include rendering, reading, writing, picking, searching, highlighting etc.

In addition, the toolkit is fully extensible allowing the programmer to add new objects and operations using sub-classing and callback functions.

2.6 Interaction issues

Exploiting Open Inventor features, a VR based interface has been developed with the leading idea of the complete replacement of standard 2D interaction (mouse and keyboard) with 3D tracking issues. Basic tasks have been implemented on glove finger pinch, like aircraft selection or flight data recall, thank to an efficient collision detection among virtual pointers and 3D models driven in the virtual space.

2.7 Digital terrain models

Nowadays the power of computer allows real-time manipulation of very large dataset, like real digitalized terrain models (DEM), on a entry level PC. An optimized Open Inventor procedure transform a generic digital grid into a reduced set of polygons, via a Delaunay triangulation and polygon reduction. In such way the digital terrain may be recalled and reused in the ATC-VR scene-graph, increasing the simulation capabilities and high level of real scenarios matching. Furthermore aerial pictures have been used as textures for realistic terrain representation.

3 Operation features

Synthetic environment may be represented with a large choice of scales from wide field views to close views. The operator chooses the point of view from which the entire scenery is sought and can virtually fly or zoom in any area where a problem is identified or predicted.

Data from radars and a/c transponders is translated in realistic graphical representations of aircraft 3D models, properly positioned and moving in tridimensional space.

Representation of graphical information pertaining all the aspect of flight paths and constraints or danger zones is performed using 3D shapes superimposed on a realistic rendering of the environment (landscapes, terrain data, weather conditions).

All these shapes consists of line-surfaces with proper characteristics and assigned to different layers, in order to maintain a wide choice of different rendering possibilities for the operator.

Different scaling is another trick used to give a more practical view and control of the scenery. Usually the z coordinate associated to height level can be amplified with respect to x-y coordinate, magnifying the differences between the flight levels and climb descending angle, especially in large scale representation.

Very important is the airport runways representation and everything can be seen by the operator as in a visual system of a flight simulator. He can choose the point of view (ranging from the cockpit view external and tower view).

Also aircraft models can be represented with augmented dimensions in order to facilitate their identification.

Flight corridors and flight paths can be represented in many ways:

- 3D curve associated with various line-types and colors;
- tubular transparent surfaces;
- sequence of rectangular frames.

Colors can be used to highlight dangerous segments of a flight paths or corridors. In fact the underlying software may predict collision danger or traffic conflicts and accordingly put colored markers or textures where these problems are predicted.

The operator may take corrective actions in a very easy way: using 3D pointing devices, he can select the a/c trajectory to be modified and choose actions to undertake.

Modify the trajectory acting on its representation using CAD techniques for the modifications: some “handles” use “spline-node” in order to drag the trajectory which can be thought as a spline curve (see Appendix).

The important feature for governing the trajectory modification resides in the control of the variations which are automatically constrained by the software in order to respect the aircraft performance limits and safety constraints, as explained in the following paragraph.

Once validated by the operator, path modifications can be forwarded directly to the aircraft by Data Link devices.

3.1 Trajectory prediction

Aircraft data pertaining flight pats, velocity etc. are handled by a supervisor software which computes predicted paths [2]. For each airplane in the controlled air space standard motion equations are integrated in combination with fuzzy-logic estimation where data are incomplete or conflicting. Fuzzy logic helps also in simulating the behavior of pilots in following the instruction stream from ATC operators.

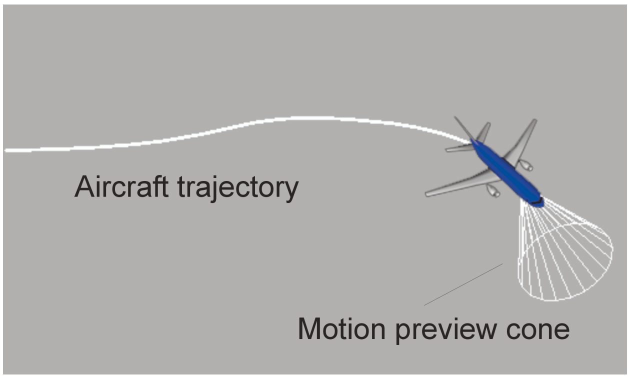

Fig. 8. Trajectory visualization and motion preview.

