A 4D Immersive Virtual Reality System for Air Traffic Control

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Abstract:

Future scenarios do not simply involve an increase in air traffic; in addition new forms of co-operation and co-ordination are expected to emerge. New IT technology affords more data to be available to many of those who run the whole ATM system. As the human factors literature suggests, the availability of more data implies new forms of task distribution and thus new co-operative strategies have to be anticipated. This implies a paradigm change when designing for new technological support.

A novel approach to 4D technology, that we call D4 – to differentiate with the existing 4D ATM concept - creates new opportunities in the way the controller will visualize and interact with information: adding a 4D metaphors in terminal area might help perceptually the management of a "funnel-like" space – an enhancement of a tube inclined perspective, typical of current ATM systems. New ways of representing the information, while not necessarily decreasing workload, provide an opportunity to reduce existing knowledge gaps, supporting optimal decisions making (as demonstrated in recent works).

Such results are part of the VIfth FP AD4 project (“4D Virtual Airspace management System”) that aims to build an innovative Virtual Air-Space representation for ATM system, providing valuable benefits to support efficient control systems where 3D real time interaction with air traffic/airport space is accessible to the controllers. Shared views of information and inter-operability between ground and on-board systems can allow workers to cooperate, managing efficiently complex operations. D4 is actually based on the extension of a technology called D3 (D-Cube), developed in a successful National project co-funded by the Italian Space Agency. This open technology supports dynamic management and scalable data elaboration for DEM, Meteorology, Pressure and Wind fields, Radar tracks and Telemetry data using auto-stereoscopic displays and 3D mouse devices. D3 is improved by 4D constructs, supported by Model Driven Architectures and Secure middleware, data-fused with real ATM systems and validated in a European ATM center. Specific Human Factors principles, together with industrial engineering processes will drive the Consortium to design, build, integrate and validate complex and valuable HMIs for the “future flight” Air Traffic Controllers.

Introduction

Air Traffic Control is intrinsically a 4D problem. Despite this fact 2D radar displays don't give controllers any visual cue on aircraft altitude, vertical separation and volume constraints such as orography, weather and restricted airspaces. Controllers are so required to build their own 3D airspace model in their head. AD4 project targets to build an innovative virtual space management system for ATC, to provide valuable benefits to support efficient control systems where 3D real time interaction with air traffic/airport spaces is presented to the controllers. New ways of representing the information, while not necessarily decreasing workload, provides an opportunity to reduce existing knowledge gaps between what controllers currently know and what they would need to know to make optimal decisions.

AD4 project is driven by Human Factors. Operational Work analysis, using an approach consistent with the principles of the User Centered Design (ISO13407), has identified a series of operational scenarios in the approach and control-tower sectors that can benefit from a 3D/4D representation of the ATC environment under control. Among the identified scenarios we can mention vertical separation between intersecting trajectories, holding stacks, 3D volumes (cumulonimbi, topography surrounding the airport, military restricted airspaces) in the approach sector as well as runway incursions, de-confliction of aircraft at junctions, combination of departures with arrivals in the control-tower sector.

AD4 provides a command and control interface that allows choosing the different layers of data that will be embedded in the Virtual Scenario, represented in 3D with the aid of immersive technologies. Incremental and fluid navigation, limited only by the complexity of the rendering area (mitigated by on-demand selected modification of the local objects in the scenario – the so-called immersion of singleton objects) is achieved. Within this environment we make use of 3D/4D interaction devices both to navigate in the scene and to select and manipulate flight information within the scene. The user’s viewpoint is typically centered on a point
of interest but can be updated to centre on any position by simply using a 3D mouse pointer. The same device will then be used to control rotation of the camera around the view centre in two degrees of freedom and zooming of the view. The presentation of relevant views of the approach as well as the tower sectors will help to demonstrate the feasibility of using scalable and performing novel approaches to the construction of system to support ATC operations.

