DESIGN AND EVALUATION OF A 4D INTERFACE FOR ATC

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Abstract

The increasing complexity of Air Traffic System is pushing toward the development of innovative and more automated tools conceived to manage it. In this scenario an important role is assumed by HCI (Human Computer Interfaces) used by air traffic controllers and operators to visualize and interact with air traffic data. Currently, information about 3D scenery are displayed with a two-dimensional representation.

This paper presents the design, development and evaluation of an innovative interface for ATC (Air Traffic Control) based on a 4D (3D space + time) visualization display.

The proposed interface allows the operator to perceive all the information, included meteorological conditions, useful for TWR/APP (ToWeR/APProach) control in a unique 4D synthetic reconstruction of the airport area. A particular attention is dedicated to the fourth variable, time, which is a fundamental parameter in ATC. A simple and fast trajectory prediction algorithm has been implemented in order to provide the operator with an effective "user assistance" tool in conflict detection activities.

The interface has been evaluated performing test simulations and collecting results and useful advices for future developments by means of questionnaires.

1 Introduction

The increasing complexity of air traffic system, which is expected particularly in Europe, is pushing toward the development of innovative and more automated tools conceived to manage it (SESAR, NGATS).

In the last decades aviation has shown great advances in automation. In ATC the evolution from procedural to radar control and the introduction of innovative decision aids such as CTAS (Center TRACON Automation System) and URET (User Request Evaluation Tool) moved air traffic control from "direct human control" to "computer-aided indirect control" according with Sheridan's classification [1]. Innovative concepts and technologies such as TCAS (Traffic alert and Collision Avoidance System), "data-link" and "free-flight", that have been recently adopted and experimented in aviation, show that the trend is to pursuit "remote supervisory control" for ATC remitting some specific tasks to aircraft's automation.

The foreseen air traffic growth and the increasing complexity of scenarios will provide ATCo (Air Traffic Controllers) with a larger amount of data to perceive, analyze and fuse in order to maintain adequate levels of situation awareness. In this context, HCI design assumes a really important role. The levels of operator's Situation Awareness (SA) and mental and physical workload are strictly connected with the quantity and quality of information re/perceived by the operator himself [2][3]. Information are mostly provided to the operator by means of HCI which therefore need to be accurately designed, developed and evaluated.

The introduction of stereoscopic 3D displays in ATC has been widely discussed in the last decade both from the cognitive aspects and from a technology-driven point of view [4][5][6][7]. The more recent works have shown much more advantages than the older ones one probably due to the increased readiness of VR (Virtual Reality) technologies [8][9][10][11].

2 Interface Design

Modern HCI comprise displays, controls and decision aids, each performing a different function. Displays are intended to be the presentation of computer-processed information to any sense of human perception, controls comprise all the devices adopted by the operator in order to obtain a desired behavior of the controlled system/process (voice command in ATC), decision aids are considered as computer processing of information to help the operator make decisions. Such components should be designed appropriately in order to provide usable, safe and error free interfaces [1].

In designing the Human Computer Interface presented in this paper we followed "user-centred design" principles. The main requirements for the interface have been set during the planning phase by a focus group, comprised both of expert ATCo and of trainees. In this context, the system can be considered usable if the user can reach his goal, which is to be aware of the traffic situation and of its possible evolutions, effectively and efficiently. Moreover, the interface implements advanced interface concepts, such as multimodality, VR and information display augmentations in order to provide a system which is more knowledgeable and simpler, reducing the workload and the need for intensive user training [12].

Thus, the design process has been deployed in two main steps: the concept generation and the development of the prototype or concept demonstrator. In the first phase we defined the basic system requirements needed in the specific application area, set the design specifications in order to meet each requirement and propose technical concepts for the prototype. Afterwards, the detailed design of each component and the construction of the prototype have been performed.

2.1 System requirements and specifications

Air traffic control can vary from a TWR/APP control to an ACC (Area Control Center) control. The quality and quantity of information displayed are different in each type of control. The interface presented in this paper refers to a TWR/APP application. In this context controllers should be provided with access to information and consultation. Therefore, the visualization system has to be designed in order to:

1. *represent a large number of airplanes separated unless 6 NM in an unique window;*
2. *represent the main information for each airplane (flight number, altitude and speed);*
3. *represent meteorological conditions;*

Currently, interfaces for ATCO represent aircrafts onto two-dimensional radar displays which provide the ATCo with a top 2D view of the air traffic. Information about the altitude of the airplanes is annotated onto labels which follow the aircraft pointer on the screen. Therefore, the controller has to mentally transform the altitude information reconstructing a three-dimensional representation of air traffic.

