DOCUMENT CONTROL

Copyright notice

© 2008 European Organisation for the Safety of Air Navigation (EUROCONTROL). All rights reserved.
No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of EUROCONTROL.

Edition history

<table>
<thead>
<tr>
<th>Edition</th>
<th>Effective date</th>
<th>Author(s)</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30/08/2008</td>
<td>Han, Shepherd, Wong</td>
<td>Deliverable due.</td>
</tr>
</tbody>
</table>

Acknowledgements

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other members of the project team</td>
<td>Middlesex University</td>
</tr>
<tr>
<td>Paola Amaldi</td>
<td>Middlesex University</td>
</tr>
<tr>
<td>Bob Fields</td>
<td>Middlesex University</td>
</tr>
<tr>
<td>Martin Loomes</td>
<td>Middlesex University</td>
</tr>
</tbody>
</table>
# Table of Contents

1. INTRODUCTION ...................................................................................................... 5

2. FUTURE DESIGN TARGETING FOR TRANSFORMATION TO NEW SYSTEM 9

3. VISUALIZATION DISPLAY .................................................................................. 12
   3.1 3D Volumetric Displays ............................................................................. 13
   3.2 Autostereoscopic 3D Displays .................................................................. 17
   3.3 Focus of Attention / Attentive Displays ..................................................... 22

4. MULTIMODAL INTERACTION ............................................................................ 28
   4.1 Haptic Interfaces for Virtual Environment Systems ................................... 28
   4.2 Multi-touch and Interactive Surfaces ......................................................... 33
   4.3 Non-touch Interaction and 3D Visualization .............................................. 40

5. DISPLAY CONCEPT INNOVATION .................................................................... 43
   5.1 3D-in-2D Displays ..................................................................................... 44
   5.2 Natural Human-Machine Interface with Immersive Virtual Reality .......... 47

6. CONCLUSION .................................................................................................... 50

7. REFERENCES ................................................................................................... 50
1. INTRODUCTION

In this document we report on a state of the art review of advance display technologies that could influence the concepts and techniques for representing and presenting information about air traffic situations under conditions of the future SESAR Level 3 ATM Capability. We look at current leading-edge technologies, and will consider them within the Future Design framework and assess how they might be used to support the control of future air traffic, or how such capabilities can be used to create opportunities for new forms or ways that enable better coordination and control of air traffic in a SESAR context.

Over the next 20 years, ATC (Air Traffic Control) systems will undergo significant changes due to the emergence of new technologies. Within the 3D-in-2D ATC Displays project, the IDC (Interaction Design Centre) has developed a number of design prototypes to support SESAR operational concepts such as “Free Flight” [1, 2]. These design concepts are aimed at reducing centralized control in the existing system allowing pilots greater freedom in choosing and altering routes, altitude and speed in real time, thus leading to reduced costs and increased capacity, with controllers intervening only when necessary to ensure adequate separation. In the context of SESAR, 4D trajectory management is expected to improve air traffic operations to meet future traffic demands, in particular by increasing the overall predictability of traffic. With the implementation of the SWIM (System Wide Information Management) network [3], it will connect and share information not previously share-able between controllers, pilots and other authorised users. The ready availability of this information, such as aircraft flight status and navigation information will enable a finer level of coordination not possible before. The concept relies on the notion of Business Reference Trajectories: which will prescribe the 4D trajectory (4DT) that defines the time that an aircraft will be at specific 3D locations with a high degree of certainty, leading to the adoption of further traffic concepts, including “Controlled Time of Arrival” (CTA). With increased efficiency arising from improved coordination between airport and airline operations at the terminals that could be achieved through “Collaborative Decision Making” (CDM), aircraft can depart on schedule, thus releasing free parking slots which in turn enable arriving aircraft to land on schedule.

In the future, we must live with the separate systems we have today, where SESAR is being developed to replace the existing air traffic management methods through the use of new technologies. Such an evolutionary process is illustrated in Figure 1.1. If SESAR is to become reality, future air traffic controllers, pilots, and airline managers will require conflict detection, resolution and visualization decision support tools.
Existing controller interfaces use flat, 2D displays with classical 2D mouse and button-based controls to monitor traffic situation. Such displays are principally based on the types of radar systems developed since World War II. Such systems were initially only in use around airports, but as air traffic volume and complexity increased and technology advanced, they were also used to monitor en-route traffic. However, these radar systems provide only 2D displays, whereas air traffic management is intrinsically a 4D (3D + time) problem. Aircraft position, altitude, speeds and trajectories as well as terrain and meteorological data must be monitored in order to guide effectively aircraft along their route. In fact the Air Traffic Control Officer (ATCO) is often required to generate mentally a 3D model/visualization of the traffic situation by integrating the information displayed in the 2D display, which seems to be a counter-intuitive and very effortful process. Under certain conditions, concepts such as Free Flight allows pilots to set their own course and resolve traffic conflicts themselves, without involving controllers except where necessary. This allows the task of air traffic controllers to be distributed across all aircraft, thus reducing their workload. However, instead of the orderly, well-regulated but rigid traffic patterns that exist today, more complex and variable flexible patterns may potentially be permissible under SESAR. Predicting and avoiding conflicts in such an environment will undoubtedly be more difficult than it is today, especially when airlines will take an active role in the future air traffic management.

While existing human-computer interfaces may be adequate for today's ATC environment, they are unlikely to be able to cope with the traffic growth that is predicted to occur in the not-so-distant future [4, 5, 6, 7 and 8]. In these cases, distributed, cooperative decision making is believed to be more efficient than centralized control that characterizes the current mode of air traffic management. New technologies, such as GPS, ADS (Automatic Dependent Surveillance) communications, and more sophisticated ATC software, will help achieve certain essential improvements regarding the design and implementation of the SWIM network which will allow sharing of information amongst pilots and controllers. However, only these technologies do not satisfy all future ATC system needs. A vital but sometimes overlooked component is the human-computer interface: that is, how controllers, pilots and others will interact with the information provided by these new technologies in a collaborative environment.
The principal objective of air traffic control is to organize movements in such a way that a certain minimal separation between neighbouring aircrafts is preserved at all times, thus ensuring safety. This requires an accurate depiction of the airspace, in terms of one or more of the parameters (heading, altitude, airspeed, etc.) to support the controller and pilot’s situation awareness of all aircraft locations; understanding of their positions relative to their own aircraft; and extrapolation of their predicted future locations. The use of the third dimension in the ATC domain will allow controllers to view and navigate the controlled airspace in four dimensions (3D position + time) in order to support their decision-making process by providing appropriate visual cues. Where 3D real-time interaction with air traffic/airport space is accessible, the controllers can benefit from the use of 3D visualization displays. In addition, air traffic controllers should have a “global vision” of the traffic flow they are negotiating, in order to help them balance the flow across two or more sectors. In this case, the 3D display could support the air traffic controllers in establishing such a balance, in terms of maintaining segregation between flows, by adopting a form of “what if” strategy.
Figure 1.2 The relationship of 3D Visualization, 3D interaction, interface and human factors in Air Traffic Control

Since controllers and pilots will need to be provided with traffic information in order to select flight paths and airspeeds in real time, research involving the displays which will assist them in accomplishing these tasks is vital for the safety and success of SESAR. We investigate the possibility of incorporating the required information through the use of various 3D visualization technologies. Our hypothesis relies on the replacement of 2D objects and normal texts with 3D objects and that 3D visualization would allow us to incorporate terrain, obstacles and weather information for a more effective working display. The validation of this hypothesis requires investigation into three domains (see Figure 1.2):

- visualization: how ATC elements should be represented
- interaction: what are the appropriate interactions between controllers and the 3D display environment?
- ATC human factors: could 3D environments be convivial working environments for controllers, in terms of spatial memories, depth perception etc?

We believe the best course of action for meeting these future needs is to combine automated conflict detection and resolution mechanisms with advanced human-computer interfaces that use intuitive 3D visualization displays and interaction controls. We will review
advanced alternative display technologies, such as 3D visualization displays that do not need goggles or other see-through augmented reality devices; and will assess their suitability for use in presenting the 4D-in-2D concepts as well as for developing innovations in display designs. These displays will be multimodal, engaging the visual, auditory and vocal channels to provide an interface that fits naturally to the way humans operate. New technologies create or enable new capabilities, which in turn result in changes in the way we work. Such displays offer the potential to reduce the cognitive workload on both pilots and controllers, resulting in faster recognition and improved situation awareness of the air traffic situation and of potential conflicts. This review is not about technological forecasting, but instead aims to inform EUROCONTROL about the possibilities that new and emerging technologies could afford.

