MSc Project Report

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Probability Grid Mapping System for Aerial Search

(PGM)

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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.

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. Priorities are encoded with a colour-coded highlighting scheme indicating probability of finding the target in each area. Probability estimates can be adaptively modified (a posteriori probabilities) as the search progresses and various parts of the search area covered. The displayed probabilities and

highlighting can be adaptively modified to reflect these changes. The conformal 3D map is displayed with appropriate perspective projection using a head-slaved optical see-through Head-Mounted Display (HMD) 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.

1. Introduction

Nature has provided humans with different sensory systems sensitive to visual, auditory, olfactory, haptic and gustatory information coupled with cognitive capabilities that allow decisions and behavioural responses to these stimuli. Despite this flexibility human perception and cognition is still limited in many ways [1]. For example, visible light represents only a small part of the electromagnetic spectrum and our field of view is limited.

Over the centuries we have developed aids to overcome sensory deficits (glasses and hearing aids) or to augment and extend our senses (e.g. telescopes, compasses or ultrasonic imagers). Until recently, these aids were designed primarily to enhance our sensory or motor capabilities and we have had less ability to enhance our cognitive capabilities [1]. The development of writing, maps, calculating instruments, mathematical tools and other aids certainly extend cognitive capabilities but real-time cognitive processing of sensory information remained largely unassisted. With the recent fusion of computer technology and personal digital technology, we can now develop and wear digital devices that mainly enhance our cognitive capabilities. Wearable computers and augmented reality offer a mobile user pervasive access to rich sources of information and tools to help manage and process that information [1].

1.1 Enhanced and Synthetic Vision

Augmented reality (AR) refers to the addition of synthetic components to visual, auditory or other sensory scenes, typically through specialised displays such as a see-through head mounted display (HMD). The addition of the computer generated entities is performed 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. For example, the computer could identify objects and overlay them with graphic outlines, labels and/or schematics [2]. Such techniques have proven effective in many domains including aviation [3], medicine [1,4], military training [1,5] and manufacturing [1].

Piloting an aircraft and working from an aerial platform can be demanding perceptual and cognitive tasks. Military aircraft pilots have relied on 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]. With the development of augmented reality systems, new 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 of synthetic vision, an artificial view of the terrain and flight environment to aid navigation, dates from the nineteen-fifties. At the time, a number of systems were conceived to provide military pilots with terrain information linked to an image of the approach. Putting these ideas into practice had to wait for the development of adequate processing power, accurate positioning systems, geographical databases and advances in three-dimensional displays and graphics that made it possible display geo-referenced 3D information in the 1990's [7].

A synthetic vision concept called "Tunnel-in-the-sky" originated with George Hoover and the Army Navy Instrumentation Program in the 1950s. Early work dealt explored the effectiveness of symbology to aid the pilot in control of the aircraft although technology limitations did not allow practical systems to be fielded at the time [7, 8]. In the 1990's researchers revived the "Tunnel-in-the-sky" concept and developed design rules for display of three-dimensional path information and navigation aids to help pilots follow precise paths during flight or landing [3].

Another synthetic vision system was developed by the National Research Council of Canada's Institute for Aerospace Research (NRC_IAR) in 2004. In this system a helicopter augmented reality enhanced vision system was developed to assist pilots in landing helicopters at night and in adverse weather conditions by following a computer generated path to the landing zone [9]. Synthetic vision systems produce artificial views of the world to support navigation and situational awareness despite variable or poor visibility conditions.

1.2 Enhanced Vision for Aerial Search

This MSc project developed and prototyped a new technique that will help pilots and their crew in their search and rescue missions. Specifically an enhanced vision system called the Probability Grid Mapping System (PGM) was developed.

The main objectives behind search and rescue missions are to recover persons or objects in emergency situations, police and security missions. 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.

Finding the target of the search is a critical first step in a successful rescue. Search is a time consuming process that depends critically on the expertise of the crew. When airborne personnel are searching for a person or an object on the ground they have to depend on their visual abilities and the verbal data provided by the search and rescue coordination centre. Many factors affect the efficiency and success of these missions such as the terrain, visibility, temperatures, time of day or night, the life or limit determination and the available resources [25].

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, with the notable exception of military weapons targeting [5, 6]. The PGM system 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.