The intuitive perception of depth in perceiving the position of aircrafts inside the environment fused with navigational, geographical, topological and meteorological information could reduce the workload. Therefore, the visualization system has to:

4. *provide a 3D perspective visualization display of the scenario;*

The ATC scenario is a 4D environment and the fourth variable, time, is fundamental to forecast traffic evolution. The actual aircraft state can be integrated with the navigational air traffic data base to support the controller in a 4D perception of air traffic data. Further specifications are:

5. *To estimate and display the current and the future position for each airplane;*

Finally, one main task of ATCo is to detect possible conflicts, elaborate separation strategies and manage the communications with pilots in order to restore the safe traffic conditions. The controller should be supported in the consultation of relevant events providing tools:

1. *To detect and highlight possible conflict zones.*

2.2 Prototype development

The interface prototype has been developed in order to experiment the above interface concepts. Since the main purpose of this study concerns the visualization and decision aids functions of modern displays, the prototype implements a selected set of features in a simulated ATCo workplace.

Workplace

The application prototype is based on the use of a Virtual PST (Passive Stereoscopic Theatre). The user posture in the PST is conceived to provide in a gaze the amount of information displayed on the large screen, which is a Silver D-Lite 2,2 x 1,65 metres vertical front-projected screen. The normal line of sight is about 10° below the horizontal line, resulting in a comfortable posture. Moreover, the user's access to the navigation functions of the virtual scenario projected onto the screen is performed by means of a mouse. The graphic workstation (4GB RAM and NVidia FX Quadro 3400 graphic accelerator) is connected to two DLP^{TM} (Digital Light Processing ^{TM}) projectors and a set of linear polarized glasses which enable to activate the stereoscopic visualization option.

Information display

The application realized is a synthetic 4D visualization software based on "Aliview" (a flight data monitoring software developed at Bologna University) [13].The main window displays a 3D representation of the geographic scene based on the actual aircraft position. Editors and interactive navigation features are also provided. Additional functions have been developed for the purpose of this specific APP/TWR application for ATCo.

Environment representation

Geographical, topological and navigational information are derived from databases and represented in the synthetic environment in order to provide the perspective visualization of the environment.

Meteorological information are continuously downloaded as a METAR (METeorological Aviation Report) code, which is available for navigation planning on the web. METAR data are automatically decoded and represented in a photo-realistic 3D fog/haze/clouds representation (Fig.1).

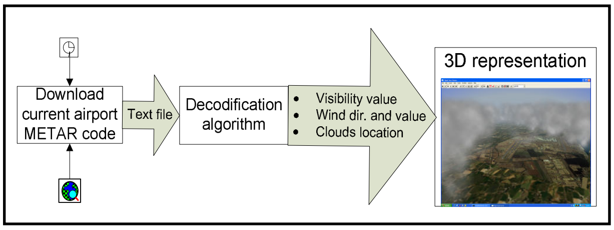

Fig.1. Meteorological data visualization

The terrain surface is built by Aliview as a quad mesh based on DEM (Digital Elevation Maps) and, as most visualization software, implements multi-resolution features to adapt the LOD (Level Of Detail) of the surface to the field of view. Terrain rendering can be achieved using free satellite pictures.

The navigational database is replicated in the virtual scenery by means of the synoptic representation of auxiliary data such as VOR (Vhf Omni directional Range) and waypoints.

The airport infrastructure, such as buildings and runways is also reproduced with the embedded editors for 3D shapes.

Airplanes Representation

Airplanes are represented in two different ways (multi-resolution visualization) depending on the position of the virtual camera that represents the point of view of the user. The operator can change the position of the virtual camera interacting with the zoom.

If the point of view is close to the scene then the representation of airplanes is photorealistic (actual geometry, actual dimensions, liveries, flaps…). Otherwise, if the point of view is far then all the airplanes are represented with transparent coloured cones whose axis is concentric with airplane's roll axis. In this configuration the height of the cone is 4% of the diagonal of the screen (Fig.2).