In AD4 a strong emphasis has been placed on the definition and development of a robust and open IT infrastructure with the aim to build on it a distributed component based system - based on secure CORBA and CCM (CORBA Component Model) - supporting standard exchange formats (e.g. ASTERIX) and allowing the interoperation with ATC components and simulation platforms like the Eurocontrol ESCAPE platform. Enhanced distributed visualization techniques are used to allow the extension of the field of view through the visualization of the 3D scene on multiple displays driven by different computers.

The AD4 development process is driven by Models: MDA driven architectures and an HMI specification collaborative engineering tool tested in collaboration with NASA and ESA, are bringing benefits to realize independency of specifications from actual implementation used to realize the targeted application, augmenting the possibility to experiment rapidly changing specification at the level of requirements.

The AD4 project

Launched in January 2005, the AD4 project is co-founded by the European Commission DG-Aeronautics and Space and is composed on a Consortium of 10 participating partners. The Consortium includes research as well as industrial partners committed to the acquisition and development of the advanced technological know-how required to address the project objectives, as illustrated in the sections above, and to the exploitation of the results that will be achieved throughout a specific ATM infrastructure and a definite demonstrator. Final users and testers of the targeted ATM field are also key contributors to the project development and assessment: they will produce specifications of real operational needs within their business cases and will co-ordinate the final phase of testing and validation of the prototype.

The consortium, which has been grouped to assure the comprehensive coverage of the expertise required to reach the Project’s objectives, is Coordinated by NEXT Ingegneria dei Sistemi S.p.A. (I) that has strong experiences in the management of EC and other International Projects; these expertise will assure the proper know how to carry out the whole project’s work, from the assessment of the User Community, the appointment and development of innovative applications, till to the demonstration activities. Partners of NEXT S.p.A. in this project are ENAV S.p.A. (I), the Italian Company of Air navigation Services and VITROCISET S.p.A. (I), Middlesex University – Interaction Design Center (UK), SICTA S.p.A. (I), Fraunhofer Fokus – Institute for Communication Systems (D), Object Security (UK), Digital Video S.p.A. (I), European Software Institute (I), Space Applications (B).

The AD4 project is planned of a duration of 24 months addressing the analysis of Operational Concepts and Human Factors, the engineering of the IT infrastructure and its core Components (4D HMIs, Middleware, Predictive and Applicative Components, Interfaces to external data e.g. Meteo and ATM system integration), the development the working Demonstrator for an operative context, the validation by the use of the MAEVA methodology and the assessment and exploitation of results. The AD4 system will be implemented in collaboration with experts in field of ATM systems, Virtual Reality, and Human factors supported by the Italian Agency for Air Navigation Services ENAV, targeting:

- A definition of the Operational Concepts and their expected impacts, including a review of the State-of-Art technologies and systems,
- A careful study of the major aspects related to the next generation 4D HMIs, driven by an extensive analysis of the Human Factors and an extensive assessment of safety and security aspects;
- The construction and on-site integration of a demonstrator in a real ATM simulation and experimental centre, tested by air traffic controllers;
- The appointment of two Workshops, involving major players of the field and key users, presenting preliminary results and the final outcomes of the AD4 project;
The D³ (D-Cube) technology

AD4 is based on the extension of the NEXT³ 3D Virtual Reality system, called D³ (D-cube), for the real time visual representation and manipulation of data in the field of Air Traffic Management and Control, both for Approach and Tower sectors.

In such a platform 3D visualization results from the integration of heterogeneous geo-referenced data (such as weather, terrain) produced by heavy elaborations and complex data-retrieval. Throughput and elaboration limitations are overcome by a scalable and distributed (multiprocessor and multiplatform) architecture. Distributed techniques for parallel large-data sets manipulation have been defined and developed in order to distribute the computational work-load among different machines.

