2005

Near-To-Eye Display and Augmented Reality Concepts for Air Traffic Tower Controllers: Issues and Challenges

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NEAR-TO-EYE DISPLAY AND AUGMENTED REALITY CONCEPTS FOR AIR TRAFFIC TOWER CONTROLLERS: ISSUES AND CHALLENGES

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Tower controllers are responsible for maintaining safe separation between airborne aircraft in the airport traffic control area, and separation between aircraft, equipment, and personnel on the airport surface. In this paper, we summarize recent work to develop and evaluate user-acceptable hardware and software solutions that will reduce diversions and augment or enhance controller capabilities, especially in limited visibility conditions. We characterized controller tasks where a near-to-eye display and augmented reality techniques can aid controller performance, and identified form factor variables that influence user acceptability of hardware configurations. We developed an out-the-window concept of operation and analyzed the hardware requirements and feasibility of three near-to-eye viewing systems: two head-mounted monocular displays and a held-to-head binocular display. When fully developed, these display systems should enhance tower controller situation awareness, and reduce such distractions as having to frequently attend to and respond to head-down (console) display information. There are potential users of this display system concept in all branches of the military services and in the commercial sector, and potential utility for surface surveillance operations in support of homeland security, law enforcement, search and rescue, firefighting, and special operations.

Introduction

Air traffic controllers in the tower environment are responsible for control of traffic on the ground and in the air within the airport traffic control area. Ground control, departure and arrival sequencing, and surface management are continuous challenges. Tower controllers live in an information-rich world, processing data from a multitude of sources. The controller must maintain situation awareness (SA) while assimilating information from such sources as out-the-window observations; scanning of head-down displays; audio management and interactions between aircrews; departure, arrival, and traffic pattern management; ground operations management, interaction between other controllers, and flight data strip management.

Controllers must frequently divert their attention away from the external scene, which could impair safe and effective operations, as the controller is the ultimate decision and management authority on an airfield. In this paper we discuss recent work we conducted in this area that was sponsored by the Air Force, and which built on the results of our previous work with the Federal Aviation Administration (FAA). The focus of the effory is to develop and evaluate user-acceptable hardware and software solutions, using near-to-eye display and augmented reality (AR) techniques and concepts, that will help reduce diversions and augment or enhance tower controller capabilities, especially at night and in limited visibility conditions.

Tower Controller Positions

The two key tower controller positions in military and civilian towers are the *Local Controller* (LC) and the *Ground Controller* (GC). The LC is primarily responsible for handling arriving and departing traffic at the airport. The LC area of responsibility includes the active runways and the airspace within a 5-mile wide radius of the airport. Generally, the LC position interfaces with Ground Control and related tower positions. The GC is primarily responsible for directing aircraft to and from the runway. The GC is also responsible for directing other aircraft/vehicular movement on the airport movement area and disseminating information to support operations (e.g. traffic, weather, equipment status, delays/flow, flight plans, etc.). Clearly, the tower environment is a dynamic environment in which the LC and GC must adjust traffic flows, evaluate new information, and closely coordinate and communicate their efforts.

Information Sources

Tower controllers obtain information required to perform their duties from many sources. Information on individual flights and their intended airborne or ground path is transferred to the controller through the use of flight progress strips, surface map displays, and verbal communications. The primary source of information regarding aircraft location is the out-the-window view from the tower. However, the controller must continually monitor a large number of console displays that provide information on local weather conditions, as well as arrival and departure information that must be relayed to pilots as needed. This must be correlated with communications between the controller and the aircraft or other air traffic control (ATC) facilities.

To acquire and maintain situation awareness, controllers must know at a minimum, aircraft and ground vehicle identity, location, and intent (Piccione, Krebs, Warren, and Driggers, 2002). A critical part of the task of knowing aircraft location and intent is the ability to identify the specific aircraft that are being controlled. This capability is augmented at some facilities with radar displays that show the identity and location of aircraft in the airspace surrounding the airport. At larger airports, ground surveillance radar provides information regarding objects on the airport movement area. An example of a ground surveillance radar display is the current Airport Surface Detection Equipment-X Series system (ASDE-X).