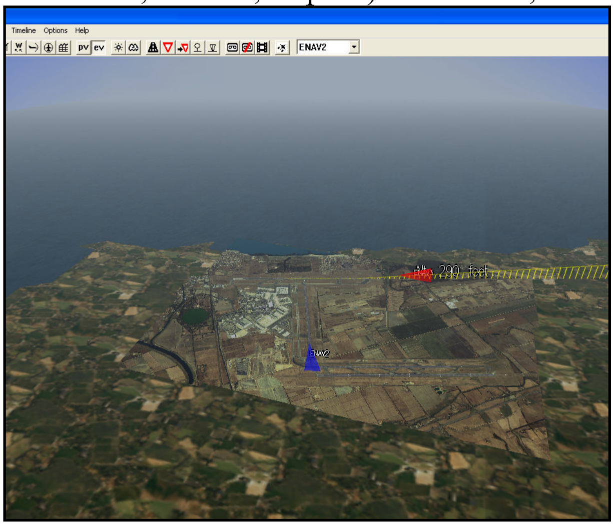

Fig. 2. Visualization software screen-shot

The colour of each cone depends on the phase of flight of the airplane it represents (see table 1).

The photorealistic representation of the vehicle turns in a synoptic representation as the user's point of view is displaced over the maximum distance from the airplane.

CONDITION	COLOUR
APPROACHING-LANDING	RED
TAXI	BLUE
TAKE OFF-DEPARTING	GREEN
TRANSIT	WHITE

Table 1. Relation between color cone and flight phase

In order to satisfy the first requirement highlighted, such "multi-resolution" visualization is preferable to the pure enlargement of airplanes because it permits the visualization of the aircraft in its real dimensions whenever the operator asks for this.

Moreover, each airplane is followed by a flag reporting the main alpha-numerical data such as flight number, altitude and speed.

Trajectory Prediction – User Assistance

Trajectory prediction in ATC is a very demanding issue [14][15]. We present a simple and fast algorithm to forecast future position of airplanes in TWR/APP sectors around an airport. It implements both geometrical and mathematical methods in order to forecast airplanes' future position from 1 to 10 minutes. The algorithm is divided into two main steps, the pattern recognition and the prediction in time.

The pattern recognition uses aircraft's states matched with a route database (DB). For each airport, the DB comprises n possible approaching and departing routes each composed of m subsequent 2D (latitude, longitude) legs. Legs are vectors between two points that can be waypoints, VOR or NDB (Non-Directional Beacon).

For each airplane, the aircraft true heading (h_a) is compared with all the legs' heading (h_{lj}). The k legs for which Eq.1 is true are selected.

$$\left| h_a - h_{l\,j} \right| \le 5\,\text{deg} \qquad (1)$$

Among these k legs the one that is located "closest" to the aircraft is assigned to it using a geometrical method which is described in the picture below (Fig.3). A vertical plane p, perpendicular to the aircraft's true heading direction and centred in the aircraft centre of gravity is drawn. This plane crosses all the k legs (except for those which are parallel to it) in m crossing points. If the distance d_i between the i-th crossing point (where the plane crosses the i-th leg) and the aircraft is minor than 600 ft then the i-th leg is assigned to the aircraft.

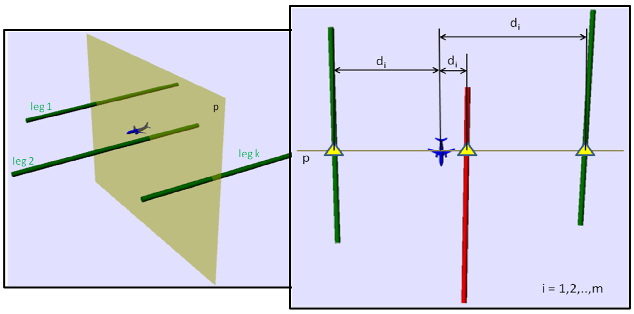

Fig. 3. Route assignment geometrical method

After the aircraft assignment to a leg there is the route assignment which is different for approaching and departing airplanes. In fact, approaching routes are "convergent" excepted for, in the landing phase, multiple runways airports. Departing routes are mostly "divergent". In approaching flights for multiple runways airports, the pattern recognition is based on the runway assignment. Otherwise, in departing flights the pattern recognition uses aircraft destination to assign the actual route.