The PGM System aims to make the search task easier and more effective by supplying the searcher with an augmented digital mapping system for the search area. Also it provides the searchers with probability of target locations presented as conformal symbology. The probability is estimated by the search and rescue coordinator or equivalent on the ground prior to the flight based data obtained about the situation. i.e. the last place the person was seen, areas already searched, etc. The map is displayed using a see-through Head Mounted Display (HMD) to superimpose it on a view of the real world.

2. Background

The PGM system is based on integrating geographically referenced symbology into an aviation AR system in the context of standard operating procedures for airborne search and rescue missions. This chapter describes the relevant background related to augmented reality, visual displays, terrain modeling and helicopter search and rescue techniques.

2.1 Synthetic and Enhanced Vision Systems

Augmented Reality (AR) involves enhancing or augmenting the user's perception of the real world. It supplements reality, rather than completely replacing it as in Virtual Reality [1, 2 and 5]. Ideally, in an AR environment, virtual and real objects coexist in the same space and merge together seamlessly. The enhancement can take the form of textual labels, symbology, virtual objects, or shading modifications.

Synthetic Vision (SV) and Enhanced Vision (EV) systems are specialised augmented reality systems that augment the real world with additional data about physical or logical features of the environment. Typically the synthetic imagery is generated based on databases of known items, such as terrain, runways, roads and buildings or based on sensor inputs (e.g. lidar data).

Since the generated imagery represents entities associated with a specific location in the real world, the virtual camera used in the rendering must accurately traverse the representation of the world based on incoming navigation sensor data [18]. The reference models and coordinate systems used in rendering affect the fidelity with which the synthetic world matches the real world. Minimizing registration errors is essential for useable SV and EV systems [18, 19].

2.1.1 Enhanced Vision Systems

An enhanced vision system (SVS) combines computer-generated elements (graphics, outlines, labels or texts) with live imagery. The live image can be from imaging sensors or from direct views of the real world itself through the use of a head-up display (HUD) or see-through HMD [18].

2.1.2 Synthetic Vision Systems

A synthetic vision system (SVS) uses navigation sensors along with data about the external world, for example terrain databases, to display a 3D perspective image to a user. In a pure SVS no real-time imagery is combined with the SV image. Thus, a SVS system is analogous to a VR system except that the user's vantage point in the synthetic world matches their location and movement in the real world.. Usually however the synthetic view is combined with a direct view of the real world or with an EV system [18]. Such a system is called an Enhanced and Synthetic Vision Systems (ESVS)

2.2 See-Through Head Mounted Display (HMD)

The graphical overlays in an ESVS system could be generated using stationary monitors but is more typically displayed using a see-through head-mounted display (HMD) providing a natural 'first-person' view of the world.

2.2.1 The History of See-Through HMD's

The first see-through head mounted display (HMD) system was developed in the 1960s by Ivan Sutherland and consisted a see-through stereoscopic display based on miniature CRTs and optical combiners to superimpose images of the displays with a view of the real world, a mechanical tracker to provide head position and orientation in real time, and a hand-tracking device [1, 13]. The tracker was necessary to couple the synthetic view to the user's viewpoint as they moved about.

The acronym HMD can also refer to helmet-mounted displays, where the display is attached to a military or aviator helmet. Notable systems include the HMD sighting system for the Cobra helicopter and the Integrated Helmet and Display Sighting System (IHADSS) used on the AH-64 Apache helicopter [9], both fielded by the US Army.

Head-mounted display (HMD) designs may be classified as immersive—also known as standard closed-view—or see-through. While immersive optics refer to designs that block the direct real-world view, see-through optics refers to designs that allow augmentation of synthetic images onto the real world [5, 14]. Closed view displays can be combined with head mounted image sensors to create a video see-through HMD. Alternatively, with an optical see-through HMD, the real world is seen through semi-transparent mirrors (optical combiners) placed in front of the user's eyes.

2.2.2 The Characteristics of an Optical See-Through HMD

Optical see-through HMDs work by placing optical combiners in front of the user's eyes. The user can see the real world through the optical combiners since they are partially transmissive. The combiners are also partially reflective, so that the user can also see computer generated images bounced off the combiners. Figure 1 shows two optical see-through HMDs and Figure 2 shows a conceptual diagram of an optical see-through HMD [5].

Figure 1. Two optical see-through HMDs, made by Hughes Electronics [5].