Flight progress strips are used at some facilities as an analogy for the flight and are manipulated on the console during the hand-off process between tower positions. They provide detailed flight information for each departure aircraft, including the aircraft type, first departure fix, flight plan, and flight identification (ID) of the aircraft. The strips are marked with updated information as an additional means of information storage and transfer. Taken together, the ASDE-X map display, flight strips, and the Digital Bright Radar Indicator Tower Equipment (D-BRITE) display (a repeater display of the terminal radar control [TRACON] display) provide a good picture of the current state of the terminal airspace and airport surface, and help the tower controller build situation awareness from multiple look-down sources.

The controller must use a scan pattern outside and inside the tower to assimilate, correlate, and integrate information to build and maintain situation awareness. The information inside the tower is presented on a variety of displays that may be imbedded in the console, placed on the console as a freestanding unit, or mounted overhead of the tower windows. The controller must determine what information is needed, retrieve that information from displays throughout the tower cab, and mentally integrate the information. Tower controllers frequently cite problems associated with the requirement to use large scan patterns inside the cab that detract from their out-the-window task of monitoring the airspace, runway, and airport movement area (taxiways and ramps). These types of typical display options currently used in a control tower all require distance viewing across a wide field of regard. This presents a challenge where user-centered solutions that reduce look-down time and improve information management for controllers would be beneficial.

Effects of Reduced Visibility

The out-the-window scene is severely degraded during night and limited visibility conditions. When visibility is restricted, controllers may be able to maintain some degree of SA by following established procedures and forming expectations of key events. However, their overall SA is still significantly degraded. Controllers must establish and maintain a mental image of the airport layout, and use graphical aids (e.g., taxiway diagrams) and position reports to determine the location of aircraft and other objects on the surface, and form expectancies of where an aircraft or vehicle should be (Piccione et al., 2002).

Potential Solutions

Two potential solutions for increasing SA, enhancing safety, and increasing throughput under daytime and limited visibility conditions are (1) to supplement the controller's visual capabilities with an Enhanced Vision System (EVS), and (2) to provide the controller with a display with text and symbology overlaid on key elements of the out-the-window, video, or EVS scene to augment the perception and understanding of the scene. The visible or EVS scene can be presented on such display devices as a head-mounted monocular display (HMMD) or a held-to-head binocular display (HHBD). An EVS can restore some of the critical visual capability that may be lost or severely reduced due to darkness or reduced visibility.

A recent study by the FAA (Piccione et al., 2002) investigated the use of electro-optic sensors to enhance tower controller visual capabilities during poor atmospheric or low-illumination conditions. The field data and modeling results suggest that using a long wave infrared (LWIR) sensor could improve controller nighttime detection, recognition, and identification of obstacles/targets on the airfield surface. Critical issues included the sensor's field-of-view, the field of regard, the mechanism for mounting the sensor(s), the display medium (e.g., head-down vs. head-mounted), and the need for a head-tracking system versus fixed sensor (camera) positions.

Need for a New Display Paradigm

Tower controllers may benefit from a near-to-eye augmented reality display that allows a continuous head-up, out-the-window view of the runway and eliminates, or greatly reduces, the time-consuming scanning, frequent eye accommodation changes, and cognitive integration currently required to access this same data on head-down displays. We examined what are called “near-to-eye” displays because such systems provide electronic and miniaturized viewing capabilities in a display placed generally within one inch from the viewer’s eye.

The use of a near-to-eye held-to-head or head-mounted augmented reality display would allow the presentation of context-sensitive information and the “scene-linking” of text or imagery that can cue the presence of aircraft and highlight the location of runways, thus improving overall ground safety. As discussed previously, these safety benefits can be significant in low visibility conditions, in which scene-linked imagery may highlight the location of planes or vehicles on a visible video or EVS mage that the controller may not be able to otherwise see directly.

Research Objectives

Our research has three objectives:

(1) To understand tower controller surveillance tasks, and how near-to-eye displays and AR and EVS techniques relate to these tasks.
(2) To analyze the technical requirements (e.g., tracking, resolution) so a feasible design of required display capability can be developed.
(3) To understand the form factors as well as the technical and social challenges for implementing such a display system.

Technical Approach and Findings

Tower Controller Tasks

Our first task was to gain an understanding of the tasks performed by tower ground controllers and local controllers, the information they need to perform these tasks, and the sources of this information. We reviewed the available technical literature to identify relevant studies. Key findings from earlier studies, as well as findings from our previous work on EVS requirements for tower controllers, are discussed in Ruffner, Deaver, and Henry (2003) and Ruffner, Fulbrook, and Foglia (2004). Relevant findings from two recent studies sponsored by the FAA and the National Aeronautics and Space Administration (NASA) are summarized below.