The system is characterize by NRT 3D Visualization and Manipulation capabilities and provides

- Visualization with (auto)stereoscopic monitors and glasses
- 3D Navigation with 3D Mouse (6 DOF)
- Near Real-time interaction with the scenario
- Construction of Scenario data independent from the rendering techniques

The use of 3D visualization devices improves the recognition of spatial relations between data, augmenting understand-ability of a representation containing a large amount of data.

Controlling the movement with the 3D mouse further achieves the immersion degree in the virtual space for the user. This Hardware component allows specifying movements with six degree of movement (three in translation and three in rotation) obtaining in this way a near real time interaction with the scenario.

The AD4 Infrastructure

The AD4 system makes use of Distributed Computing with remote heterogeneous components providing data to be processed and/or displayed. In this context heterogeneity refers both to data (radar tracks, flight plans, weather and terrain data provided by different components running on different machines) and the way these data are provided (the use of TCP/IP protocol with exchange formats or Distribute Object Computing Middleware like CORBA are common approaches used in the ATC context).

To overcome the difficulties coming from this high degree of heterogeneity we adopt architectures and technologies that decouple the "business logic" from the infrastructural aspects:

- CBSE (Component Based Software Engineer)
- CCM (CORBA Component Model)
- MDA (Model Driven Architecture)

CCM introduces component concepts to CORBA allowing encapsulation of implementation, deployment, multiple interface objects and the definition of receptacles (needed interfaces).
Using CCM developers can concentrate on business logic and application development is done by composition of components.

In MDA models are the central artifacts in the development process. Models are specified as PIMs (Platform Independent Models) or PSMs (Platform Specific Models). Model transformations are applied to generate more specific models up to the source code level. PIM to PIM and PIM to PSM transformations are accomplished by a Tool Chain developed in the course of the project itself.

Higher integration in ATC systems raises many security issues: more attack paths, more possible attackers, easier targets, greater damage. For all these reasons we need a better protection of future ATC systems. In AD4, we show that secure ATC systems can be built, using innovative concepts and tools provided by a Framework (OpenPMF) for definition, management and enforcement of security policies in distributed systems.

**Interoperability with ATC components and simulation platforms**

AD4 project places a strong emphasis on interoperability with ATC components and simulation platforms. In this context AD4 aims to integrate with well known simulation platforms like ESCAPE by Eurocontrol and ATRES by Vitrociset and adopt consolidated interfaces in the field, like the ones defined in AVENUE, and standard exchange formats like ASTERIX.

AD4 will interoperate with simulation and experimentation platforms to identify limitations and opportunities of the AD4 4DHMI concepts and validate the innovative virtual airspace representation in the course of real time simulations.

In more general terms the project aims to define a test-bed environment to be used to assess ideas and concepts related to 3D/4D representations in the ATM context.

The AVENUE EC project (4th FP) has defined Data Dictionaries and Interfaces (also evolved in the course of the G2G Project) for the ATC domain to promote interoperability among components developed by companies actively involved in the ATC field.

Adopting AVENUE Data Dictionaries and Interfaces (an AVENUE-compliant AD4) we make possible to use AD4 with other AVENUE-compliant ATC components and adopt a well known and consolidated logical model.

ASTERIX (All purpose STructured Eurocontrol suRveillance Information eXchange) is a protocol for the exchange of data between different systems (e.g. ASTERIX cat. 062 for radar tracks). We have developed a "AD4 ASTERIX gateway". The "ASTERIX gateway" is responsible of converting operational data provided by ATC (simulation) components into suitable formats for AD4.
Conclusions

The AD4 infrastructure will enable to determine what benefit, in terms of enhanced understanding and clarity of perception, 3D displays and/or 3D representations in 2D displays, combined with enhanced information presentation, can provide to the ATC controller for approach and tower sectors.

It is hoped that improvements in this area will permit more efficient and safe management of more aircraft over a wider airspace (using data and scenario for post-accident/incident investigation).

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 the ATC application area in the future.

More information about the project can be found at the project Web site: http://www.ad4-project.com