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AUGMENTED AND VIRTUAL REALITY IN THE AIRPORT CONTROL TOWER

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Abstract

As a matter of fact, airports are considered as the bottleneck to increasing the capacity of the overall Air Traffic Management (ATM) system. While augmenting throughput in high performing airport operations, attention has rightly been placed on doing it in a safe manner. Many of the advances in airport operational safety come in the form of visualization tools for tower controllers.

The increasing interest in Synthetic Vision (SV) and Augmented Reality (AR) technologies has led various analysts to positively esteem the adoption of new tools enabling both pilots and controllers to seamlessly operate under Visual Meteorological Conditions and Instrument Meteorological Conditions.

This paper presents the motivations, the objectives, the proposed methodology and the expected impacts of the RETINA (Resilient Synthetic Vision for Advanced Control Tower Air Navigation Service Provision) project that has recently been granted by the SESAR (Single European Sky Air Traffic Management Research) Joint Undertaking.

The two-years exploratory research project will investigate the potential and applicability of SV tools and Virtual/Augmented Reality (V/AR) display techniques for the Air Traffic Control (ATC) service provision by the airport control tower.

1 Introduction

The long-range vision for the future Single European Sky includes objectives for operating as safely and efficiently in low-visibility conditions as in high-visibility conditions [1][2].

On the airside, the research on all-weather operations cockpits is already far advanced and Head Up Displays (HUDs) technologies are widely being applied both in civil and military flight operations. HUDs are based on displaying data on a transparent screen allowing pilots to simultaneously look outside and see the projected data. Data that are commonly displayed on HUDs are speed, altitude, optimal flight path and, in general, some information which is usually displayed on the Primary Flight Display. A considerable interest is currently being focused on the possibility of displaying conformal symbols, intended as geo-referenced graphics that supports the operator in the comprehension and projection of the operational environment [3] [4]. In this case HUDs are also called Spatial Displays, since they allow implementing Augmented Reality (AR) in panoramic views. This made HUDs popular for applications in car dashboard while applications in Air Traffic Control have also been reported [5].

The project will assess whether those concepts that stand behind tools such as Head-Mounted Displays (HMDs), Enhanced Vision Systems (EVSs) and Synthetic Vision Systems (SVS) can be transferred to ATC with relatively low effort and substantial benefits for controllers' Situational Awareness (SA). In doing so, two different AR systems will be investigated: Conformal-Head-Up Displays (C-HUDs) – which, potentially, can be made to coincide with the tower windows – and See-Through Head-Mounted Displays (ST-HMD). This will be done by means of commercial-off-the-shelf AR hardware components. A dissimilar third tool, i.e. a virtual reality based Table-Top interface [6], will be investigated as well, since the upper view is the easiest way to visualize the airport digital model.

2. The RETINA Concept

The RETINA project takes the idea of augmented vision and investigates its application to on-the-site control towers through the use of synthetic vision.

Since the focus of the project will be the placement of information over the actual window view, the collimation between conformal (registered) information and the user's perspective is a major issue. This subject has been widely studied in other fields such as cultural heritage, entertainment and virtual interaction. Thus, the AR system would know the controller's head position and the direction of his/her gaze allowing the interface to present the most beneficial information without adding needless clutter. Cues to critical situations that take place outside of the controller's view can also be placed in controllers' peripheral vision, to draw their attention in that direction. Overall, the information that is currently displayed on the head-down computer screens (flight tags, runway layout, intrusion warnings) could be displayed on either the see-through glasses or the head-up displays, therefore superimposed to the controller's line of sight.

As a common database between the V/AR systems, a three-dimensional Aerodrome Traffic Zone (ATZ) model is considered, providing precise positioning for simulated aerial and terrestrial objects. Multiple simulated or recorded data sources such as Airport Surveillance Radar, Surface Movement Radar or other ground-based sensors (e.g. video or infrared cameras) will provide the displayed information (Fig. 1). In this respect, the RETINA project foresees a technology transfer between remote and on-site tower operations. Indeed, a proper 2D camera distribution within the simulated environment can provide reliable data regarding the positioning, speed, speed direction and size of ground-based objects. This is particularly convenient for smaller airports, where installing an Advanced Surface Movement Guidance and Control System (A-SMGCS) is deemed too much expensive. In larger airports, such sensors could still be useful to cover distant and blind spots, improving the controllers' SA of the surrounding area.