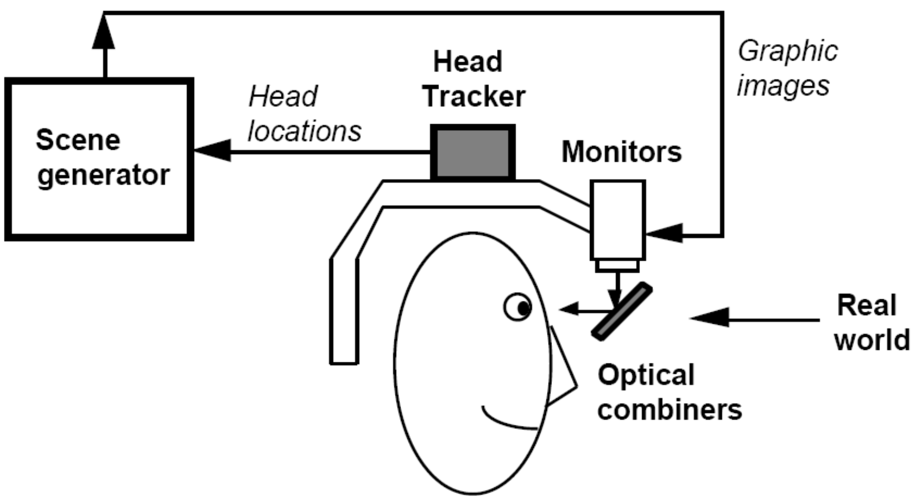

Figure 2. Optical see-through HMD conceptual diagram [5].

Choosing the reflection to transmission ratio and hence the level of blending is a design problem. The ratio can be chosen to match the brightness of the displays with the expected light levels in the real-world environment [13]. Most existing optical see-through HMDs reduce the amount of the incoming light from the real world. Without power the optical see-through HMD works as a pair of sunglasses [1, 5]. The synthetic images appear as semitransparent ghosts floating in front the real scene [15]. Optical see-through displays have relatively simple structures and they are widely used [15]. Optical see-through HMDs have the advantage that the real world image is preserved without any degradation except for a reduction in light levels.

There are many advantages and disadvantages in using optical see-through HMDs in augmented reality systems due to their characteristics.

The major disadvantages of optical see-through HMDs are sensitivity to latency and inability to support realistic occlusion. The system latency or lag is the largest source of registration errors in most current HMD systems [13]. If the head moves in the presence of latency the synthetic imagery will not be immediately updated and will appear to move or ‘swim’ with respect to scene. Typically latency is minimized through system design [5, 13] and prediction is used to minimize the effects of head movements [1, 5]. However, sudden movements will still cause misregistration. In real life, an opaque object can block the view of another object so that part or all of it is not visible and occlusion is a compelling monocular depth cue. In computer graphics it is not a problem to generate computer objects that occlude each other. However, it is more difficult to make real objects occlude virtual objects and vice versa since proper occlusion requires that the depth of real objects must be determined and, furthermore, real objects cannot be easily removed from the scene [13].

Some of the major advantages of using optical see-through HMDs include safety, simplicity, and visual fidelity. From safety point of view the user still has a direct view of the real world even when the device fails or is not powered. Optical blending is simple and cost effective as there is only one stream of video to process and the images of the real world are from the eyes natural vantage point. Field of view for the real world image is not linked to the display size and can be relatively unrestricted.

A resolution close to that obtained with the naked eye is provided and distortion is minimal [1, 5 and 13]. Similarly, the depth of field when viewing objects in the scene is not degraded and the eye can naturally focus on objects at various distances.

In contrast in a video see-through display the resolution, field of view and depth of field is restricted by the camera and display characteristics and there needs to be compensation for the offset between the camera and eye vantage points. However, video and computer generated imagery can be matched for latency, focus and geometrical registration. Recovery of depth and structure of the real world is facilitated by having a video image and realistic occlusion is possible.

The field of view using see-through HMDs is different from the user perspective by being one of three kinds: Monocular, Biocular or Binocular [14].

Optical see-through HMDs typically provide from 20° to 60° overlay FOV which may appear somewhat limited. Larger FOVs have been obtained, up to 82.5 x 67 degrees, at the expense of reduced brightness, increased complexity, and massive, expensive technology [13].