2. FUTURE DESIGN TARGETING FOR TRANSFORMATION TO NEW SYSTEM

The initial work undertaken in the current research project has identified the key elements of ATM that might require significant modification. We expect decision makers would be better able to recognize deceptive threats if they used a compensatory decision aid that mitigated the effects of their cognitive limitations in the following aspects: perception, attention, and memory; which enhance conflict detection and de-confliction capabilities, and allow operators to:

- discover conflicts in a shorter time,
- acquire better situation awareness,
- derive better and more varied de-confliction measures.

However, many investigations on how to improve the Controller Working Position (CWP) with existing techniques have already been carried out, all with limited results. This disappointing outcome may be explained by the infrastructural constraints of existing visualization displays, especially in highly-populated areas where most of the demand for air transport originates. If the situation does not improve significantly, a rise in major air-traffic incident rates over the next 10-20 years may occur as the existing ATC system appears to be nearing saturation. Current radar-based surveillance and communication systems based on voice radio will not be sufficient to meet future demands, and safety improvements to the technical systems both on board aircraft and on the ground will consequently have to be made. In addition, controllers will be exposed to the challenge of being more and more efficient, not only in the maintenance of flight safety but also in the management of flight operations. Further decision-support tools and information is needed to assist controllers in coping with these new challenges.
The current situation has led some researchers to seek alternative information display systems to replace traditional 2D radar visualization displays. This has been motivated by a desire to ease controllers’ workloads, increase ATM capacity and provide much more precise and up-to-date information than was possible previously with traditional 2D radar displays. In terms of the SESAR model, (Figure 2.1), we may consider ourselves currently in the ‘future design’ stage, specifically concerning the design of new kinds of systems for which the work is yet to be defined, and where many aspects of the work and the working environment is still not known, or not knowable. Such challenges arise when designing or developing new technologies for new work situations that currently do not exist, or are anticipated to be radically different. For future design purposes, the aim is to surpass the traditional target of developing faster, better and cheaper designs and instead to seek innovations involving new forms of technology, and explore the opportunities these present.

The fundamental relationship between technology and work is an intriguing subject. The complexity of modernized human-computer systems, in particular mission-critical or safety-critical systems, makes it extremely difficult at the design phase for designers to predict all possible scenarios that may arise from any particular situation. Instead of analyzing specific task sequences and/or variations thereof, our proposed approach, dubbed ‘future design’ [10], aims to identify space characterized by boundaries in which a variety of human work situations can be allowed. We refer to this as the space of permissible actions (Figure 2.2). This space is bounded by the goals we are trying to achieve, the technology that is or will be available, the limits of human abilities, and the values, priorities and expectations of the user in the future work environment. Design with a formative approach, where we would identify
the space of permissible actions, instead should target solutions to help the researcher cope with all work situations in an adaptive way.

![Diagram of Space of Permissible Actions]

**Figure 2.2 Space of permissible actions [11]**

As discussed earlier, the introduction of the SESAR operational concept, along with advances in communication, data links, and accurate navigation, is predicted to increase air traffic management capabilities. Consequently, new scenarios are being discussed within the aviation community, such as free-flight, curvilinear approaches, and new approaches to navigation in difficult terrain. These anticipated changes can also affect the tasks and informational requirements of the controller, pilot and other relevant users in the future. In order to manage these changes, more than a simple modification of existing ATM systems will be required. Indeed, fundamental changes in ATC systems will be needed, so that systems for controlling aircraft movements, both on the ground and in the air, can be harnessed to improve traffic management whilst ensuring that safety standards are maintained.

It is in the context of such radical change that novel alternative display technologies offer significant advantages for the field of air traffic management. However, the latent potential of these technologies lies in their capacity for being used to manipulate, display and combine multi-dimensional data sets with ATC-specific tasks. Within the air traffic control community, these novel alternative display efforts have evolved into four key categories:

- Navigating and controlling air route in air traffic management
- 3D visualization and interaction in air traffic control
- Focus of attention and multimodal information display
- Interactive collaborative environments for ATM

The research framework of this report is to investigate the use of up-to-date visualization display techniques, with emphasis placed on introducing new capabilities and characteristics for user interactions in a synthetic environment created by some specific devices that could
be suitable for ATC interactions. Thus, having identified the design domain of permissible actions, we can now attempt to generate future designs that address the space, in a way that would help us distinguish between good ideas that can satisfy future ATM needs, and the implementation of these ideas as a design solution.

3. VISUALIZATION DISPLAY

All objects in the ATM environment, such as geographical position, altitude, speed and foreseen trajectories, will be assigned intrinsically a location of a volume of airspace as a function of time, and a ’natural’ display of multidimensional information representation may exploit this perceptual ability to communicate information to a viewer in meaningful ways [12]. With Standard 2D radar display, controllers have to expend time and energy in the translation of the 2D alpha-numeric information into a dynamic 3D mental model of the traffic situation [13]. This often poses a very demanding cognitive challenge especially in the context of complex air traffic situations consisting of 3D traffic locations and restricted volumes, such as terrain, weather, military, etc. In contrast, when using a 3D visualization display, with a sense of depth along the line of sight [14], controllers can obtain a single integrated view of a scenario that would otherwise require multiple 2D views or non-spatial codes on plan-view. An extensive review of the advantages and disadvantages between 3D and 2D has been reported elsewhere [15] and are summarized in Table 3.1.

Table 3.1 Relative advantages and drawbacks of 2D and 3D display [15]

<table>
<thead>
<tr>
<th>Display type</th>
<th>Advantages (+)</th>
<th>Drawbacks (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D Display</td>
<td>Global traffic picture always available;</td>
<td>Do not represent spatially altitude information, and requires the controller to read and interpret alphanumerical altitude data to produce and maintain 3D picture;</td>
</tr>
<tr>
<td></td>
<td>Supports correct distance estimation, focused attention tasks;</td>
<td>Suffers from cluttering. Overlapping labels and blips difficult to read.</td>
</tr>
<tr>
<td></td>
<td>Supports improved performances for visual search tasks;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Easy to orient. User maintain easily orientation awareness;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Navigation and Selection are easy to achieve.</td>
<td></td>
</tr>
<tr>
<td>3D Display</td>
<td>Supports Superior performance for integrated -shape understanding--tasks;</td>
<td>Hampered distance estimation performances due to perspective distortion effects ;</td>
</tr>
<tr>
<td></td>
<td>Supports development of accurate mental model of traffic and terrain,</td>
<td>Not possible to oversee global traffic/global sector out of camera view ;</td>
</tr>
<tr>
<td></td>
<td>effective training tool;</td>
<td>Traffics at the far end of the scene difficult to locate, due to decrease in resolution;</td>
</tr>
<tr>
<td></td>
<td>Supports effective decision making for a/c maneuvering on the vertical plane;</td>
<td>Navigation and selection difficult, user can get lost when moving the camera;</td>
</tr>
<tr>
<td></td>
<td>Supports at glance assessment of consistency of implemented maneuver</td>
<td></td>
</tr>
<tr>
<td></td>
<td>with the original one as intended by controller;</td>
<td></td>
</tr>
</tbody>
</table>
Although 3D displays may inhibit precise reading of distance values along any particular axis [16], they are more suited to supporting integrated attention tasks that require the integration of information across the three dimensions: such as understanding the volumetric shape of a complex weather front; and instructing an aircraft to descend and to take off. These help the controller to ‘see’ the actual situation rather than having to rely on a mental image, thus shortening time required for decision-making. However, results from early research [17 and 18] into performance effects of adopting 3D displays suggest that no obvious differences were observed for the majority of task judgments used for the evaluation [19]. This may not be entirely true because when a controller makes the transition from a 2D radar display upon which the bulk of their experience is based, to an unfamiliar 3D display, there may be an unintended ‘negative transfer’ of experience.