Other information that can be displayed to the controller includes SWIM (Sys-tem Wide Information Management) related data, such as weather conditions, wind direction and speed, wind shear and wake vortexes visualization. Within the SESAR (Single European Sky Air Traffic Management Research), the SWIM concept is the enabler for ensuring the delivery of the proper information, with the required quality, to the appropriate person at the right time [7][7].

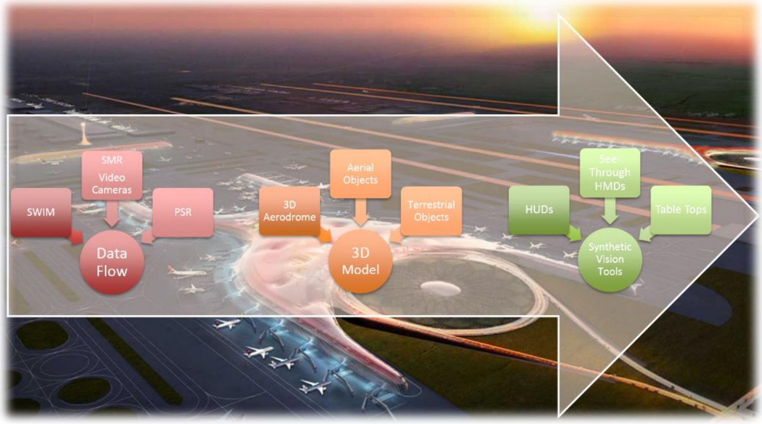

Fig 1. The overall RETINA Concept.

3. A Taxonomy for Virtual/Augmented Reality Tools and Synthetic Vision Systems

Augmented Reality Technologies aim to enhance the real world perception combining synthetic information and the real world. The techniques to merge the synthetic and virtual world rely on the so-called see-through or transparent displays that can provide a view of what is behind the synthetic information layer. When the combination of the real and virtual image is performed by means of lenses, mirrors or other optical components the system is classified as and optical combined display. On the other hand, this combination can be obtained using cameras to transform the real world view in a video feed that is merged with the synthetic information and depicted in a so called video display. A third approach, not relevant for the specific needs of the RETINA project, is based on the direct projection of the synthetic information on the real objects.

Despite the approach used to merge the synthetic and real worlds, a unanimous classification of the Augmented Reality Technologies is the one conceived by Bimber and Raskar in [3]. This taxonomy is based on the location of the AR device along the optical path between the real object and the observer's eyes. According to this classification three types of devices are considered:

1. **Head–attached devices** that require users to wear the display system on their head.
2. **Hand-held devices** that require users to hold the display in their hands.
3. **Spatial devices** that detach most of the technology from the user and integrate it into the environment.

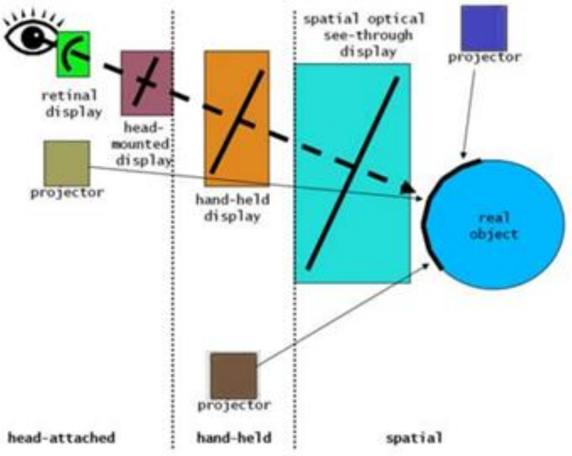

Fig 2. Classification of the Augmented Reality Technologies by Bimber and Raskar [3]

3.1 Head –attached devices

Head –attached devices category includes three main types of hand-wearable displays:

- **Retinal Displays** make use of low-power semiconductor lasers to scan modulated light directly on the eye retina.
- **Head-mounted Displays** commonly referred to as HMDs consist in a class of devices that make use of very small displays put in front of the user's eyes. They can be either "optical see-through HMDs" or "video see-through HMDs" depending on the way the real and the virtual image are combined.
- **Head-mounted projectors** adopt miniature projectors that project images on the surface of the real world. Depending on the type of surfaces that are targeted they can be further distinguished as Head Mounted Projective Displays (HMPDs) or Projective Head Mounted Displays (PHMDs). In the first case the target

surface is a retro-reflective one in front of the viewer whereas in the second case it is a diffuse one. It's worth to remind that the projector based systems are not suitable to those environments where the real objects are located far away from the user. Additionally, the performance of such systems are strongly affected by the environmental lighting conditions. These are the main reasons behind the choice of considering those systems as not relevant for the scope of the RETINA project.