However; in optical see-through HMDs the user can still use his/her peripheral vision around the device, thus increasing the total real-world FOV to numbers that match closely one's natural FOV [1].

2.3 Representation of Terrain and Landscape

A digital elevation model (DEM) is a digital representation of ground surface topography or terrain. It is also widely known as a digital terrain model (DTM). Typically a DEM is represented as a raster (a grid of squares) or as a triangular irregular network. It is generally refers to a representation of the Earth's surface or subset of it, excluding features such as vegetation, buildings, bridges, etc [20].

Data for DEMs are usually obtained using remote sensing or land surveying techniques such as LIDAR, Topographic Maps and Inertial surveys. DEMs are used often in geographic information systems, and are the most common basis for digitally-produced relief maps. In addition DEMs are widely used in flight simulators and navigation and localization tools based on the Global Positioning System (GPS) [20].

2.4 Global Coordinate Systems

In order to express a DEM in a meaningful way a coordinate system needs to be associated with physical features of the local terrain or of the globe it self. The latitude-longitude coordinate system uses angular measurements to describe a position on the surface of the earth relative to arbitrary but standard reference coordinates. Latitude-longitude systems date from Ptolemy's first world atlas in A.D. 150, have been used by mariners and aviators ever since [21] and remain the basis of many modern maps, charts and navigation systems.

Currently, the most common lat-long standard among geographical coordinate systems is the global coordinates system, where the Prime Meridian and the Equator are the reference planes used to define latitude and longitude [21].

The geodetic latitude of a point is the angle from the equatorial plane to the vertical direction of a line normal to the reference ellipsoid. The geodetic longitude of a point is the dihedral angle between a reference plane and a plane passing through the point, both planes being perpendicular to the equatorial plane and passing through the centre of the reference ellipsoid. The third coordinate, the geodetic height is the distance from the point to the nearest point on the reference ellipsoid [22] Figure 3. The most recent world geodetic system that defines a reference frame for the earth is WGS84 dating from 1984, which will be valid up to 2010 [21].

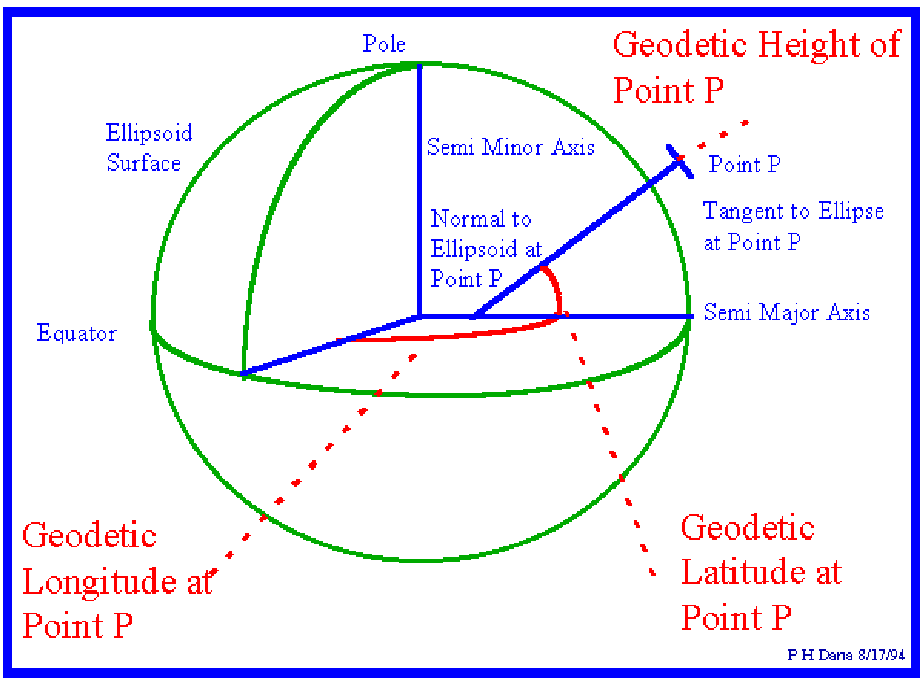

Figure 3. The Geodetic Coordinate System, picture is taken from [22].