*FAA Tower Controller Study***.** The FAA recently conducted a study to examine factors contributing to the complexity of tower controller tasks (Koros, Della Rocco, Panjwani, Ingurgio, and D’Arcy, 2003). This study produced data on tower controller decision-making strategies, information requirements, and information sources for both the LC and GC positions.

The most important information *elements* common to the LC and GC, in descending order of importance, were: (1) aircraft position, (2) aircraft identification, and (3) route to be followed during taxi operations. The most common information *sources* were: (1) out-the-window visual observation, (2) flight strips, (3) communication with the pilot, and (4) the D-BRITE radar display. Visual observation was considered the first or second most important source of information for over 60% of the information elements.

*NASA Surface Management System Study***.** Under NASA sponsorship, researchers from Booze, Allen, and Hamilton, and Ohio State University conducted a human factors assessment of the developmental Surface Management System (SMS) (Hitt, Duley, Kressen, Mafera, Smith, and Spenser, 2002). SMS is being developed as a decision support tool that provides controllers and airline personnel with aircraft-specific information and predicted departure demand information.

Both LCs and GCs desired aircraft identification and flight-specific information to be presented via data blocks on a surface map display similar to the ASDE-X display. The specific information provided, as well as the desired area to be covered by the map display, depended on the controller position. This result reflects the controllers’ need to have integrated information in one location. Display clutter (i.e., excessive text and graphical information) was identified as a critical issue Because tower controllers interact with each other frequently to exchange information, the respondents judged that the displays need to be clearly visible to all tower controllers, and that the display designs need to be standardized in their use of color-coding and symbology.

In addition, the SMS study identified the primary tasks and subtasks for the ground and local controller positions, and developed procedural flow diagrams for the LC and GC tasks. The project report describes the tasks to be executed and the times where decisions were required for the tasks (e.g., Maintaining Runway

Balance) and subtasks (e.g., Determine Delay to Runway Threshold). In addition, the report lists the information requirements (e.g., aircraft type, aircraft identification) for each task and subtask, and the source(s) from which information can be obtained (e.g., out-the-window, map display).

Technical Issues

There are several technical issues that must be resolved for a near-to-eye augmented reality tower controller display concept, capable of interfacing with an EVS, to prove feasible and practical. These issues include the minimum acceptable field-of-view (FOV), resolution, sensing and head tracking requirements, and the implementation strategy for selecting and superimposing text and symbology on the out-the-window display field-of-view.

Display Field of View and Resolution. Field of view and resolution are key parameters of any head-mounted display system, and often are traded off during the design decision making process. Studies of pilot performance with head-mounted displays (HMDs) indicate that wider FOVs generally result in better performance and situation awareness. Our analysis indicated that, in general the field of view for a tower controller HMMD/HHBD should be variable; a typical wide angle to telephoto range (e.g., 28 mm – 200 mm, or with a visual angle of approximately 10 to 100 degrees) is desirable. Both the HMMD systems and HHBD systems we evaluated appear to have sufficient FOV and resolution. Specifically the HHBD (NVIS Virtual Binocular™) has a FOV of 40 degrees diagonal, and the HMMDs have FOVs of 23 x 17 degrees (Microvision Nomad™) and 16 x 12 degrees (MicroOptical SV-6 PC Viewer™) respectively. All displays have a minimum of 800 x 600 pixel resolution. In short, all the displays appeared to have sufficient, effective visual presentations.

Augmented Reality. AR techniques allow the visualization of complex data by superimposing supplementary information relevant to the task at hand, which is referenced to the real world. AR display enhancements to support operator tasks include presenting cueing information to guide attention throughout the visual scene, and providing supporting textual or graphical information. AR displays let users see the surrounding real world and augment their view by overlaying 2-D or 3-D virtual objects on or near their real world counterparts to create the impression that virtual and real objects coexist (Azuma, 2001).

AR display issues include: (1) registration (aligning objects in the real and virtual scene), (2) sensing (detecting and identifying objects in the environment), (3) latency (lag between the display presentation of the actual and displayed event), and (4) head tracking. In a static AR environment, the real-world objects must be carefully modeled to capture their geometry so that virtual objects are properly aligned with real objects in the scene. In a dynamic AR environment, such as in the ATC tower, position and orientation of moving objects must be continually updated in the scene-graph so that virtual objects are correctly rendered and registered. The timeliness and accuracy of the information is of paramount importance (Martinsen, Havig, Post, Reis, and Simpson, 2003).