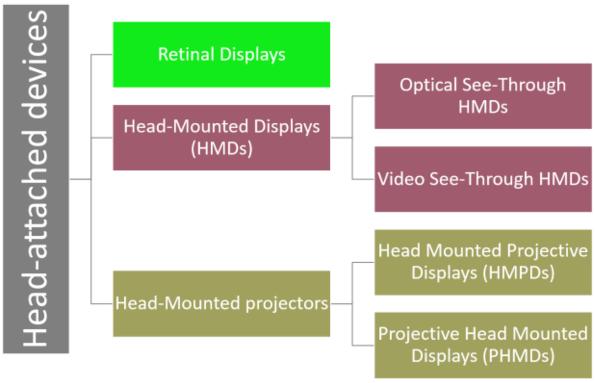

Fig 3. Head-attached devices taxonomy

3.2 Hand-held devices

Hand-held devices consist in:

- **Hand-held** displays that are often embedded within consumer devices, namely Tablet PCs, PDAs (Personal Digital Assistant), or smartphones, working as video see-through displays. Alternative solutions based on optical see-through hand-held displays are diffused to a lesser extent.

- **Hand-held** video-projectors which is a projector-based system that depicts the synthetic information on the real object by directly projecting it on the object surface.

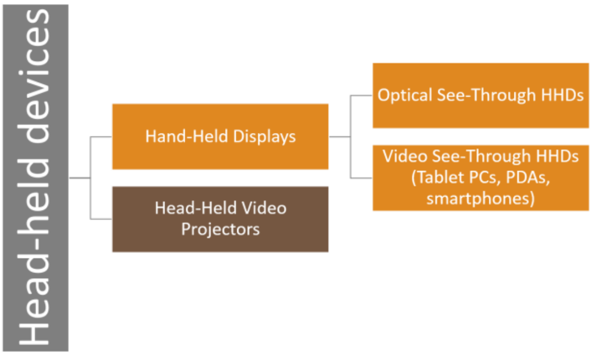

Fig 4. Hand-held devices taxonomy

3.3 Spatial devices

Spatial devices differentiate from head-mounted and hand-held devices as they are not fixed to the user, they are instead linked to the space, e.g. to a desk, the ceiling or the floor. They are classified as:

- **Screen-based** video see-through that make use of video see-through on a display providing the so-called "window on the world" effect.

- **Spatial Optical See Through** that make use of an optical combiner (e.g. planar or curved mirror beam splitters, transparent screens, or optical holograms) to mix the light emitted by the real environment with the light produced with an image source that displays the rendered graphics. The images produced are aligned within the physical environment as they do not follow the users' movements but rather support moving around them. In literature they are often referred to as Head-Up Displays (HUD).

- **Projection based Spatial Displays** that apply front-projection to seamlessly project images directly on physical objects' surfaces.

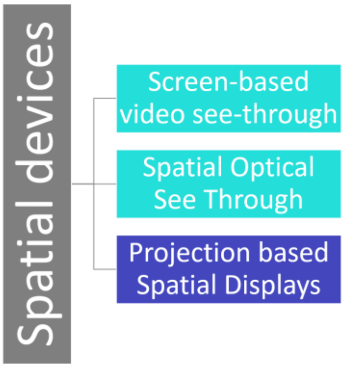

Fig 5. Spatial devices taxonomy

3.4 Virtual Reality tools

The taxonomy described above was conceived by Bimber and Raskar to address the specific aim of classifying Augmented Reality devices. Nevertheless, it is possible to derive a similar classification for Virtual Reality visual devices as well.

Virtual Reality differs from Augmented Reality as VR aims at replicating the real world while AR target is enhancing it. Compared with Augmented Reality that supplements reality, Virtual Reality is supposed to fully immerse the user in a synthetic environment. While AR technologies are focused on the vision sensory system, VR technologies can address many additional sensory systems such as auditory, proprioception and, in extreme applications, taste and smell. The exploration of VR devices addressing other sensory systems but vision and hearing is out of the scope of this document as the ATC tasks rely on visual and auditory perception of the environment. Nevertheless, a comprehensive taxonomy for existing VR technologies can be found in [8] that classifies the most recent input/output VR commercial devices.