2.5 Universal Transverse Mercator (UTM) Coordinate System

The Mercator projection is a map projection of the globe onto a cylinder. The cylinder has its axis aligned with polar axis and tangent to the equator. Lines of latitude (parallels) and longitude (meridia) map to horizontal and vertical lines in this projection. Scale is true at the equator or at two standard parallels equidistant from the equator. Distortions of scale, distance, direction and area increase away from the central meridian which is why it cannot be used at high latitudes [22]. The projection is often used for marine navigation, where all straight lines on the map are lines of constant azimuth, since it easy to find the shortest route between any two points. Also it is easy to index any position on the map or at any particular geographical feature using x, y coordinates.

In spherical coordinate systems like latitude and longitude, the distance covered by a degree of longitude differs as you move towards the poles and only equals the distance covered by a degree of latitude at the equator. However as land navigation typically only considers a very small part of the world at any one time local coordinates specified in distance would be convenient. The UTM system allows the coordinate numbering system to be associated with distances on the earth [23].

The Universal Transverse Mercator (UTM) projection was developed by the US Army Corps of Engineers. It is used to define locations on the earth's surface world-wide by dividing the surface of the Earth into grid. The world is divided into 60 longitudinal zones, each 6º wide and a Transverse Mercator projection performed for each zone. A Transverse Mercator projection is a cylindrical map projection like the Mercator except that the cylinder is rotated 90º so that its axis lies in the equatorial plane. The meridian at which the cylinder is tangent to the sphere is known as the central meridian. Distortions of scale, distance, direction and area increase away from the central meridian [22]. In UTM, a Transverse Mercator projection is defined for each longitudinal zone with the central meridian of the projection aligned with the centre of each longitudinal strip. Use of a separate projection for each strip minimizes distortion since all projections are centred on the area of interest.

Currently, the WGS84 ellipsoid is used as the underlying model of the Earth in the UTM coordinate system [22, 23].

UTM zone *numbers* designate the 6º longitudinal strips extending from 80º South latitude to 84º North latitude. UTM zone *characters* designate 8º zones extending north and south from the equator [22, 23]. These number-letter combinations denote square patches in the UTM projection grid as shown in Figure 4.

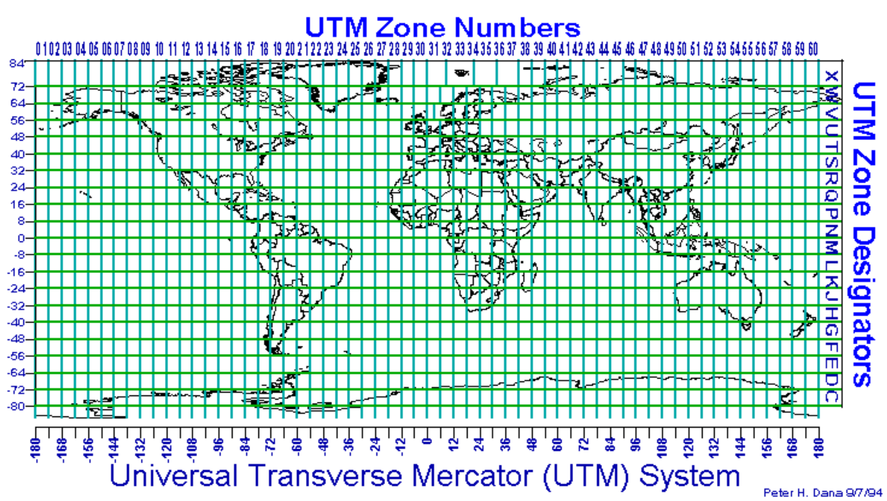

Figure 4. Universal Transverse Mercator (UTM) system picture is taken from [22].

Within each patch of the grid positions are defined in terms of distance expressed in metres. The zone is defined so that the central meridian through the zone is aligned with the vertical dimension of the zone—all other meridian in the zone will map to curved lines. Also there are no negative numbers or East-West designators. Within each patch positions are specified as distance eastward to the point (known as the Easting) and northward to the point (known as the Northing) as in an X-Y Cartesian coordinate system, and thus Cartesian coordinate mathematics can be used [23]. The Eastings are defined relative to the central meridian of the zone which is assigned an arbitrary Easting of 500,000 m which prevents the need for negative numbers. The Northing is defined as distance relative to the equator, which is assigned a Northing of 0 m for measurements in the Northern hemisphere [23].

