Probability Grid Mapping System for Aerial Search

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***Abstract*—Aerial search for targets on the ground is a challenging task and success depends on providing proper intelligence to the searchers. Recent advances in avionics enhanced and synthetic vision systems (ESVS) offer new opportunities to present this information to aircrew. This paper describes the concept and implementation of a new ESVS technique intended to support flight crews in aerial search for search and rescue missions and other guided search scenarios. Most enhanced vision systems for aviation have targeted the pilot in order to support flight and navigation tasks. The Probability Grid Mapping system (PGM) is unique in that it aims to improve the effectiveness of the other officer in the aircraft who is managing and performing the tactical mission. The PGM provides the searcher with an augmented, conformal, digital moving map of the search area that encodes the estimated probability of the target being found in various locations. A priori estimation of these probabilities allows for prioritization of search areas, reduces search duplication and improves coverage and ideally maximizes search effectiveness. The conformal 3D map is displayed with appropriate perspective projection using a head-slaved optical see-through head-mounted display allowing it to be registered with and augment the real world. To evaluate the system prior to flight test, a simulation environment was developed for study of the effectiveness of highlighting methods, update strategies, and probability mapping methods.**

Keywords-component; Enhanced Synthetic Vision Systems; Search and Rescue Operations; Aerial search; Optical See-Through HMD; Augmented Reality

I. INTRODUCTION

Augmented reality (AR) systems add synthetic elements to the user's view of a real scene, typically through specialized displays such as a see-through head-mounted display (HMD). The goal is to add the synthetic entities in such a way that they become perceptually integrated into the user's perceptual 'reality'. The user of such a system perceives and interacts with the real world, but has valuable additional information, such as descriptions of important features or instructions for performing physical tasks, superimposed on the world [1]. Such techniques have proven effective in many domains including aviation [2], medicine [3,4], military training [3,5] and manufacturing [3].

Piloting an aircraft and working from an aerial platform can be demanding perceptual and cognitive tasks. Military aircraft pilots have relied on heads-up displays and sophisticated sensors such as night vision and thermal imaging equipment to aid in their missions for decades. These capabilities have increasingly become available in civilian aviation especially in areas such as policing or search and rescue [6]. Recently, augmented reality systems have been developed for fixed- and rotary-wing aircraft that are known as enhanced synthetic vision systems. The goal of these systems is to augment and extend the pilot's visual and cognitive capabilities based on data from other sensors, navigation instruments and geospatial databases. The concept dates from at least the 1950's [7,8] and has become feasible in recent years. Particularly, relevant to the current paper is the Canadian ESVS demonstrator project in the mid-1990's. This system used synthetic vision to produce artificial views of the world based on terrain databases to support navigation and situational awareness in adverse weather conditions [9]. The present paper describes the concept and implementation of a new ESVS concept intended to support flight crews in aerial search for search and rescue (SAR) missions and other guided search scenarios.

Aerial search can be challenging, particularly when the target does not wish to be found. For instance, some persons with dementia are at risk of wandering away from their homes becoming lost and confused. Such a situation can be life threatening particularly in extreme cold or heat making an effective and timely search essential. Fear and disorientation can sometimes cause these individuals to avoid detection.

Typically police helicopter search and rescue or surveillance operations are done in teams of at least two in the aircraft. One person typically flies the aircraft and assists with the search while the other is primarily responsible for performing the operational task. Most enhanced vision systems for aviation have targeted the pilot in order to support flight and navigation tasks [5,6], with the notable exception of military weapons targeting. The system described here is unique in that it aims to improve the effectiveness of the other officer in the aircraft who is managing and performing the tactical mission, in this case the search task.

II. PGM System Concept

The Probability Grid Mapping System (PGM) aims to make the search task easier and more effective by supplying the searcher with an augmented digital mapping system for the search area. The goal of PGM is to superimpose indicators of search probability directly onto the user's view of the real world as they search. The symbology is conformal and geographically referenced so that it remains fixed to the appropriate portion of the real world terrain as the aircraft travels or pilot moves their head.