3.1 3D Volumetric Displays

Volumetric displays produce 3D images in a three-dimensional volume. They can be observed simultaneously without glasses by multiple users who can often literally walk around the image. 3D volumetric displays (3DVD), such as FELIX 3D Display [20], have been subject to much research, and attempts have been made to develop real-world applications for them. 3DVDs enable the display of 3D images by projecting a laser beam onto a rapidly rotating helix, (Figure 3.1, Figure 3.2 and Figure 3.3); with the ability to produce an all-round view without the need for special hardware, such as glasses or head trackers. The timing of laser pulses and the position of the helix render stationary voxels that can be used to construct images of objects [22]. Using the parallax created by the head and body movement of the observer, this display scheme presents a more natural method of determining intra- and inter-object relationships. Consistent depth information is provided as there is no discrepancy between accommodation and convergence.
Figure 3.1 Schematic illustration of the volumetric 3D display and a photograph of the flight simulation over complex geomorphic [23].

Figure 3.2: (a) Intersection of a vertically diffused ray of light with the circular locus of viewpoints V; (b) Seen from above, rays leaving the mirror diverge from the projector’s reflected nodal point to multiple viewpoints. The viewpoint corresponding to vertex Q is found by intersecting the vertical plane containing ray P--Q with the viewing circle V; (c) When pre-processing a light field, the intersection point V0 determines the nearest horizontal views to sample.

Figure 3.3 An example of a photograph of the runner simulation over [79].
Volumetric displays allow simultaneous viewing by multiple persons, who are able to move around a transparent 3D image to obtain differing views. Each viewer’s eyes observe a separate image that can be focussed at different depths. The trade-off is cost and complexity. Most volume rendering techniques available at present are still at the developmental stage; they are also expensive and require an extremely large supply of computing power to produce a single 3D image [19]. These displays are typically appropriate only for high-end professional and military markets in which a limited number of transparent pixels are sufficient to give useful depth information, with additional visual cues (e.g. parallax, stereo cues) over 3D perspective displays [16]. Hanson [25] extended the analysis of 2D versus 3D displays to include the potential benefits of presenting weather information on 3D volumetric displays. According to Hanson, the volumetric display could potentially allow controllers to take advantage of holes in weather areas that otherwise would have gone unnoticed on a 2D weather display. A similar display framework by Dang [21] describes a virtual environment that allows a controller to view airspace, terrain, and weather areas in 3D stereoscopic visualizations.

More recently, K.F. Van Orden and J.W. Broyles (2000) [27] compared human performance on different 2D and 3D display formats over four visuo-spatial tasks. Qualified air traffic controllers completed aircraft speed and altitude judgement tasks, a vectoring task, and a collision avoidance task using four display systems: 2D top-down (plan-view), 3D perspective, 3D stereo and laser-based 3D volumetric. The variables measured were: accuracy of depth perception and time required for each judgment task. The results are illustrated in Figures 3.4 and Figure 3.5.

![Figure 3.4 Task judgment accuracy and display view](image-url)
Tasks requiring participants to view and predict future locations of multiple display symbols as they traverse a confined space appear to be well suited for 3D rendering. Compared to 3D stereoscopic and perspective displays, the veridical display of localized spatial information within a volumetric display provide high fidelity stereoscopic and parallax cues, improving human perception performance for some tasks [27]. For the collision avoidance task, presentation on the 3D volumetric display was found to be superior to that on 3D perspective, 3D stereoscopic, or 2D displays.

In another evaluation of depth perception when viewing 3D scenes, Grossman and Balakrishnan [28] systemically compared volumetric displays to other 3D display techniques (perspective, stereo, stereo head) instead of using a single task with task scenarios as illustrated in Figure 3.6. They used a total of three tasks that always appeared in the same order, with the duration of each task being about 5-7 minutes. As illustrated in Figure 3.7, for each of these tasks, display technique had a major influence on the corresponding error rate. From their results fit was concluded that, as expected, volumetric displays provide improved depth perception and collision detection compared to stereoscopic displays, even when the stereo view is coupled with additional head tracking hardware. However, this display system did not perform as well in the path tracing task.
3.2 Autostereoscopic 3D Displays

Most of the perceptual cues that humans use to visualize the world’s 3D structure are available in 2D projections. Such cues include occlusion (one object partially covering another), perspective (point of view), familiar size (we know the real-world sizes of many objects), and atmospheric haze (objects further away look more washed out). Four cues are missing from 2D media:

- stereo parallax — seeing a different image with each eye,
- movement parallax — seeing different images when we move our heads,
- accommodation — the eyes’ lenses focus on the object of interest, and
convergence — both eyes converge on the object of interest.

The well-known 3D displays that require the viewer to wear special glasses present two different images in the same display plane, the glasses are typically a pair of shutters (Figure. 3.8) synchronized to a fast scanning monitor. When viewing stereoscopic displays, the observer usually has to wear glasses that have colour-filtered lenses, polarized lenses, or lenses that occlude each eye sequentially in order to channel each of the images in the stereo pair to their respective eyes. 3D images can be implemented using various multiplexing approaches: colour (anaglyph), time, polarisation, and location, as well as time sequentially controlled polarization. These approaches result in differences in image resolution and quality, efficiency of transmission, costs of obtaining such systems, suitability for multiple viewers, etc. Detailed descriptions are presented in [29 and 30].

![CrystalEyes™ shutter-type stereoscopic glasses](image)

Figure 3.8 CrystalEyes™ shutter-type stereoscopic glasses

All these technologies provide stereo parallax and convergence cues. When combined with headtracking, they can provide movement parallax for a single viewer. However, these devices have a range of applications but are limited by the need to wear special glasses and the isolation from the real world caused by being able to see only the glass-mounted display. In addition, the prolonged use of this technology is widely reported to cause headaches. See-through headsets are available, but the display is then always seen against the background of the real world, again limiting their applicability.

Today there is significant commercial interest in stereo 3D for electronically driven displays, both in the generation of content and in the various techniques employed for displaying this content. Recently, global leaders in 3D display technologies, including Alloscopy [31], Sunvay Technologies Ltd [32], Philips 3D Solutions [33 and 34], SeeFront [35] and Spatial View 3D Displays [36] announced they will be introducing their new autostereoscopic 3D
LCD display technology. Typically, these autostereoscopic 3D Displays align additional optical elements — such as parallax barriers or lenticular screens (see Figure 3.9) — with the display to ensure that a viewer will see a different image with each eye. If an observer places the right eye in one window, and the left eye in another, each eye sees a different image on the display. If the images constitute a stereo pair, then a 3D image is seen, as illustrated in Figure 3.10, 3.11.

Figure 3.9 Lenticular lens screens manufactured by Philips technology in 3D-LCD technology
Figure 3.10 (a) Parallax-barrier and (b) Lenticular (microlens array) are glasses-free 3D displays the two major approaches to glasses-free 3D

Figure 3.11 Generation of viewing windows in autostereoscopic displays

For example, Alioscopy [37] manufactures the optical components for the lenticular array of their 3D displays, and have developed software for rendering both still images and video to give an effective illusion of depth, as shown in Figure 3.12. Such 3D display technologies provide significant advantages over other variations for 3D displays such as SenseGraphics 3D display [38] (see Figure 3.13), which integrates the Phantom haptic device into the interaction with their 3D displays. Their 3D displays however, still require the use of a set of polarized stereo glasses to create the 3D effect.
Figure 3.12 Alioscopy 3D display showing Panneau-beaudieu Beau Dieu Cathédrale d'Amiens.

Figure 3.13 SenseGraphics 3D display with passive polarized stereo glasses, integrated with haptic interaction.

With advanced lenticular lens technology, Autostereoscopic display:

- Autostereoscopic 3D displays enable the 3D experience without the need for special glasses.
- Large 3D viewing zone.
- Multiview slanted lenticular lens technology leads to full brightness, full contrast, and true color representation. It allows multiple users to experience 3D at the same time.
- Integrated display signal processing and hardware engine gives full control over the quality and depth-effect characteristics of the picture.
- Content creation tools to support the creation of 3D content from 3D animations or games, converting stereoscopic video content, or even upgrading existing 2D content to 3D.
- Optimal viewing distance: 3 meters.

In addition, the displays can be applied to a broad range of applications, since it can be operated in both 2D and 3D modes. The system solution is designed for maximum reuse of content/concepts from the 2D world. The flexible 3D data format, for example, in the form of 2D-plus-Depth in Philips 3D Solutions, or mixes these eight views on an optical filter-coated panel, transforming images that would otherwise appear fuzzy on a standard TV into stunning impressions of depth in an their screen, allows easy creation or adaptation of applications and content for the display.