Spline interpolation can be used by the operator in modeling the intended flight path. Usual CAD modeling techniques allow 3-D trajectory modification using 3-D pointing or pinching devices. Supervising software maintains the modifications in the limits allowed by performance and safety constraints.

A "motion preview cone" (Fig. 8), representing a volume in which the aircraft position may be contained in the following time steps, is introduced for safety purposes. Together with predicted or intended flight paths it allows the evaluation of the probability of under-separations or of flying in dangerous areas.

In this way motion preview may positively prevent dangerous situations or even collisions. In this case a blinking message is displayed on the ATC-VR environment, recalling operator attention onto potential dangerous situations.

3.2 Weather conditions

Meteo conditions are graphically represented with texture-rendering techniques, very effective in highlighting danger zones which must be properly avoided.

Wind shear phenomena are represented using a combination of texture and vector rendering techniques (similar to wind tunnel data visualization) (Fig. 9).

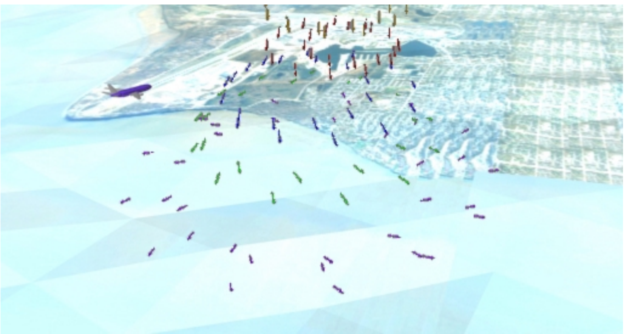

Fig. 9. Wind shear vectored visualization.

Turbulence can be highlighted in similar ways particularly straight-forward and intuitive can be visualized of large aircraft wakes, giving a direct visual information to the operator who is alerted in the case of a predicted path intersecting the wake (Fig. 10).

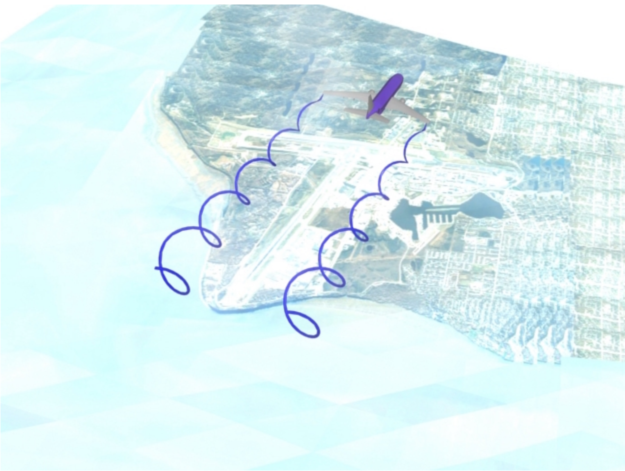

Fig. 10. Wake representation.

Wind is reported as vector field by data fusion techniques from different data sources as local meteo stations, satellite images, meteo radars etc.

Poor visibility levels are also evidenced in the final approach path or were reported. Other dangerous situations connected with weather condition (storms, ice, etc.) may be easily represented in the general scenario.

4 Assessment

The new interface is being evaluated to verify its compliance with human factors guidelines and principles. This is done using simulation, actuated through an Instructor Workstation (Fig. 11).

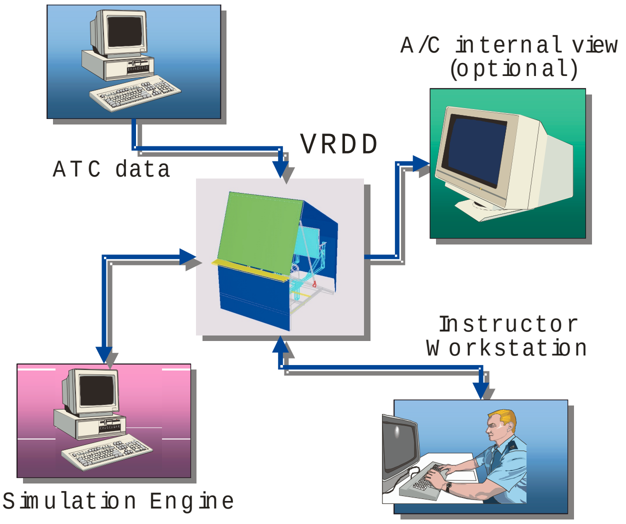

Fig. 11. ATC-VR integrated layout.