The goal is to have markers to direct the searchers' scanning activity without obstructing their view of the terrain to be searched. Ideally, these markers would reflect both the a priori search estimates and be dynamically updated to reflect the probability of finding the target in given areas as they are covered and searched during the flight. By presenting the symbology in an ESVS display, the searcher can automatically associate markers that code the search priorities with physical locations.

This augmented reality can help automatically guide the searcher's scan behaviour to high probability regions by providing fixation cues and visual highlights to attend to. Presenting the display as a geo-referenced augmented reality also avoids the need to look, interpret and transform data presented on traditional paper maps or 2-D moving map displays into coordinates in the scene viewed out the window.

The view of the real world can be either direct as in the current implementation or could be itself an ESVS display based on sensors such as LIDAR, infrared cameras and other sensors.

Challenges in implementing this vision include the typical challenges of effective and precise augmented reality—tracking, latency, registration, world modeling, and so on—as well as the requirements of effective highlighting of the areas to be searched without interfering with the search process within those areas. This paper describes a prototype implementation that embodies much of the PGM concept for evaluation of the concepts in both simulation and in real aircraft.

III. PGM Implementation

"Fig. 1", shows a block diagram of the PGM system. As an aviation AR system, the PGM must present synthetic data appropriate for the current aircraft location and in the context of standard operating procedures for airborne search. The system relies on a helmet-mounted display to present the augmentation to the user, sensors on the helmet and aircraft to estimate the current pose, and databases of terrain to be flown over and of search probability estimates. The PGM System integrates four different sources of data: head position and orientation data, navigation data, terrain data and input search data and fuses these to present the required highlighted probability map augmentation, registered with the real world, onto the see-through HMD.

We have developed two variants of the PGM, one for integration into a research helicopter platform and the other for integration in a simulation environment. The actual flight testing is designed for the National Research Council of Canada NRC Bell 412 helicopter, where the NRC provides the helicopter and the crew for testing the PGM system.

A. Probability Maps

The PGM system provides searchers with probability of target locations. The probability is estimated by the search coordinator or equivalent on the ground based on data obtained about the situation. "i.e. the last place the person has seen, or if any areas has been already searched, etc". The map is displayed using a see-through head HMD to augment it with the real world.

Providing the searcher with an optical see-through HMD allows them to see the real world highlighted with different colours while the helicopter is flying over it. For each region of the search area, a probability of detection (in the region) is estimated and the colours are assigned to code the likelihood of detection in the area. Table 1 illustrates the five different colours currently used in the PGM system with their probability ranks.

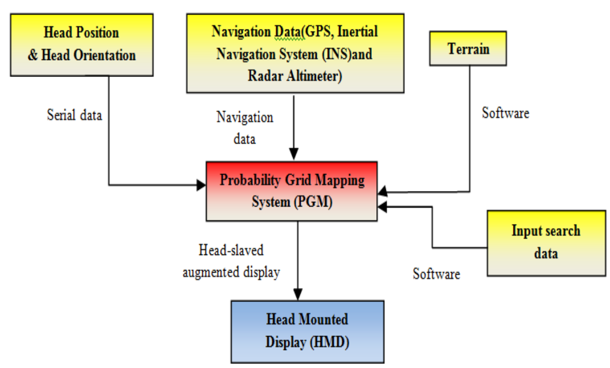

Figure 1. Block diagram of the PGM system.

TABLE I. The priority of the search area in the PGM system is displayed using one of the different colours. Red indicates the highest priority search area.

Probability Ranks	Colour
1	Red
2	Yellow
3	Pink
4	Orange
5	Purple

These colours were chosen based on their ease of discrimination from natural vegetation and terrain colouring. The probability ranks could be interpreted literally as the expected likelihood of finding the target within the coloured area. Alternatively, the rankings can indicate degree of coverage in previous search (i.e., red indicates 0-15% coverage with 85% of the area unsearched previously). Most often the rankings will represent relative likelihood of finding the target in the various areas – for instance on a scale from 1 to 5. In any case, a higher probability ranking indicates a higher priority for searching the specified area.