Standard video can be shown as well as specifically-3D content, rendered with typical 3D software such as 3ds Max, Maya, Lightwave, and XSI. In addition to real-time and offline content creation tools, there are also many applications that operate on a 3D dataset. Most of these applications, such as games, design, etc. use the OpenGL or DirectX API. The WOWvx OpenGL Control support real-time extraction and usage of the depth information and thus real-time visualization on the 3D display.

### 3.3 Focus of Attention / Attentive Displays

When viewing visual presentations, a user can only be attending to a relatively small part of the displayed content at any one time. Instead of rendering information at the same level of detail everywhere, attentive display systems track the user’s visual attention and render information in full detail only at the user’s current focus of attention, while reducing information in peripheral areas. It is assumed that the content being looked at will be the most important to the viewer at a given point in time. By shifting human perception from peripheral regions to the region located in the user’s focus of attention, attentive display systems can provide faster response times with higher subjective display quality than systems distributing their resources equally across the screen. Attentive display prototypes have been applied to a variety of visually demanding tasks, including driving simulators, advertisements and art [33], and we believe it has considerable potential for future air traffic management.

The first example of an attentive display is the gaze-contingent display (GCD) [40]. As a movie scene rendered using a GCD from the movie ‘The Gladiator’ in Figure 3.14, as the
user focuses on the face of the shot’s main character, all other display content is rendered at reduced resolution, substantially reducing the overall rendering effort for this frame; and having the added advantage of the viewer being able to instantly focus on the face of the main character in the shot. As the movie plays, the high-resolution region moves with the user’s focus of attention, so that the spot at the user’s focus is always rendered in high resolution. This effect is achieved by tracking the user’s gaze thus selecting the region of interest with a sensory device such as an eye tracker (Figure 3.15). The degradable collision handling mechanism shown in Figure 3.16 evaluates object collisions within or near the user’s focus of attention with greater precision than collisions occurring in the user’s periphery. By saving processing time that would otherwise be wasted on collisions outside the attentive area, extra processing time is then made available for spending on collisions in the user’s focus of attention. This results in an overall improvement in the perception of the simulation [41]. In addition, while the approaches described here follow the user’s attention, attentive displays have also been used to direct the viewer’s attention. In another example (Figure 3.17), by controlling luminance, colour contrasts, and depth cues, the painter is able to guide the viewer’s gaze toward the depictions of Christ and the kneeling woman.

Figure 3.14 Gaze-contingent display shows a scene from the movie “The Gladiator” (Original image © 2000 DreamWorks SKG and Universal Studios; gazecontingent rendering and resolution map courtesy of Bill Geyser)
Figure 3.15 Eye contact sensors (Human Media Lab)

Figure 3.16 Eye-tracking can be used both to evaluate metrics for perceptually adaptive collision handling [41]
Previous research of gaze contingent displays succeeded in addressing only the case of lossy resolution compression of peripheral image regions. New research is extending GCDs to support arbitrary resolution maps, which enable the exploration of additional aspects of attentive displays. First, foveal regions of arbitrary shape and size may be created, with peripheral regions degraded by arbitrary means -- for example, using colour or contrast reduction, not just resolution. Secondly, multiple foveal regions may be displayed at the same time. (Multiple foveal regions provide a suitable display strategy for future systems capable of predicting the user’s next point of focus.) The downside is that GCDs can only be used in single-user environments, because the eye-tracking device is only capable of tracking the gaze of a single user. To overcome these limitations, researchers have proposed the concept of Region of Interest Displays (RoID) to accommodate multiple users, using pre-defined Regions-of-Interest (RoI) areas, without any specialized eye-tracking hardware.

Focus plus context screens achieve a high-detail/low-detail effect by combining a wall-sized low-resolution display with an embedded high-resolution screen [42]. The installation shown in Figure 3.18 uses an LCD inset combined with projection for generating the low-resolution context. This can be built from relatively inexpensive off-the-shelf components, a cost-
effective alternative to complex multiprojector high-resolution screens. Customized software is used to display image content across both display regions, such that the scaling of the image is preserved, while its resolution varies across the two display regions. By slaving the focus display to the user’s gaze, future versions may obtain high resolution wherever the user looks, thereby widening the applicability of focus plus context screens to applications where users continuously look around.

Figure 3.18 (a) The workplace prior to the modification; (b) The foam core projection screen is placed around the flat panel display; (c) A projector is positioned at the opposite side of the office; (d) A paper mask is added to cover the frame of the flat panel display. [43]

In the example shown to the right of Figure 3.18, the user is examining a specific neighbourhood on a satellite image of a city. If the user was using a regular monitor displaying the same level of detail, with many residential areas looking very much identical, he would find it difficult to identify where the displayed portion of the satellite image is located within the city. Adding the low-resolution context screen space brings the peripheral areas into view, providing additional landmarks that simplify orientation. When the user moves the mouse, the entire displayed content pans, which results in the scrolling display moving into the focus region where it is rendered in high resolution. For tasks involving large maps or detailed chip designs, focus plus context screens have been shown to help users to work between 20%–35% faster than when using standard displays with the same number of pixels and homogeneous resolution or multiple views. For an interactive driving simulation, users’ error rates were found to be only a third of those in a competing multiple-view setup.
This technology suggests a useful way of optimally routing air traffic to minimize the visual work load, and we believe it could be adapted for air traffic control tasks.

Focus of attention display perhaps look as if being related with a big assumption, which is that rendering the entire scene in an ATC display will place too heavy a load on current and future CPUs. However, this is not really reason for us to develop attention display, particularly with the rapid development of GPUs. In fact, both the pilot in Free Flight and controller on the ground need not keep track of all neighbouring aircraft, but rather only the ones that threaten to result in a conflict. Regardless of the approaches and concepts we may use, which may be these techniques mentioned above or any other emerging techniques of the future, the main benefit for introducing attentive displays for ATC can be summarized as: Attention display provides an effective approach to help and to direct the controller or pilot to sift through all the available information and extract only the relevant/important aspects, thus decreasing unnecessary work overload of visualization information of air traffic situation to affect perceptive performance for carrying air traffic management task. As an example, in 3D-in-2D displays, we used depth cue variation in the visualization display to provide air traffic controllers with selective 3D views of areas of interest to assist them in producing 3D mental reconstructions of the current traffic situation in a very short time, while to maintain global awareness of the traffic situation that is available through the familiar 2D plane view radar display. This effect was achieved by incorporating a variety of attention display techniques, including gaze-contingent display and focus plus context screens, as described above; and by controlling resolution, luminance, colour contrasts, and depth cues, etc. This presents us with inspiration for areas of possible future research.

However, “focus of attention display” in visualization alone does not guarantee success as a tool for all air traffic situations. How to reduce visual complexity and make better use of the human perceptual system, as well as provide interactive control of what is being presented, are clearly primary concerns of the researchers who are seeking alternative sensory techniques aimed at decreasing perceptive overload during visualization. It is a fact of life that humans naturally employ multimodal information channels (e.g., speech, gaze and gesture during a conversation) during their everyday activities. It is well established that multimodal communication can result in increased information transmission and perception, whether multiple modalities convey different information or encode the same information redundantly [44]. Some studies have shown that dual display is advantageous as the mental workload is distributed across the two modalities. The channels required to process visual information are different from those that process other sensory information. By providing different information to each of the senses, using both senses, the workload may be reduced.
An interesting issue arises regarding the possibility of using multimodal information channel in various ways, such as eye-tracking devices for gaze-contingent display, cross modal attentional links between touch and vision, and cockpit display using tactile sensation, etc. The impression of immersion within a 3D virtual environment is also greatly enhanced by inclusion of 3D spatialized sound within AR air traffic scenario. More interestingly, voice commands may be identified to allow the user the choice of an alternative way of accessing a much wider range of commands and actions without recourse to a static keyboard or complex sequence of buttons. Thanks to the motion-tracking abilities of the Wii, we can also track hand locations or handheld objects that the user manipulates to allow gesture-based control mechanisms. All these techniques could possibly strengthen air traffic situation awareness since the objects would naturally treat as what we do in real life; consequently we believe these techniques will have a significant role to play in the future of air traffic information display.