3.5 Synthetic Vision devices

Synthetic Vision devices are application-oriented systems where data coming from different sources is filtered and fused providing the pilot with a comprehensive view of the flying environment in poor visibility conditions. Based on the type of data that is considered to reconstruct the external view and the mean used for visualization, Synthetic Vision devices can be classified into three main categories:

- Enhanced Vision Systems (EVS) and Enhanced Flight Vision Systems (EFVS)

- Synthetic Vision Systems (SVS)

- Combined Vision Systems (CVS) and Verified Combined Vision Systems (VCVS)

An Enhanced Vision System (EVS) (or Enhanced Flight Vision System) is an electronic means to provide a display of the external scene by use of an imaging sensor, such as a Forward-Looking InfraRed (FLIR) or millimeter wave radar. It provides pilots with a clear live video image of the world that s/he could not otherwise see at night, and in poor visibility. As far as technology is concerned, the main difference between EVS and EFVS consists in the alignment of additional information with the external view and the use of head-up displays to show them that are essential features for EFVS.

By contrast, Synthetic Vision Systems (SVS) provide situational awareness by placing a 3D geographical image on a cockpit display using terrain, obstacle and other databases. Navigation and positional information is obtained from GPS and Inertial Reference Systems. SVS presents a “clear day” view of the world, but is only as good as the most recent update to the database which can be days, weeks, or even months old.

Combined Vision Systems (CVS) is a term applied to the combination of EVS and SVS whereby EVS is used to provide a real time confirmation (validation) of the SVS environment. In CVS the pilot is doing the comparison and alignment of the two systems. An evolution of CVS is represented by Verified Combined Vision Systems (VCVS) that perform a smart processing to verify and correct GPS positional error (if any), automatically resolve differences between SVS and EVS and align the images.

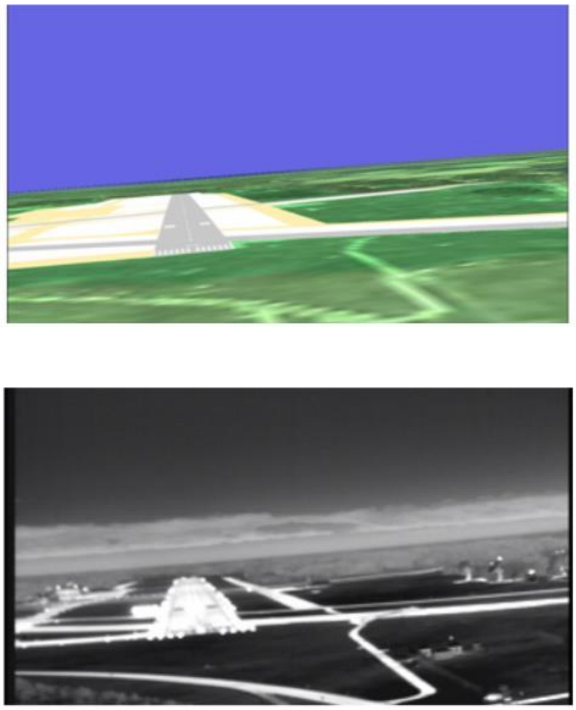

Fig 6. Comparison of SVS (upper) and EVS (lower)

Besides the type of data source used for the external view reconstruction, Synthetic Vision devices usually integrate additional data. These systems may be shown on head-down, head-up, helmet-mounted, and navigation displays and be combined with runway incursion prevention technology; database integrity monitoring equipment; taxi navigation and surface guidance maps; advanced communication, navigation, and surveillance technologies; and traffic and hazard display overlays.

4 Methodology

Air Traffic Control is a safety critical environment where the operators undergo different levels of mental workload being able to deal with easy tasks and familiar events, as well as with unfamiliar, time consuming and unexpected events.

Under these circumstances, human-computer interaction design should consider the complexity of the whole work domain instead of focusing on the user. Within the RETINA project, the interface design will draw from the Ecological Interface Design (EID) approach [9].