Success of a guidance system such as PGM that is based on estimates of a priori search probabilities depends on the reliability of those estimates. When initiating a SAR operation, controllers must make a series of timely and critical decisions including development of a plan for the SAR mission proper [10]. The search planning task includes the determination of the last known position, developing a plan that maximizes effort allocation, selecting search patterns and track spacing to achieve suitable area coverage [10, 11]. Data for estimation of the priorities (the last reported position, a confirmed sighting, a radar image, etc.) have limitations, bias and imprecision [11]. In searches for lost persons, the search planners rely heavily on lost person behaviour profiles and statistics for developing search priorities. The search area is defined by empirically derived statistics that give probabilities for distanced travelled from last known position [12, 13] and limited by any geographical features that may make travel impossible or unlikely. Finally, analysis of the subject's behavioural profile, past incidents, and any intelligence delineate the most likely area [12]. The profiles include "hunters, hikers, children (by age group), the mentally retarded, berry pickers and the elderly" [13].

A point and click user interface was developed for colouring the probability map and defining the search priority areas "Fig. 2". The system provides a 2-D map view of the area to be searched and allows for zooming and panning. The user selects colours from the coding scheme and paints a geo-registered overlay layer defining the probability map. This overlay is then exported to the serve as the input probability grid for the PGM system.

B. Terrain Data Repository

The PGM symbology is overlaid and conforms to the terrain flown over. To register and align the symbology with the appropriate part of the scene, the system needs an accurate terrain model. In the PGM system this is provided by a repository of terrain data in the form of digital elevation models (DEM). Typically a DEM is represented as elevation samples along a raster (a grid of squares) or as a triangular irregular network. It represents the elevation and contour of the surface of the earth and usually excludes features such as vegetation, buildings, bridges, etc [14]. DEMs are widely used to represent terrain shape in flight simulators and navigation and localization tools based on the Global Positioning System (GPS) [14].

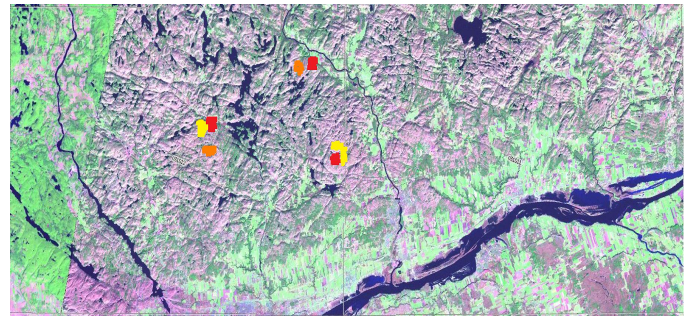

Figure 2. The 2D map picture for the Ottawa region with areas of interest highlighted according to the probabilities.

The Universal Transverse Mercator (UTM) coordinate system is used in PGM. In this system, the surface of the Earth (modeled as the WGS84 ellipsoid [15, 16]) is divided into 60 longitudinal zones, each 6^o wide and a Transverse Mercator projection performed for each zone. Use of a separate projection for each strip minimizes distortion since all projections are centered on the area of interest. Within each patch of the grid positions are defined in terms of distance expressed in meters.

The DEM used in the PGM system is provided by Geobase Canada (www.geobase.ca). For our experiments we used data from the Ottawa region (Geobase sections 031G11 and 031G12). The Canadian Digital Elevation Data (CDED) consists of an ordered array of ground elevations at regularly spaced intervals. The DEM map was converted to ESRI ASCII grid known as ARC/INFO ASCII grid which holds the geodetic data in UTM format.

C. Motion Tracking and Pose Estimation

The Bell 412 helicopter is equipped with a differential GPS receiver integrated with an Inertial Navigation System (INS) and radar altimeter that provide the necessary geodetic data to specify the helicopter location. The flight computer estimates navigational data (a NovAtel model 3151M OEM GPS card receiver, Micropack IMU, LN-200 IMUs and medium accuracy LTN-90-100 [17]) and passes navigation data packets over Ethernet. The PGM is designed to receive these packets to obtain the current aircraft position and orientation in world coordinates so that the terrain digital elevation map can be aligned with current aircraft position.