4. MULTIMODAL INTERACTION

The term “multimodal” has multiple meanings depending on the context. It can mean interaction with multiple devices [45], the use of multiple human skills (writing, drawing, gesturing, talking) [4] or the use of different sensory channels [46]. The first definition is centered on technology while the two others are human-centric. In this report the term is used simultaneously in all meanings — a multimodal HCI system usually needs to use a number of different devices. At the same time multimodal applications require the use of multiple skills and sensory capabilities. Current human-computer interfaces use only a small subset of possible human modalities, usually just text and images, with mice, keyboards, cameras, etc. Alternative communication channels (speech, gestures, body-language), have not been significantly exploited. It is possible that the use of these alternative channels can improve the user interface [47]. Multimodal interaction offers several potential benefits over uni-modal interaction.

4.1 Haptic Interfaces for Virtual Environment Systems

Of the major human senses of vision, audition, tactility, only the first has been extensively engaged in most human-machine interfaces used for air traffic control applications, and a consequently a disproportionate majority of research has been conducted on visual display systems. However, in the context of certain problems, including disorder on- board aircraft, the presence of obstacles or bad weather in the vicinity of the aircraft may prevent pilots from adequately attending to visual information, especially in single-pilot operations.
envisaged for future air traffic situations. In such circumstances, the visual (and/or auditory) channel may be unavailable, inadequate, or overloaded [48]. A number of different cases may be identified, including: reaching the limits of the visual processing capabilities; visual perception degradation under high graphics loads; visual attention decrease when tracking multiple visual information sources; and, in certain circumstances, the generation of pilots’ visual vestibular illusions, and the misinterpretation of visual information [49]. In many of these situations, the tactile channel can become an important or even vital alternative in the design of future cockpits.

Recently, the tactile sense has been considered as an effective channel for displaying flight information [49, 50 and 51]. In recent experiments, such information is usually conveyed through tactile sensations transmitted via a seat, a vest worn by the pilot, or through fingertip vibrators sewn into gloves [49]. In one system, path angle error information is displayed through the tactile display to enable the pilot to maintain an appropriate vertical trajectory (Figure 4.1). The path angle error is defined as the error angle between current flight path and interception path to the target trajectory (Figure 4.2). If there is an error between those two paths, a tactile signal is generated. During the preliminary phase of the research, a series of flight simulation experiment was conducted to investigate the effectiveness of the proposed display device by comparing some combinations of tactile and visual information.

![Figure 4.1 Cockpit display using tactile sensation](image1)

*Figure 4.1 Cockpit display using tactile sensation*

![Figure 4.2 Error between current and ideal path](image2)

*Figure 4.2 Error between current and ideal path*
Gray et al. have focused attention on the cross-modal attentional links between tactility and vision [52, 52 and 53]. Haptic cues, from along the forearm [52,53], or at one of four quadrants on a user’s back [54,55,56], were used to affect the speed and accuracy of perception of visual targets by tactile pulses simulating motion, or redirecting spatial attention (Figure 4.3). Some of the subjects benefited from the haptic cues, while others managed to ignore the (mostly invalid) ones. These results are interpreted as evidence that the use of haptic cues to reorient a person’s visual spatial attention is natural and intuitive when the validity of the haptic cues is high. More recently, these authors have compared the effectiveness of haptic and auditory cues on estimating approaching visual target times [46]. It was found that appropriate haptic cues have a much larger effect on estimating these times than auditory cues.

Figure 4.3 The haptic back display

Shown here is a 3-by-3 tactor array. Each tactor is fastened, by two crisscross elastic bands, to a piece of supporting fabric that is draped over the back rest of an office chair [54].

Figure 4.4 Fish tank VR setup
Equally interesting is the use of haptic force on improved performance in steering tasks. In one study, this was evaluated by asking subjects to move a cursor down a ‘tunnel’ to a target [58]. A related concept is the use of force feedback to guide a user in carrying out manual and supervisory control tasks [42]. Komerska and Ware [60, 61 and 42] have combined a number of technologies, such as head-tracking and stereo glasses to develop a haptically enabled fish tank VR, called the Haptic-GeoZui3D (Figure 4.4). This provides a platform for path planning for Autonomous Undersea Vehicles (AUVs), and focuses on the providing constraints on user tasks, rather than mimicking physical object forces. Figure 4.5 provides an example of each of the elements that have been visually and haptically rendered, including a bathymetric surface, a vehicle representation, and a vehicle trackline waypoint object.

In order to combine constraints with a direct manipulation interface, Komerska and Ware have implemented a number of haptically enhanced data objects and interaction widgets. While working in this mode, the only force constraints presented to the user are imposed by the bathymetric surface and the placement grids, as shown in Figure 4.6. These constraint forces are calculated using simple force functions, and the bathymetric surface object is haptically rendered as a unidirectional constraint surface, which blocks the user from performing the undesirable action of placing trackline waypoints or vehicles below the ocean floor.
This application represents an attempt to integrate a typical mission planning task -- path planning -- into an interactive 3D environment, in order to provide a more intuitive means of defining transit paths to help alleviate path safety concerns. The use of haptics provides immediate feedback on permitted interactions with both the hepatic widgets and data elements; the user is visually and haptically restricted from doing things that are not safe. In future air traffic contexts, when ATCOs wish to make navigational changes to avoid weather disturbances, re-route a flight, or navigate through complex terrain to avoid a potential conflict, instead of completely relying on a visualization display, the use of haptic interaction to guide steer control (perhaps based on an extension of the Haptic-GeoZui3D concept) would provide a novel and potentially highly effective alternative means of carrying out relevant ATC tasks.

One of the driving forces steams from SESAR is the requirement for greater 3D predictability of aircraft, that is, as described above, an aircraft will be at a specific 3D location with a high degree of certainty in time, aimed at “Controlled Time of Arrival”. The enhanced prediction will come from better on-board navigation systems and better representation of information, which simply implies more opportunities to automate the aircraft aviation. Due to the development of new techniques, such as Global Positioning System (GPS) and Automatic dependent surveillance (ADS) system, etc, pilots can use the airplane's own navigation information (possibly derived from GPS) to calculate aircraft position at specified time and transmit this information to ground-based control facilities, or to nearby aircraft as well. However, since we could be assured to obtain the accuracy and reliability of this information (this poses another research problem), we are still left with the great challenge of how to
navigate (to operate) the aircraft flight around various flight obstacles it encounters, in a suitable way and at precisely the right time, especially when we are required to face to a more complex flight scenario than to what we live today.

Of more effective solution related how to avoid a series of erroneous operations made by pilot in flight route management. It is clear that awareness of flight situation in existing flight control system relies heavily on visual information. Thus the presence of unexpected obstacles or bad weather can easily prevent the pilot from acquiring the required visual information, resulting in human error with often disastrous consequences. In this case, the tactile sense could perhaps allow the pilot to avoid such occurrences, e.g. path angle error information, as shown in Figure 4.2, is presented via tactile display to assist the pilot keeping maintaining the appropriate vertical trajectory. It would also be interesting to expand the concept of employing force feedback to guide a user in carrying out manual and supervisory a steering task in aircraft route, as Haptic-GeoZui3D for path planning for Autonomous Undersea Vehicles (AUVs). Since controlled flight into terrain is one of the leading categories of civil aircraft accidents, a related issue will be how to calculate and to combine constraints from terrain obstacles with a direct manipulation interface, with a number of haptically enhanced data objects and interaction widgets. If the transform is successful, we may further expand this work to a dynamic environment, like weather, etc. In this way, the obstacles are haptically rendered as a unidirectional constraint surface, which visually and haptically blocks the user from performing the potentially dangerous action. We believe combined constraints operation systems will impact flight crew operational procedures for achieving “Controlled Time of Arrival”.

4.2 Multi-touch and Interactive Surfaces

Multi-point touch interfaces have been prototyped by a number of different organisations. Among the earliest reported works were the Mulit-Touch Intearaction by Jeff Han at New York University in 2006 [62] which is based on the FTIR ‘frustrated total internal refraction’ sensing technique (Figure 4.7). As an example, Figure 4.8 shows the smartskin sensor configuration in constructing such a system: a mesh-shaped sensor grid is used to determine the hand’s position and shape. (Details may be found in [63].) This technique allows multiple points of contact with the touch screen to be detected and responded to.
Figure 4.7 Multi-point touch interaction allowing two-handed, multi-finger interaction

A Meshshaped Sensor Grid is used to determine the hand’s position and shape.