Display Symbology. An AR display concept involves superimposing text and screen-referenced or scene-linked symbology on an out-the-window scene similar to what is done with an aviation or automotive head-up display (HUD). A HUD eliminates, or at least minimizes, the need for refocusing and for extensive eye scan movements between panel-mounted instruments and the out-the-window visual scene. Dividing attention across stimuli belonging to separate "domains" or perceptual groups (e.g., a digital altimeter vs. a wire-frame outline of a tank linked to a feature in the visual scene) can lead to attention narrowing, This effect is reduced somewhat with scene-linked, or conformal symbology (Yeh and Wickens, 2001).

There are two key challenges to display/real-time imagery integration. The first is providing screen-referenced text and symbology that presents information related to the scenes and real-time events as they unfold during normal duty performance (e.g. wind direction). The second is the more difficult challenge of providing scene-linked text and symbology information that directly links an object or event appearing in the display with the text/symbology information as it is dynamically presented. An example is that if an aircraft is taxiing on the airfield and the display is directed to gaze on the aircraft, identifying symbology will be automatically presented and tagged to the aircraft. Moving the gaze to another aircraft will cause the display to recognize, retrieve, and present a new set of data.

Critical essential information for scene-linking includes: aircraft identification (ID), surface vehicle type/ID, aircraft position (runway, taxiway location), and flight plan data (departure runway, location fixes, destination, etc.). Achieving augmented reality capabilities in a near-to-eye display involves the integration of sources into an interactive and dynamic presentation that enhances a user's situation awareness and task capabilities without overloading the person. This scene-linking represents a level of technological capability that has not been reliably demonstrated for similar situations to date.

Development and Implementation Issues

Display Concepts. We investigated two different display concepts: (1) an optical see-through head-mounted display (see Figure 1) and (2) a held-to-head simulated binocular video see-through display (see Figure 2). Both display concepts can provide users with either screen-referenced or scene-linked symbology using near-to-eye display technology. The main difference between these two approaches is how the user interfaces with and interacts with the display. In the first case, the symbology is optically superimposed on the real world scene. In the second case, the symbology is superimposed on a video image of the real world scene. There are strengths and weaknesses for each approach, and technical challenges that must be overcome to make either one work (see Rolland and Fuchs, 2001).

Figure 1. *HMMD optical display concept.*

Form Factors and User Acceptability. We understand "form factor" here to mean the physical platform or mechanism that serves as the host for the display, or into which the display is attached or integrated. Even the most technologically sophisticated ATC display concept will not be used by tower controllers if it is too heavy, cumbersome, intrusive, or otherwise difficult to use. Accordingly, a fair question for either display concept is "Will controllers actually use one of these devices for extended periods?" The answer will likely be reduced to the issue of whether the advanced capabilities and benefits afforded by the technology offset the problems and costs induced by the encumbrance and potential sensory conflicts. Good human factors and ergonomic deign will be critical for achieving user acceptance.

Figure 2. *HHBD concept with thermal imagery.*

Augmented Reality Symbology Issues. A key issue is the type, amount, and placement of overlaid text and symbology, and the potential for information overload. There are guidelines for selecting and displaying imagery on aircraft HUDs for aircraft in-flight and surface operations (e.g., Mejdal, McCauley, and Beringer. 2001). However, it is not known how well the guidelines generalize to the tower cab environment. A new guideline development effort will likely be needed. Another issue is controller reaction to potential degradation or complete failure of a see-through HMMD or HHBD visual scene during operations.

Concept of Operations (CONOPS). Figure 3 and Figure 4 illustrate how the displays and symbology might appear and be used in an operational tower environment. Illustrated here are a daytime out-the-window situation (Figure 3) and night/low visibility condition situation using an EVS (Figure 4).

Conclusions

A near-to-eye display solution is feasible for air traffic tower controllers, especially when coupled with AR and EVS technologies. There are unique benefits to both HMMD and HHBD solutions and potential for the two systems to work together, as well as individually, in the tower cab environment. However, there are significant design, engineering, integration, and usability issues and challenges to achieving a solution that must be met. Our future efforts will involve developing a fully functional prototype AR display system, integrating the display system with available information sources, and conducting a usability assessment.