2.6 Aerial Search and Rescue Missions

2.6.1 Description of Aerial Search and Rescue Techniques

As defined by the national SAR manual [24] "search and rescue (SAR): comprises the search for, and provision of aid to, persons, ships or other craft which are, or are feared to be, in distress or imminent danger."

Any SAR mission aims to prevent loss of life and injury; also it aims to minimize damage to or loss of property if possible. The SAR operations in Canada are divided into two categories; aeronautical SAR and maritime SAR [24]. Aeronautical incident involves search and rescue of aircraft, while maritime incidents involves search and rescue of ships and boats.

In response to the occurrence of an air incident, controllers at one of the three Canadian Rescue Coordination Centers (RCC) must make a series of critical decisions on the appropriate procedures to follow in order to deal with the incident. These decisions and procedures (called case prosecution) include an assessment of the degree of emergency, a formulation of the hypotheses on what might have happened and where, the development of a plan for the search and rescue (SAR) missions and in the end, the generation of reports [25].

3. Probability Grid Mapping System for Aerial Search (PGM)

3.1 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.

3.2 PGM Implementation

Figure 5 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.

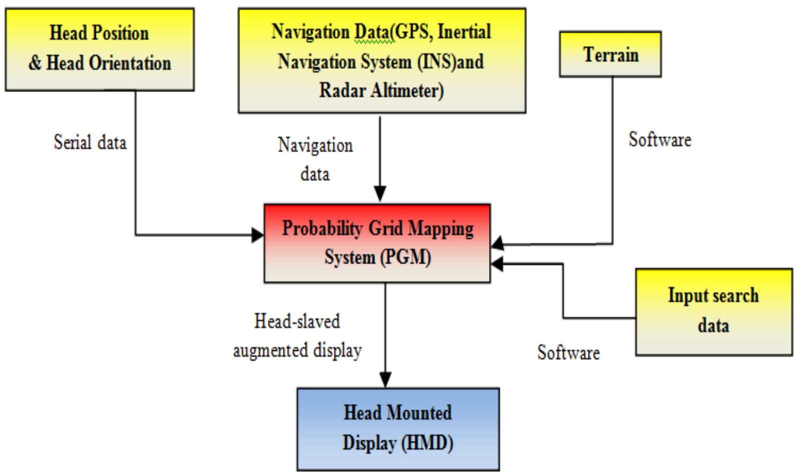

Figure 5. Block diagram of the PGM system.

3.2.1 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 mounted display (HMD) to augment it with the real world.

Providing the searcher with an optical see-through head mounted display allows them to see the real world highlighted with different colors 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 colors currently used in the PGM system with their probability ranks.

Table1. The priority of the search area in the PGM system is displayed using one of the different colors. Red indicates the highest priority search area.

Probability Ranks	**Color**
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. A continuum of color was not chosen because of the risk that it might be confusing for the searcher. The probability ranks could be interpreted literally as the expected likelihood of finding the target at any given point in 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.

A point and click user interface was developed for coloring the probability map and defining the search priority areas Figure 6. The system provides a 2-D map view of the area to be searched and allows for zooming and panning. The user selects colors 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.

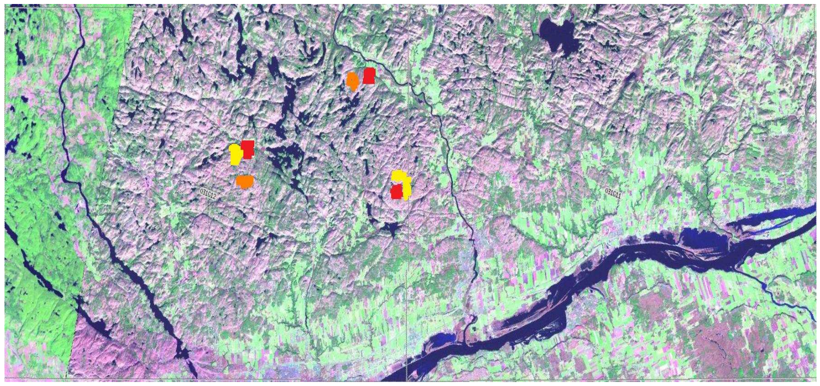

Figure 6. The 2D map picture for the Ottawa region with areas of interest highlighted according to the probabilities.