In the simulation environment, the INS packets are generated by running an instance of the open-source flight simulator Flightgear, augmented with a custom GPS sender simulator. The simulator runs on a separate Linux-based computer than the PGM and sends simulated navigation packets appropriate for current aircraft position to the PGM system via Ethernet. Thus, in both simulator and real aircraft cases, identical PGM software processes incoming navigation data to update the displayed 3-D map so that it is aligned and appropriate for the current position in the scene.

Since the display is head mounted, the displayed scene must be updated to reflect the user's head pose for the synthetic imagery to be correctly registered with the scene. For the simulation environment we use an IS900 hybrid acoustic-inertial six degree of freedom (6DOF) position and orientation tracking system to track the head movements. In the aircraft, the acousto-inertial tracker is not feasible and a 6DOF Laser BIRD 2 head tracker “Fig. 3”, is used to track the head position and orientation relative to the cockpit [18]. Both devices use a similar protocol interface and appear equivalent to the software.

Figure 3. Laser BIRD 2 head tracker.

D. *Display and Image Generation*

An optical see-through helmet-mounted display superimposes the geo-referenced imagery onto the user’s view of the scene. For the flight system a see-through Liteye HMD (LE-750) is used as the display. It uses a 800x600 pixel resolution microdisplay and “it weights 78 grams” see “Fig.4” For the simulation system a see-through N-Vision Datavisor HMD is used as a helmet mounted device is not necessary. It is a full-colour micro-CRT based display with 1280x1024 resolution at 60 Hz (180Hz colour sequential).

Image generation and sensor data collection to present augmented imagery is performed by COTS hardware on a standard personal computer (CentOS5 Linux, dual Intel® core 2 dual™ CPU 6600@2.40 GHz, 2025 MB memory, and NVIDIA GeoForce 8800 GTS video card).

IV. Software Architecture

Custom C code generates the augmented images in real time using the OpenGL application programming interface (API). The VE (Virtual Environment) API is used to display the virtual environment. VE provides abstractions for both the output displays the input devices allowing for run-time re-configuration and substitution of input and display devices [20].

A. *Map Data*

The total area of each map segment is 2,171,407,920 m^2. The map is divided into small squares; each corresponding to 200X200 meters in the real world with 54,285 squares per map segment. The highlighted PGM maps are saved in portable gray map image format (.pgm) for import by the PGM system.

The data from the PGM image is stored in a 2D array that represents input search data in the form of *x-y* coordinates each with an associated probability value *p*. The p value ranges from 1 to 5 representing the probability rank.

The (*x,y,p*) values are compared with another 2D array containing the terrain pixels during rendering in real time. In the terrain 2D array the *x* and *y* values are space on a 50 m square grid and the *z* value represents the elevation.

Figure 4. Liteye HMD (LE-750) [19].

B. *Viewpoint Computation and Registration*

1) *Head Pose Estimation*

The navigation data provided through the INS/GPS, as well as head tracker data are converted to x, y and z coordinates in order to connect the terrain map with the current location of the aircraft. The aircraft orientation is combined with the head tracking data to compute the view direction and vantage point. The terrain map is converted to UTM Cartesian system coordinates for registration purposes. “Fig. 5” illustrates the head pose estimation dataflow

C. *Scene Augmentation*

Since the HMD’s used both in the simulation and in the helicopter are see through HMDs, the searcher will be able to see the real world, as well as the highlighted areas. For illustration see “Fig. 6” and “Fig. 7”.

Recall that the terrain map in the PGM system is divided into small sections or grids of 200x200 meters. “By associated each section” with the corresponding input search data, the search priority will be linked to the spatial map. During the rendering process the sections will be coloured with the appropriate colour indicating the priority of the search. Two different methods of highlighting the terrain map will be evaluated: In the first method the colour will be filled over the whole section (the shading method), while in the second method the colour will be given to the borders of the section (the wire frame method) as shown in “Fig. 8.a” and “Fig. 8.b”. Both methods will be tested to determine which way is more effective. In both methods, only areas of interest will be highlighted while areas not of interest will not be rendered to minimize latency and visual clutter. We also plan to explore other highlighting schemes such as marker and flagpole analogies that have better visibility in rugged terrain.