The evaluation team uses this workstation to generate traffic scenarios with different kinds of incoming-outcoming flows.

Any problem evidencing poor awareness and/or control of the situation is reported and corrective actions on the software are undertaken.

5 Conclusions

A novel integrated ATC and flight simulation interface has been developed in a Virtual Reality environment. ATV-VR represents an advancement in terms of human-machine interface applied to air traffic management. From software simulations it has been noticed a significantly enhanced control in terms of dangerous conditions perception and prevention, coupled with a reduced work-load of the operator(s) comparing to traditional ATC systems. The Virtual Reality also greatly improves operator immersion in the environment and is well suited for a more intuitive and easy approach to these critical tasks, resulting in a reduced training time.

First simulations show that co-operation and a better integration between different tasks and specialisations in traffic management are improved.

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Appendix

Trajectory management using CAD techniques

Inside ATC-VR aircraft positions can be assembled to obtain a spatial interpolation curve.

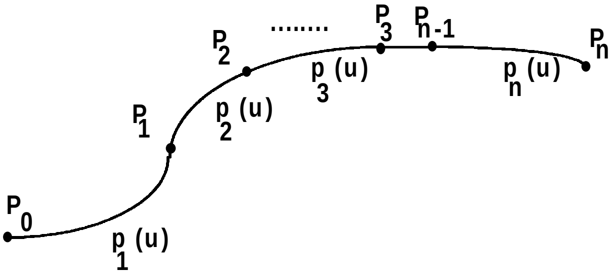

Fig. 12. Spline curve.

To facilitate the visualization of aircraft tracks and trajectory prediction, a piecewise cubic curve has been used (generally called “spline”) (Fig. 12).

For 2 consecutive curve pieces (i.e. $P_{k-1}P_k$-P_kP_{k+1}) we can write:

$$\begin{aligned}&p(t)=A_0^k+A_1^k t+A_2^k t^2+A_3^k t^3\\&\quad \text{for}\quad 0\le t\le t_k\\&p(t)=A_0^{k+1}+A_1^{k+1}t+A_2^{k+1}t^2+A_3^{k+1}t^3\\&\quad \text{for}\quad 0\le t\le t_{k+1}\end{aligned}\tag{1}$$

where A_0^k, A_1^k, A_2^k, A_3^k, A_0^{k+1}, A_1^{k+1}, A_2^{k+1}, A_3^{k+1} have to be calculated from boundary conditions.

C^1 continuity can be written as:

$$\begin{aligned}&p(0)=P_1 \;\Rightarrow\; A_0^k=P_1\\&p(t_2)=P_2\Rightarrow A_0^k+A_1^k t_2+A_2^k t_2^{\,2}+A_3^k t_2^{\,3}=P_2\\&p'(0)=P_1' \;\Rightarrow\; A_1^k=P_1'\\&p'(t_2)=P'_2\Rightarrow A_1^k+2A_2^k t_2+3A_3^k t_2^{\,2}=P'_2\end{aligned}\tag{2}$$

$$\begin{aligned}&p(0)=P_2 \;\Rightarrow\; A_0^{k+1}=P_2\\&p(t_3)=P_3\Rightarrow A_0^{k+1}+A_1^{k+1}t_2+A_2^{k+1}t_2^{\,2}+A_3^{k+1}t_2^{\,3}\\&p'(0)=P_2' \;\Rightarrow\; A_1^{k+1}=P_2'\\&p'(t_3)=P'_3\Rightarrow A_1^{k+1}+2A_2^{k+1}t_2+3A_3^{k+1}t_2^{\,2}=P'_3\end{aligned}\tag{3}$$

and C^2 continuity may assume this face:

$$P_1''(t_2)=P_2''(0)\tag{4}$$

Two more boundary conditions are needed to solve the equation system. First point and last point can be assumed with zero second derivative:

$$P_1''(0)=P_n''(t_n)\tag{5}$$

Equation solution provides p(t) function (spline interpolation), representing the real-time position of the monitored aircraft. It also easy to get p’(t) from standard derivative.