Figure 4.9 is a screen shot from a video showing how the interactions work. In a similar vein, Microsoft Research in Cambridge have developed a sensing technology that can turn...
regular LCDs into a sensing surface for the detection of fingers and other physical objects placed closed to or on the display surface. This will allow the surface to be used as a multi-touch interface, or for tangible computing applications (see Figure 4.10 and Figure 4.11) [64].

Figure 4.9 Multi-touch application in a wide screen [65]

Figure 4.10 ThinSight multi-point tracking
Following the inspiring tabletop environment presented in Wellner’s DigitalDesk system [66], many novel tabletop systems, including Diamond Touch and Microsoft’s Surface [67], have been developed, and their suitability for different tasks has been widely evaluated. Several example applications of the tabletop are shown in Figure 4.12. This particular display technology has not only improved in quality, but also in the way that users can interact with large surfaces. In Ryall’s work [68], involving diverse groups of people (i.e. varying in age, culture, gender and technical background) participating in a broad range of non-controlled settings (i.e., from casual to focused usage scenarios), across a broad set of applications (i.e., from collaborative to independent to competitive); a number of common usage patterns in touch interactions, multi-point interaction and identification and organization of content were uncovered. Throughout the study of these literatures, a number of different types of user interactions were logged, including:

- Plugging and unplugging a device;
- Dragging media onto and off the surface via palettes;
- Creating, moving and resizing windows for media, parcels, notes and carves;
- Interacting with windows using toolbars and scrollbars.
Figure 4.12 Tabletop iDwidgets in action: (a) DTMap; (b) Table-for-N; and (c) TeamTag
Each application uses a MERL DiamondTouch table, which serves as an interactive tabletop [56].

More recently, touch interfaces have been able to respond to multiple touches and gestures, increasing the possibilities for interaction and for multiple users to collaborate. Although interactive tabletop environments are becoming increasingly common, there are few ATC applications that are able to exhibit their full potential. As new emerging technologies appear, researchers are focusing their concern on their novel interface features. We concluded the following possible features for an interactive, large vertical/horizontal display:
• Multi-user zooming in and out;
• Multi-point interaction and identification;
• User can interact directly with the system;
• User can deliver information each other;
• Multi-finger and whole hand interaction;

These literatures illustrate interaction with multi-user speech and whole-handed gestures on a digital table. The touchTable system allows multiple users to visualize, navigate and analyze larger quantities of information using a large high-resolution display and an intuitive gesture-based user interface. Networking touchTables also allows people operating from different locations to work together sharing a common virtual space. This work represents a key step towards providing rich collaborative opportunity in co-located environments.

The interaction paradigm of ATM task management in the last few years has been based on the concept of the ‘individual operation environment’, in terms of the arrangement of air traffic controller roles. In this scheme, each controller has only one designation device (a mouse or a trackball) and his/her own screen(s). However, the increasing volume of air traffic has created a growing demand for air traffic control, particularly in the face of high workload situations that may require for the presence of more than two controllers at a given position. This places the emphasis on access to tools that may be more efficient when shared by several users for different purposes, sometimes at the same time, with the ultimate aim to improve on ATCo operational efficiency.

To explore new possibilities of collaboration based on modern en route control tools, EUROCONTROL proposes the concept of Multi-Actor Man Machine Interface (MAMMI) based on single equipment where ATCos would share not only the information, but also the means of managing this information. A new project, called the MAMMI project, started in July 2006. Regarding the MAMMI, Vales et al. [69] focused on collaboration between en route controllers, basing their work on/around the following three principles:

• Several ATCOs able to interact collaboratively at a single en route position
• Real-time tasks and workload repartition
• Lower levels of ATCo specialization

For the design of the future illustrators and prototypes, they linked these three principles with two axes:

• Flexibility of the organization
• Sharing of information

ATC deals with traffic organization such that safety is maintained regardless of traffic complexity within a defined, limited capacity. In the future, instead of part of existing
controller’s daily ATC tasks, pilots will set their own course and resolve most conflicts by themselves, without involving controllers except when needed, following the development of SESAR. No longer obliged to perform those daily tedious, repetitive tasks, air traffic controllers on the ground can now have the opportunity to focus their attention and expend more energy on more challenging ATC management tasks, that is a vital but frequently overlooked component in our existing air traffic systems. Although we cannot specify with certainty what the future airspace environment will look like, it is expected that complex ATC tasks such as the coordination and management among other sectors, flight flow control, conflicts detection and resolution, weather, etc, should occupy more of the controller concerns, not only in the maintenance of safety of flights but also in the management of flight operations. However, until fairly recently, the limitations of existing single user desktop systems have restricted the potential to improve teamwork for ATCos, when new task requires more corporations, sometimes, more participators from multiple sections and specialization.

Collaborative decision-making can be promoted by providing group members with equal access and direct interaction with digital information, displayed on an interactive table surface, required to solve the task. The sensor configuration for the inactive surface, as shown in Figure 4.8, maybe be extended to create alternative techniques, for an example, they may be utilized as a special input device for developing novel attention focus displays: when visual performance output in local zone can be operated with point interaction features by controlling luminance, colour contrasts, depth cues, or even additional textual information, or anything else that computers are usually able to display.

In addition, Apple Computer Inc. has already made similar advanced multi-touch technology commercially available, firstly for the recently released iPhone, iPod Touch, MacBook Air, and soon afterwards, on its MacBook and MacBook Pro series of laptop computers. The multi-touch works both directly on a touch-sensitive screen (e.g. iPhone) and on a track-pad (e.g. MacBook Air) Apple has developed a list of multi-touch gestures that combine thumb and finger actions into combinations called ‘chords’. The meanings associated with each of these chords can be modified and re-configured by the user [70]. Figure 4.13 shows the ‘pinch’ gesture used to re-size a displayed picture.
4.3 Non-touch Interaction and 3D Visualization

The possibility of visualizing and interacting with a three-dimensional model while immersed in a virtual environment provides ATC with a potentially naturalistic way of managing ATC tasks. Such a configuration allows highly interactive visualization and control of a 3D scene, enabling users to interact in a similar way to how they would interact with everyday environments. By giving controllers an effective perception of the features under observation, their understanding can be considerably enhanced.

Unfortunately, most 3D user interfaces for immersive and semi-immersive virtual reality applications suffer from poor usability, and make for rather user-unfriendly interaction. In this context, the choice and the integration of input devices, as fundamental components of immersive 3D user interfaces, are very important. Simple and non-obstructive tools, by freeing users from cables and wired devices, can provide an intuitive means of interacting with data of interest.

Voice control is now capable of controlling all features of the system (with the exception of some more complex navigational tasks) and for selecting aircraft and performing routing operations on them without recourse to a static keyboard or complex button combinations [59]. The voice recognition system can be implemented using a small program developed using the Microsoft Speech Application Programming Interface (SAPI), which provides facilities for the development of applications using discrete voice pattern recognition system. SAPI has been developed from the voice recognition research and development of Lernout and Hauspie which was acquired in a strategic partnership by Microsoft in 2000. The voice recognition program executes on a separate PC system and communicates with the main
application using TCP sockets to send simple text commands to control the features of the application.

Through such developments, the addition of voice control to the 3D visualization display system in ATM has opened up the possibility of reducing the number of commands which must be mapped onto the 3D interaction devices, as shown in Figure 4.14, while reducing the use of a keyboard to control the entire system. The exploitation of carefully selected voice controls frees the user to work within the VR environment using little or no hand-based interaction. It is hoped that improvements in this area will permit safer and more efficient management of more aircrafts over a wider airspace. This makes for a very relaxed working environment for the controller without recourse to a keyboard. The controller can use the voice system to switch on and off all of the visual display features of the system, to control some of the simpler navigation using commands to rotate, elevate and zoom the camera, and also to focus on specific flights. However, more complex navigational and interaction tasks, such as selecting a flight and manipulating the waypoints defining a planned flight path, still rely on the use of a 3D wand. The researchers are currently exploring methods and commands which might make even these functions available through the voice interaction system.