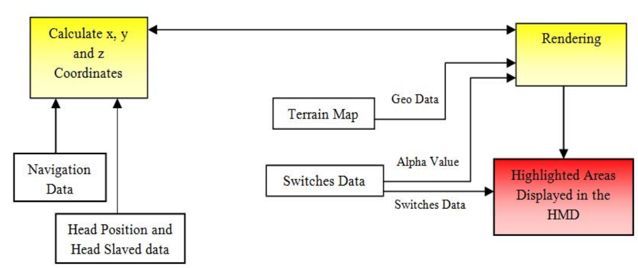

Figure 5. Head pose estimation data

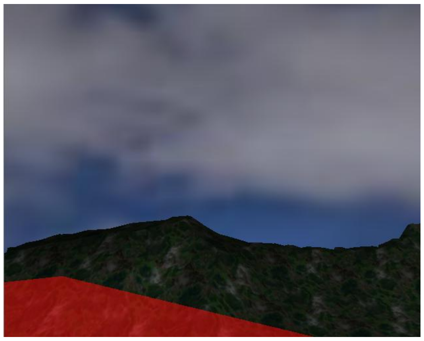

Figure 6. A simulation for real world and an area of interest highlighted with red.

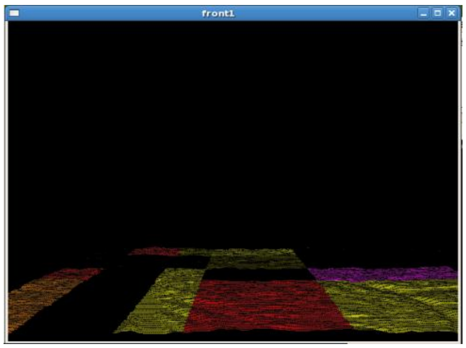

Figure 7. A screen shot illustrates the terrain map highlighted with different colours according to probabilities.

For flexible effects to cope with variations in lighting and terrain colouring, the ability to blend the transparent object's colour with the real world behind it is important. When an object is rendered on the screen, an RGB colour and a z-buffer depth are associated with each pixel. Another component, called alpha (α), can also be generated and optionally stored to represent the degree of opacity of the highlights [21]. OpenGL blending is used with these alpha parameters to make areas of interest appears transparent to enhance visibility and clarity for the search.

V. EXPERIMENTS

Two sets of experiments were designed to evaluate the PGM system, the first simulation experiment will be held in the lab prior to flight test while the second experiment is the actual flight test.

A. *Experiment 1*

A simulation of the helicopter visual environment and the aircraft hardware was needed to evaluate the grid mapping system. The augmented reality hardware and software configuration for this simulation setup were described previously. For the simulation environment, three Linux based computers are used, one for displaying the PGM system and two to run Flightgear simulator as a master and slave to mimic the pilot and the tactile officer tasks.

The flight simulation environment is displayed in a large immersive projection environment to simulate the cockpit view

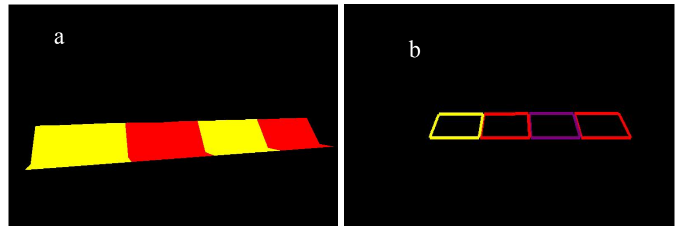

Figure 8. (a) Different areas highlighted with the shading method (b) Different areas highlighted with the wireframe method.

and make the experiment more realistic. The pilot (an experimenter) controls the flight path using a joystick. The user playing the role of tactical officer wears the helmet-mounted display which augments the view of the simulated world presented on the projected display. Button presses on another joystick are used for them to indicate the locations and the time of finding a target.

The objective behind detecting the time and the location of the target is to test whether the time of the search will decrease using the PGM system and if so by how much. Also it tests if the probability of detection for the searcher will increase and if false positives will be reduced. The essential question is whether the efficiency of the search will improve with the augmentation.