Figure 3. *Daytime display CONOPS.*

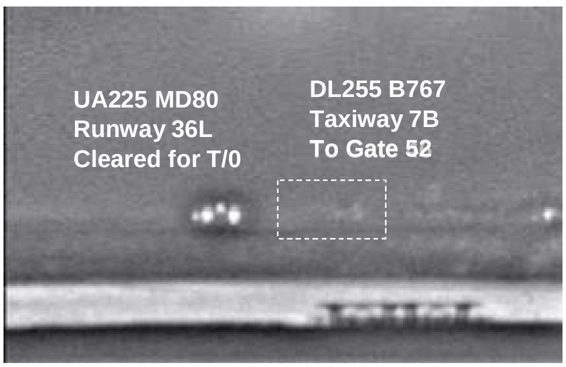

Figure 4. *Night/limited visibility display CONOPS*

Acknowledgments

This work was funded through an Air Force Phase I SBIR Phase I project, Contract Number F33615-03-M-6363, Dr. Peter Marasco, Air Force Research Laboratory, Wright Patterson AFB, OH (Technical Monitor), as a follow-on to FAA Contract GS-23F-0303K, Dino Piccione, (Technical Monitor). The authors acknowledge the assistance of Dr. D. Michael McAnulty, FAA, and Dr. James Hitt of Booz, Allen, and Hamilton. The statements made in this paper reflect the opinions of the authors, and do not represent the position of the U. S. Air Force, the FAA, or DCS Corporation.

References

Azuma, R. T. (2001). Augmented reality: Approaches and technical challenges," In W. Barfield, & T. Caudell, (Eds.). *Fundamentals of Wearable Computers and Augmented Reality*. Lawrence Erlbaum Associates, Inc., Hillsdale, NJ.

Hitt, J. M., Duley, J., Kressen, S., Mafera, P. Smith, P., & Spenser, A. (2002). *Air traffic management and system development and integration: Surface Management System human factors assessment,* National Air and Space Administration, Washington, DC.

Koros, A., Della Rocco, P. S., Panjwani, G., Ingurgio, V, & D'Arcy, J. F. (2003). *Complexity in air traffic control towers: A field study. Part 1 - Complexity factors.* (DOT/FAA/CT-TN03/14), Federal Aviation Administration William J. Hughes Technical Center, Atlantic City, NJ.

Martinsen, G. L., Havig, P. R., Post, D. L., Reis, G. A., & Simpson, M. A. (2003). Human factors requirements of helmet trackers for HMDs. *Proceedings of the SPIE Helmet- and Head-Mounted Displays VIII: Technologies and Applications Conference,* pp. 95-103, Vol. 5079, Bellingham, WA: The International Society for Optical Engineering.

Mejdal, S. McCauley, M. E., & Beringer, D. B. (2001). *Human factors design guidelines for multifunction displays* (DOT/FAA/AM-01/17). Washington, DC: Office of Aerospace Medicine, 2001.

Piccione, D, Krebs, W. K., Warren, P, & Driggers, R. G. (2002). Electro-optic sensors to aid tower air traffic controllers. *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting,* pp. 51-55, Santa Monica, CA: Factors and Ergonomics Society.

Rolland, J. P., & Fuchs, H. (2001). Optical versus video see-through head-mounted displays. In W. Barfield, & T. Caudell, (Eds.). *Fundamentals of Wearable Computers and Augmented Reality.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Ruffner, J. W., Deaver, D. M., & Henry, D. J. (2003). Requirements analysis for an enhanced vision system for air traffic control tower surface surveillance. *Proceedings of the SPIE Enhanced and Synthetic Vision Conference,* Vol. 5081, pp. 124-135, Bellingham, WA: The International Society for Optical Engineering.

Ruffner, J. E., Fulbrook, J. E., and Foglia, M. (2004). Near-to-eye display concepts for air traffic tower controllers. *Proceedings of the SPIE Head- and Helmet-Mounted Display Technologies and Applications,* Vol. 5442, pp. 120-131. Bellingham, WA: The International Society for Optical Engineering.

Yeh, M. & Wickens, C. D. (2001). Display signaling in augmented reality: The effects of cue reliability and image realism on attention allocation and trust calibration. *Human Factors.* Vol. 43, pp. 355-365. Santa Monica, CA: Human Factors and Ergonomics Society.