![Figure 4.14 Combination of voice and Tablet-PC image](image)

We are considering the use of a wireless, ergonomic and intuitive device in future ATC systems – the Nintendo Wii controller, for tasks that involve the actions of manipulating and pointing. The Wii Remote (colloquially ‘Wiimote’) controller was announced by Nintendo in September 2005 as an interface for the Wii games console (see Figure 4.15) [71]. The Wii Remote distinguishes itself from more conventional games controllers in that it has a built-in
accelerometer to measure accelerations in the X, Y, and Z axes, and an infra-red sensor for accurate pointing. The main feature of the Wii Remote is its motion-sensing capability, which allows the user to interact with and manipulate items on screen via movement and pointing by means of the accelerometer and infrared sensor technologies. The motion-tracking abilities of the Wii can provide a strong immersive experience in terms of sensory perception, reality of the movement in the virtual environment. This type of experience is best encapsulated by games which simulate sports such as tennis, bowling, baseball and boxing. Calculations, which include the effects of gravity, were used to determine the relative rotations and velocities.

The Wii Remote is a wireless device which uses the Bluetooth standard for two-way communication to other Bluetooth devices, including PCs. Up to 4 controllers can be used with same Wii console at the same time. The Wiimote also has 9 buttons, including a D-pad (which is a 4-button composite control) and a trigger control (located underneath and operated with the index finger). Conventional, single-handed usage involves holding the controller with the infrared camera on the front-panel pointed away from the user and towards a Sensor Bar. The controller also has a speaker and provides limited haptic (rumble) feedback.

The interactive features we have identified in our research thus far include the following:
• Object rotation / translation – to visualize the 3D model from all possible points of view;
• Zoom in / out – to better focus regions of interest;
• Object cropping – to remove inessential detail and view relevant elements;
• Pointing – to point out a precise point of the visualized data;
• Control at run-time of the depth perception – to move inward / outward the object in the virtual space.

The starting point for our own experimental work has been the C# version of the Wiimote communication library written by Brian Peek [72]. This library has been extended to build a stand-alone driver for the Wiimote in a multiple-sensor-bar virtual environment. Information from several unofficial websites has provided accurate technical information enabling us to reverse engineer the functionality of the Wiimote, thus potentially allowing ATC-specific applications to be developed. [73 and 74].

5. DISPLAY CONCEPT INNOVATION

Most computer users are familiar with such 2-dimensional (2D) interface input methods as a keyboard and mouse. And while these 2D input devices, for the most part, are still needed for 2D space and some 3D interactions; they are not applicable to more immersive 3D environments. A major problem with existing display techniques is that they are usually designed with some specific function in mind, meaning that each one will possess different advantages as well as limitations. Thus no particular display will provide a direct match in every respect for the user’s specific requirement. This is especially so when the exact nature of requirements may still be ambiguous at the time of design, or even seemingly unachievable. In our case, for future air traffic ATM we have attempted to exploit and elaborate upon a number of ideas in an imaginary application environment for which research evidence does not yet exist. Such working environments may appear unstable, unimaginable, or unpredictable, but unexpected requirements often emerge from carrying out experiments in such contexts. However, ‘flavours’ of 3D interaction techniques, which refers to the concept of adding features or complexity to a fundamental technique to arrive at some variants of the original technique, can be occasionally used to improve usability and suitability with respect to the relevant situation [75]. Often we are exploiting new concepts for 3D interaction techniques to produce a maximum of intuitive and natural user interface, and immersion in virtual environments, and consequently such flavours can be designed by considering the types of usability problems uncovered when using the fundamental techniques in unfamiliar work environments.
5.1 3D-in-2D Displays

It is in this context that we were funded to research novel display interfaces for future air traffic control. The 3D-in-2D displays we have been exploring were originally conceived as a design that would enable air traffic controllers to maintain global awareness of the traffic situation that is available through the familiar 2D plane view radar display, while at the same time providing selective 3D views of areas of interest. It is hoped that this will help controllers to produce 3D mental reconstructions of the current air traffic situation, and enable both strategic planning and the identification and resolution of any potential conflicts. This technique allows viewers to examine the small items in detail while providing context within the entire information hierarchy. Additionally, smooth transitions between views help users maintain orientation within the complete information space.

The crucial research question is how to enable rapid prototyping of such an innovative 3D-in-2D concept – both in terms of ‘mutating’ existing display techniques as well as novel interaction methods. Figure 5.1 shows how the concept has been implemented using the ARToolkit, an open source software for developing augmented reality applications. Within this prototype, the concept of flavours of 3D interaction techniques were explored, aiming to realize the user interface interaction of direction manipulation. The controller could use a hand to manually select the area of interest as identified from the 2D display, grab it, and present it on the palm of the hand. Similarly, we also prototyped an AR Magnifying Glass on such a 2D display (Figure 5.2) by using a cardboard frame. Thus, as the ‘lens’ is moved over parts of the 2D radar screen, instead of magnifying (in size) the specified region, these lenses could exhibit anything from a 3D representation of the selected area, additional textual information, or any additional relevant data that a computer is capable of displaying. This is a novel visualization technique that will allow us to combine 2D and 3D technologies in such a way that not only compensates for their individual shortcomings but also retains the desirable aspects of the respective display techniques.

![Figure 5.1 Implementation of the AR-in-your-hand](image-url)
Figure 5.2 AR magnifying glass display

We also presented a 3D Wall View prototype aiming to assist in conflict avoidance and resolution, accurately displaying information about each aircraft's position at some future time. Using a suitable combination of the Precision View and the 3D Local View rendered on AR, it was deduced that 3D Wall Views had the potential to convey meaningful 3D representations of localized traffic as precise 2D depth information, especially during holding stack management and approach control. (The two cases are shown in Figure 5.3 and Figure 5.4 respectively.)

Figure 5.3 3D wall view for approach control
The Tabletop Display is a scaled-up variation of the ‘AR in your hand’ concept, and is created by representing the entire sector in 3D and presented over a ‘table-top’ using AR technology. The controllers’ feedback was quite positive; the results indicate that the representations could be a suitable option for displaying information of critical weather phenomena (such as thunderstorms), in particular with regard to volume, extension and spatial position within a coherent spatial configuration. It could be an asset for controllers to support them in decision-making, especially in multi-sector planning tasks. Such displays deliver a rapid representation of airspace volumes and the way they are set out in the airspace; which can be difficult to imagine – can no longer rely on mental pictures, e.g. in the context of complex restricted military airspaces, weather fronts, or indeed combinations of restricted airspace.

An isolated Table Top Display may suffer from position judgment problems. In order to resolve these problems, different ‘tools’ (such as the 3D Wall with altitude ruler) must be incorporated to assess aircraft altitude in a selected part of the airspace. Figure 5.5 illustrates an early paper mock-up of how the 3D Walls could be implemented on the Tabletop Display. The composite display provides the ideal platform for a single controller (or a shared platform for a group of controllers) to analyze and discuss complex air traffic situations, ranging from weather, military, to aircraft collision detection, etc. Further, controllers will be able to obtain useful and accurate 2D information on the particular area of interest, whilst maintaining a global awareness of air traffic situation.
5.2 Natural Human-Machine Interface with Immersive Virtual Reality

Immersive virtual reality approaches have been tried to re-create work environments to enable natural interactions with a system. Such systems however require un-natural extensions such as head mounted displays which stop the user from perceiving cues from the physical world in which he works, or it may require the user to enter a CAVE (Cave Automatic Virtual Environment) in order to experience a lower fidelity replication of the real-world. Such CAVEs often lack the actual physical and verbal cues generated by team members necessary for coordinating the work with one another. It may also require additional shutter glasses goggles to see and interact with virtual artefacts in the CAVE [76]. This also makes it difficult to share and brief one another without having to leave their workstations to such a specialised place which may be rigged with electromagnetic sensors to track the location of the user(s) in order to create the virtual responses to actions such as walking around an artefact to view it from another angle. In work environments, individual information analysis of evidence as well as cooperative activities such as discussions and sharing of evidence, are often engaged in collectively. Any attempt to develop a support system will require that the investigators and analyst are not closed off from the world and the people that they work with. Also that the evidence they have and the analysis they have done on it, be available in a visually persistent way.