A four-level between-subject design will be used (i.e., four groups of ten participants each). Each participant will participate in one session; the length of the session is half an hour. All groups will be given a 2D map of the search area. The first group of participants will also use the PGM system with the shaded method through the HMD. The second group will see the PGM system with the wireframe method through the HMD. The third group will not use the PGM system and will be only given the 2D paper map with no areas highlighted. The fourth group will not use the PGM system and they will be given the 2D paper map but with areas highlighted on it.

Each participant will be given the same scenario about the missing targets, the target sizes and colours will be different e.g. people, cars, pets, etc. When a participant sees a target he/she will be asked to push a button on the joystick for the detection and when the helicopter is hovering above the target and he/she discovers it is true target he/she will push another button for the discrimination purpose. Each time a button is pushed the navigation data and the time will be recorded. Also information about which target was found will be manually recorded.

B. *Experiment 2*

In experiment 2, subjects will be asked to perform the same tasks as in the simulation in the real aircraft. The searcher will perform one or more sessions from the levels described in the experiment 1. The 2D static maps will be displayed on a head down display placed in the center of the instrument panel. The limitation of the number of trials is due to time and cost. The searcher will be asked to flick one of the toggle switches on the helicopter collective stick up in the detection task and down in the discrimination task "Fig. 9". As in the simulation the navigation data and the time will be recorded. Also the information about the target type will be recorded.

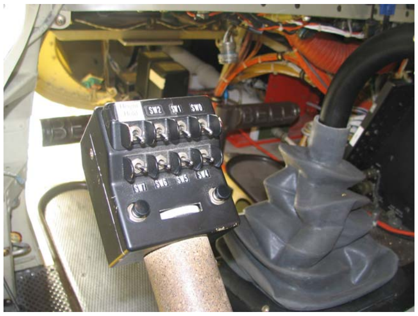

Figure 9. The switches in Bell 412 helicopter which will be used in the detection and discrimination process.

VI. DISCUSSION

When cueing visual search, one must decide how to weight a priori estimates in light of the inherent trade-off between the cost/benefits of accurate and inaccurate cueing. If probabilities are highly inaccurate, then cueing is counter-productive. Accurate cueing facilitates detection and reduces search time but at the same time produces two sorts of costs. First, it raises awareness to targets in high probability zones which may lead to both more hits and also more false alarms. Second, cueing draws attention towards high priority zones and away from low (but not zero) probability zones. This attentional bias has been shown to reduce the detection of unexpected targets in the environment [22].

A related issue is the attentional demands of the HMD itself due to reduced field of view and cognitive tunneling driven by attentional to the task relevant display. Cognitive tunneling can be reduced by explicitly directing attention to critical information in the real world [22]. The use of see-through HMD has the benefit of reduce scanning and geo-registration while accessing information but with some reduced visibility of the real world due to overlay or the image combiner.

The PGM system is a novel ESVS system concept that aims to improve the effectiveness of airborne personnel that are not flying the aircraft. In security applications the system is intended to aid the other officer in the aircraft who is managing and performing the tactical mission.

PGM is specifically intended for guided aerial search. The PGM helps the searcher by guiding his/her scan behaviour to high probability regions through augmented reality markers.

By presenting the markers as a geo-referenced augmented reality the system aims to avoid the need for cognitively demanding tasks of interpreting and transforming the data presented on traditional maps.

The PGM system could be applied in the future to night vision systems, permitting a similar augmented capability at night.

REFERENCES

[1] W. A. Hoff, ,and K. Nguyen.. "Computer vision-based registration techniques for augmented reality," proceeding of Intellegent Robots and Computer Vision XV, vol. 2904, pp. 18-22, November 1996 [Boston, MA, pp. 538-548.] "published"

[2] C. Jennings, A. K. Barrows,, K. Alter, And J. D. Powell. "Synthetic vision displays instrument landings and traffic awareness-development and flight testing," IEEE Philadelphia, PA, USA, vol. 1, pp. 2A2/1-2A2/8, 2000. "published"