Once an aircraft has an assigned route the prediction step starts. The future position of aircraft is forecasted at time t by means of integration of aircraft speed - along the assigned route - in time.

The results of prediction algorithm are displayed in the 3D environment by a polyline ahead the aircraft.

The user can vary the forecasting time step up to 10 minutes moving a cursor on a time-bar.

Moreover, the "user assistance" tool [12] is improved by the highlighting of possible conflicts. Data coming from prediction algorithm are used to compute distances among aircraft at time t. If a conflict occurs (two or more airplanes are separated unless than 6 NM horizontally and 1000 ft vertically), a red circle highlights the possible conflict zones.

3 Evaluation

The validation process of innovative interfaces must pass through the evaluation phase. There are many techniques that can be used in order to evaluate an interface design and they come from several research areas such as cognitive psychology, ergonomics, statistic and system engineering. Evaluation techniques can be classified by the number of judges involved in the evaluation (single, focus group, large group), or by the type of metrics adopted (qualitative or quantitative). As in many time and risk critical contexts, in ATC the main objective of HCI evaluation is the measurement of operators' SA and of mental workload. In literature we can find several examples of metrics and tests used to measure SA and mental workload such as Nasa TLX, SAGAT (Endsley) and Eurocontrol SASHA[16][17][18].

ATCo have been involved in all the phases of the design of the interface proposed. In the evaluation phase an expert TWR/APP controller was asked to observe a ten minutes sequence of airplanes on an airport represented through the interface. After this session ATCo answered to a brief questionnaire.

3.1 Test set-up

The scenario modelled for the evaluation represents Rome – Fiumicino international airport (LIRF). All the runways and the main buildings were modelled in order to enhance photorealism. Also waypoints and VOR were represented in a synoptic way.

Five airplanes are involved in the sequence approaching and landing from the airport (table 2). A conflict between AZA 004 and AZA 002 occurs, they are separated by less than 1 NM.

The questionnaire proposed to ATCo is composed of 20 scaled questions, it was constructed following the principles of Likert scale for subjective questions. It is divided in three parts asking about three different aspects of the interface proposed:

- 3D vs 2D
- Airplane representation
- Trajectory prediction

There are almost two questions for each task: the first asking about the feasibility of the task, the second asking about the usefulness of the representation proposed in order to perform the task.

3.2 Results

On the whole, the ATCo's judgement has been positive on all the three surveyed fields of interest.

It's to notice the positive judgement that has been given about the first topic studied: the introduction of 3D, stereoscopy and photorealism. Results are shown in the diagram below (Fig.4).

The use of coloured cones to represent airplanes was intended to be useful in performing two tasks : counting airplanes and understanding how they are moving related to the airport. Related to the second task ATCo advised to reduce the number of colours from four to three.

Finally, the trajectory prediction tool has been judged as effective by most of the operators involved in the evaluation phase.

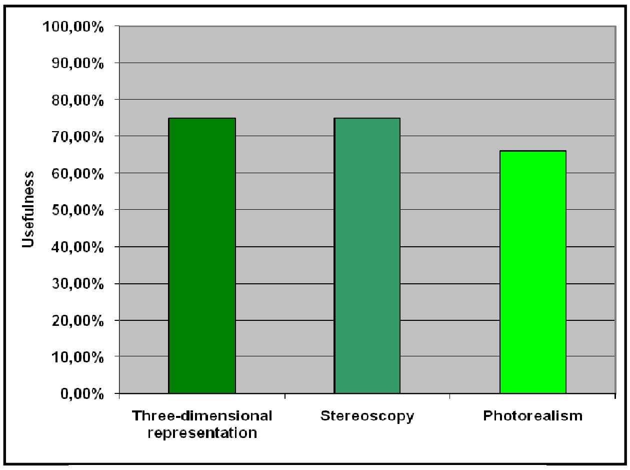

Fig.4. Experimental data diagram

4. Conclusions

The proposed system has showed to provide ATCO with a comprehensive interface to view and interpret complex flight data.

The introduction of 3D stereoscopic visualization results useful in reconstructing a "mental picture" of ATC scenario.

Due to the modular approach adopted, this architecture can also provide an effective test environment to experiment new concepts, methods and technologies.

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