In this part, we propose to develop a natural Human-Machine Interface (HMI) that can be deployed in the investigator or analyst’s natural work environment. This will require that the

Figure 5.5 Early paper mock-up illustrating how the 3D wall view display can be used in a 3D space to provide precise altitude information
technology be non-intrusive or at least causes minimal disruption to work in an open office environment, and that it should ideally be un-encumbered technology. To this end, we will attempt to avoid the use of immersive goggles i.e. goggles that block visual contact with the real world, and wire-free technologies that do not tether the user to a particular place due to cables needed for data transmission. We believe that the best approach for meeting these future needs is to combine automated conflict detection and resolution mechanisms with advanced human-computer interfaces that use intuitive and natural 3D displays and 3D controls. This is especially true of our concepts as applied to cockpit display in the Free Flight domain, when discussed in any previous visualization effort. In this case, the 3D view should be egocentric, following an individual aircraft to see the pilot’s perspective, which provides a suitable mode to allow the user to navigate and view the scene in 3-D.

Research at Carnegie-Mellon University and Middlesex University are currently investigating ways of combining different variations of infra-red sensors and infra-red emitters to allow un-encumbered interactions in 3D space. Johnny Lee [77] has developed techniques for using single Nintendo Wii remotes to track two points in a 2D plane in space. On-going work at Middlesex University, originally intended for developing interfaces for future air traffic control, is extending this capability to track four points of IR sources in x, y and z dimensional space. Such a capability will enable 3D drawing and interaction with information generated and presented in 3D spaces to pick up relevant information, flick away unwanted data, snap together connections, can now be applied, albeit in early working prototype form. Such 3D interactivity without the use of goggles or traditional data gloves will enable the creation of information handling processes in a more natural and more compatible way. For example, one will now be able to “reach into the display” and “grab” an area of data that may reside within a set of relationships that may reside within a visual data space. Although the reported work is intended to use goggles and cables, this limitation is being overcome by combining alternatives technologies, such as 3D volume display, Autostereoscopic 3D Displays etc. Such a technology gives an illusion of depth, or to make images appear to change or move as the image is viewed from different angles, without use goggles. The interaction with these different visualisations can be achieved in many different ways, and the 3D-ATC application is provided with different interaction interfaces allowing navigation, selection and manipulation of 3D objects present in the scene, that is, tracked wand, Multi-point touch interfaces, and voice commands, as well recently released iPhone, iPod Touch, MacBook Air, etc. The details of these contents have been explored in Section 3 and Section 4.

Shortcomings in the Natural HMI. We see the following shortcomings in current technologies to create a more natural human-machine interface, which we believe to be important for
creating designs to support SESAR ATC display requirements:

- The current virtual and augmented reality technologies are intrusive, and can obscure or block cues between workers in the natural work environments.
- Current available registration systems often require some form of cabling to connect the sensors in the virtual environment with the display system in particular the goggles used by the operator. This makes it difficult for operators (trainees) to work and cooperate freely with one another.
- Much leading edge work in natural HMI is experimental or has produced laboratory prototypes (except for, perhaps the Apple iPhone or iPod touch), and have yet to be integrated to address the kind of complex real-time 4D spatial-temporal reasoning problems we will encounter in SESAR.

Innovations in the Natural HMI. We will be presented with opportunities for:

- Developing a framework for understanding the solution space for combining different interaction technologies in meaningful ways for use in emergency management training.
- Combining advanced HMI technologies such as the 3D lenticular displays to create for example, fish-tank virtual reality views of data, using IR or similar position tracking systems, which can be prototyped using devices such as the Nintendo Wii remote.
- Eliminating the need for ‘tethered’ devices that limit the movement of the worker; and enclosed goggles that obscure significant cues that occur in the real-world, by using technologies such as multi-touch interaction, and 3D-gestural interaction.

We have the following plans to continue developing the visualization and interface techniques for aiding the future free flight:

- A strong immersive experience in sensory, action and mental,
- Smooth viewpoint transitions aid spatial awareness
- A user-friendly natural interaction way, and
- Flexible maneuvering controlling in aircraft heading orientation and velocity in aircraft scenario, and
- Visualizing conflicts and solutions

Such displays offer the potential to reduce the cognitive workload on both pilots and controllers, resulting in faster recognition and improved situational awareness of the air traffic situation, potential conflicts and solution.
6. CONCLUSIONS

The most fundamental aspect in the future development of flight control is the transition from reliance on a central ground control-base – where all messages, signals and instructions that are passed between individual aircrafts are first received and/or relayed via this ground base; to a more automated and independent system whereby individual pilots in air are able to make such decisions for themselves, resorting to ground control only when absolutely necessary. This increased level of independence and pilot-centric system is predicted to decrease data volume, reduce redundant data etc, thus increasing flight control efficiency, amongst numerous other advantages. We believe the best course of action for meeting these future needs is to combine automated conflict detection and resolution mechanisms with advanced human-computer interfaces that use intuitive 3D visualization displays and interaction controls.

The report recognized the importance of “interaction”: both in terms of visualization displays – concerning the accuracy, the method, the accessibility etc; and also in terms of human-computer interaction – the most efficient, the most convenient, and the most accurate ways to access and retrieve required information. Within the air traffic control community, these novel alternative display efforts have evolved into the four key categories of: Navigation and control of air route in air traffic management; 3D visualization and interaction in air traffic control; Focus of attention and multimodal information display; and Interactive collaborative environments for ATM. It is therefore fitting this is precisely the area in which our focus is placed.

We have selected and reviewed a number of alternative display concepts in terms of the kind of visualisations they provide, multimodal interactivity, and a couple of innovations such as the 3D-in-2D displays. We also introduced the notion of “Future Design” and the framework that can help us reason about the nature of ATC work under SESAR Level 3 ATM Capability that has yet to be realised. More importantly, through Future Design, the review will provided us with further opportunities to exploit the combination of various visualisations with interaction modalities, to give rise to new and potentially innovative techniques which will be investigated further within the 3D-in-2D ATC Displays project. It is clear that innovations are continuing in this field, examples include how to construct more interactive, self-interacting, “natural”, displays that can change and focus according to the user’s angle of perception. Various touch and non-touch technologies were compared, including the functions newly commercialised Wii and the realism provided by the Wii remote as judged when used in conjunction with Wii games. Further, our report centred on how to combine new 3D visualization display technology with interactive technology, together into a
realistic information display environment, presenting the ATM controller, or pilot with a more flexible, more natural mode, complete with the motion sense provided by the Wii remote, and in-built motion-sensor, in order to provide a more comprehensive understanding of flight formation. Future work performed on this basis is still ongoing.

7. REFERENCES

32. http://sunvay.net/
33. http://www.business-sites.philips.com/3dsolutions/about/Index.html
38. http://www.sensegraphics.com/,
41. O’Sullivan, C., Dingliana, J., and Howlett, S. Gaze-contingent algorithms for interactive graphics. The Mind’s 42. R. Komerska and C. Ware, “Haptic Task Constraints for 3D
42. Eyes: Cognitive and Applied Aspects of Eye Movement Research. J. Hyönä,
54. H. Z. Tan, R. Gray, J. J. Young, and P. Irawan, "Haptic cueing of a visual change-detection task: Implications for multimodal interfaces," in Usability Evaluation and
63. SmartSkin: An Infrastructure for Freehand Manipulation on Interactive Surfaces Jun Rekimoto

68. Experiences with and Observations of Direct-Touch Tabletops, Kathy Ryall, Meredith Ringel Morris, Katherine Everitt, Clifton Forlines, Chia Shen, Mitsubishi Electric Research Laboratories, Cambridge MA, USA, 2Stanford University, Stanford, CA, USA, 3University of Washington, Seattle, WA, USA


70. Kathy Ryall, Meredith Ringel Morris, Katherine Everitt, Clifton Forlines, Chia Shen, Experiences with and Observations of Direct-Touch Tabletops, Mitsubishi Electric Research Laboratories, Cambridge MA, USA, 2Stanford University, Stanford, CA, USA, 3University of Washington, Seattle, WA, USA


74. WiiLi, a GNU/Linux port for the Nintendo Wii, http://www.wiili.org


76. http://www.cs.ucl.ac.uk/research/vr/Projects/Cave/


79. Andrew Jones Ian McDowall? Hideshi Yamada† Mark Bolas‡ Paul Debevec, Rendering for an Interactive 360_ Light Field Display , To appear in the ACM SIGGRAPH conference proceedings