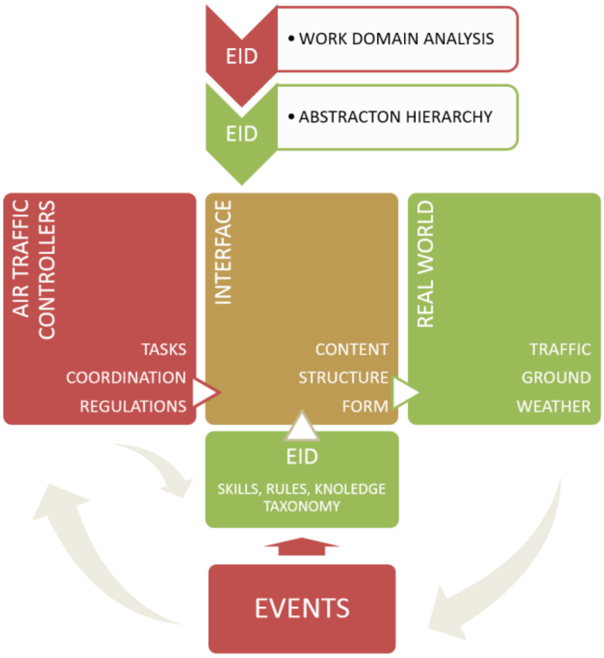

Fig 7. The EID theoretical framework applied to the control-tower work domain.

EID differs from User-Centered Design (UCD) insofar it focuses on the analysis of the work domain (a.k.a. Work Domain Analysis - WDA) rather than on the end-user or his/her specific tasks. EID attempts to provide the operators with the necessary tools and information to become active problem solvers as opposed to passive monitors, particularly during the development of unforeseen events. Interfaces designed following the EID approach aim to decrease the mental workload when dealing with unfamiliar and unanticipated events, which are attributed to in-creased psychological pressure. Doing so, EID makes use of two theoretical pillars from cognitive engineering research: the Abstraction Hierarchy (AH) and the Skills, Rules, Knowledge (SRK) taxonomy. The application of SRK taxonomy to the ATM work domain has been recently investigated providing relevant results

5 Expected Impacts

In 2014, within the European Civil Aviation Conference Area (ECACA), an average delay per flight of 9.7 minutes was developed [11]. Further analysis of the rationale behind the delay show that 0.51 min were due to weather, mainly strong wind, snow and low visibility conditions, whilst 0.96 min were due to restrictions at the departing or arrival airport, including the typical Low Visibility Procedures (LVP) restrictions defined in section 1 [11]. Also, please notice that these data do not account for cancelled or redirected flights.

If the RETINA concept will ever become operative the proposed solutions will provide concerned actors with high-quality 4D information (position, height and speed over time) in any operational condition (traffic, weather, airport complexity, etc.). Thus, the resilience and efficacy of the control tower IT system will be improved as well as the controllers’ SA. This will allow Instrument Landing System (ILS) or SV equipped aircrafts to seamlessly operate under any visibility condition at synthetic vision equipped airports.

Complex airports will benefit from the implementation of the RETINA concept by preserving airport capacity in all weather conditions, even when LVP apply. This will result in financial savings for carriers and larger incomes for Air Navigation Service Providers (ANSP). In addition, nearby airports will not face the risk of saturation. With fewer delay, a reduction of the environmental impact of flights in terms of fuel burnt, emissions, CO_2, etc. will be achieved.

The project will also exploit the SWIM concept allowing for a cost effective standardization and better re-use of data sets and services between the control tower IT systems. With no need for duplicates, significant savings for all ANSP will be achieved.

The RETINA project is expected to push the Technology Readiness Level (TRL) for V/AR technologies in the control tower from 1 to 2 and consolidate the leading role of European companies (ANSP and industries) into the field of air navigation.

6 Conclusion

The RETINA project motivations, objectives, proposed methodology and expected impacts of are presented in this paper. Although it is in its early development phase, the following key messages are defined for the RETINA concept:

- In the RETINA concept, controllers will be no longer limited by what the human eye can physically see out of the tower windows.

- As trust in digital data will continue to grow, RETINA’s concept will allow the controller to have a head-up view of the airport traffic even in low visibility conditions similar to the synthetic vision currently used in the cockpit.

- RETINA will build upon the technologies developed in SESAR, such as remote tower, safety nets, A-SMGCS, SWIM, etc., to provide augment reality tools for the tower controller.

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Copyright Statement

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