[3] J. P. Rolland and H. Fuchs. ''Optical versus video seethrough head-mounted displays,'' in Fundamentals of Wearable Computers and Augmented Reality, W. Barfield and T. Caudell, eds. (Erlbaum, Mahwah, N.J., 2001, pp. 113–156. "published"

[4] M. Rosenthal, A. State, H. Lee, G. Hirota, J. Ackerman, K. Keller, E. D. Pisano, M. Jiroutek, K. Muller and H. Fuchs. "Augmented reality guidance for needle biopsies: An initial randomized controlled trial in phantoms," Medical Image Analysis, vol. 6, no. 3, pp. 313-320, 2002. "published"

[5] R. T. Azuma. "A survey of augmented reality," Presence Teleoperators and Virtual Environments, vol. 6, no. 4, pp. 355-385, 1997. "published"

[6] Young, Warren R. and the editors of Time-Life Books. "The Helicopters," Time-Life Books, Alexandria, Virginia. 1982. "published"

[7] E. Theunissen, and M. Mulder. "Open and closed loop control with a perspective tunnel-in-the-sky display". AIAA Flight simulation technologies conference, Scottsdale, pp. 32-42, August 1-3, 1994. "published"

[8] S. Julier, M. Lanzagarto, Y. Baillot, L. Rosenblum, and S. Feiner. "Information filtering for mobile augmented reality," IEEE Int'l Symp. Augmented Reality, pp. 3-11, 2000. "published"

[9] "New virtual-reality helmets designed to help save more lives-Canada," http://www.nce-rce.gc.ca/media/success/geoide99204_e.htm captured on April 28th, 2009. "published"

[10] I. Abi-Zeid, Q. Yang, and L. Lamontangne, "Is CBR applicable to the coordination of search and rescue operations? A feasibility study," In Proceeding of the third International Conference on Case-Based Reasoning, Springer, Seeon, Germany, pp. 358-371, 1999. "published"

[11] B–GA–209–001/FP–001 DFO 5449, "National SAR manual," May 2000. "published"

[12] R.J. Koester, "The lost Alzheimer's and related disorders search subject: new research and perspectives," Response NASAR Proceedings, National Association of Search and Rescue, Chantilly, VA, pp. 165-81, 1998. "published"

[13] R.J. Koester, and D.E. Stooksbury, "Lost Alzheimer's subjects–profiles and statistics," Response, Fall 1992. "published"

[14] J. P. Wilson, and J. C. Gallant. 'Terrain Analysis: Principles and Applications." pp. 1–27, 2000. "published"

[15] Dana and H. Peter. "Entries: national map accuracy standards (NMAS), 304-305, Projection, 348-351, Universal Transverse Mercator (UTM), 497-498." In Encyclopedia of Geographic Information Science. Ed. Karen K. Kemp. Los Angeles: Sage Publications, 2008. "published"

[16] Snyder and P. John. "Map Projections - A Working Manual." U.S. Geological Survey Professional Paper 1395. United States Government Printing Office, Washington, D.C., 1987. "published"

[17] B. W. Leach, and k. Hui. "Low Cost Strapdown Ineertial/DGPS Intergration for Flight Test Requirements". Aeronaut. Space J., vol. 45, No. 3, Canada, pp. 253-263, September 1999. "published"

[18] "Ascension laserBIRD 2™," 5DT Fifth dimention technologies virtual relaity for the real world, http://www.5dt.com/products/plaserbird.html, captured on April 29th, 2009.

[19] Inition, "LE-750 see-through head mounted displays" http://www.inition.co.uk/inition/product.php?URL_=product_hmd_litey e_700&SubCatID_=15, captured on May, 27th, 2009.

[20] "The VE 2.2 user manual," http://www.cse.yorku.ca/~ivy/ve-2.2/. Captured on April 20th, 2009.

[21] M. Woo, J. Neider, and T. Davis. "OpenGL programming guide," Second Edition. Addison Wesley, 1997.

[22] M. Yeh, C. D. Wickens, and F. J. Seagull, "Target cueing in visual search: The effects of conformality and display location on the allocation of visual attention," Human Factors, vol. 41, pp. 524 – 542, 1999. "published"