3.2.2 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 [20]. DEMs are widely used to represent terrain shape in flight simulators and navigation and localization tools based on the Global Positioning System (GPS) [20].

The Universal Transverse Mercator (UTM) coordinate system is used in PGM. In this system, the surface of the Earth (modeled as the WGS84 ellipsoid [22, 23]) is divided into 60 longitudinal zones, each 6º 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.

3.2.3 Motiom 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 [26]) 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 Figure 7 is used to track the head position and orientation relative to the cockpit [27]. Both devices use a similar protocol interface and appear equivalent to the software.

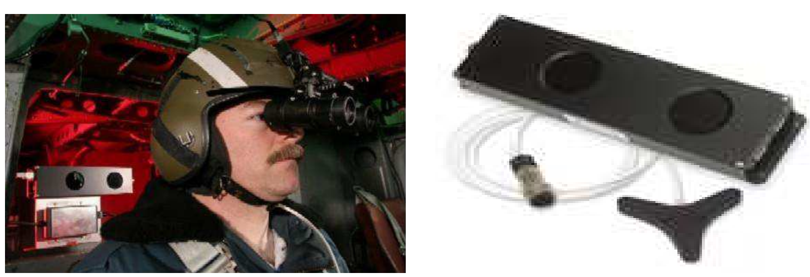

Figure 7. Laser BIRD 2 head tracker

3.2.4 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 Figure 8 For the simulation system a see-through N-Vision Datavisor HMD is used as a helmet mounted devise 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).

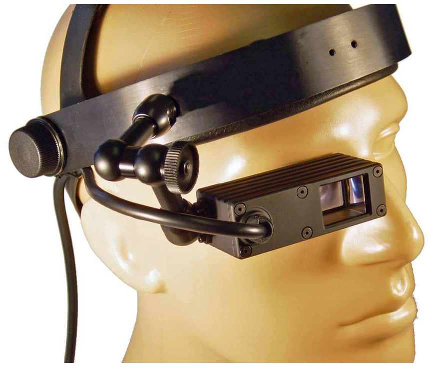

Figure 8. Liteye Head Mounted Display (LE-750) [28].

3.3 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 [29].

3.3.1 Map Data

The total area of each map segment is 2,171,407,920 m2. 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.

3.3.2 Viewpoint Computation and Registration

3.3.2.1 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 computer the view direction and vantage point. The terrain map is converted to UTM Cartesian system coordinates for registration purposes. Figure 9 illustrates the head pose estimation dataflow.

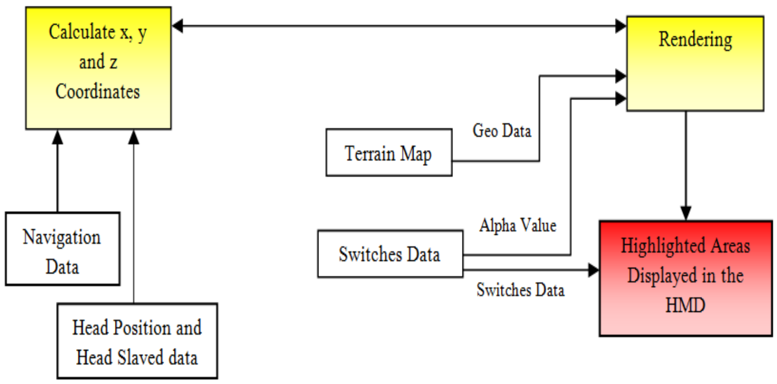

Figure 9. Head pose estimation data.

3.3.3 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 Figure 10 and Fig 11.

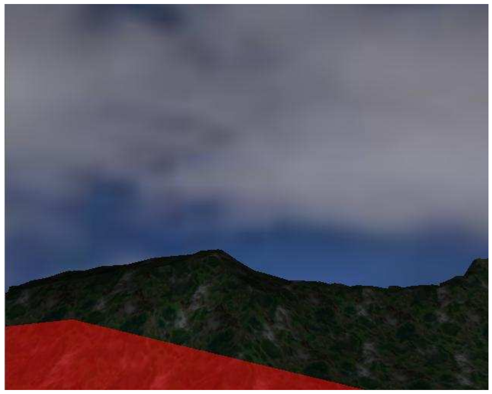

Figure 10. A simulation for real world and an area of interest highlighted with red.

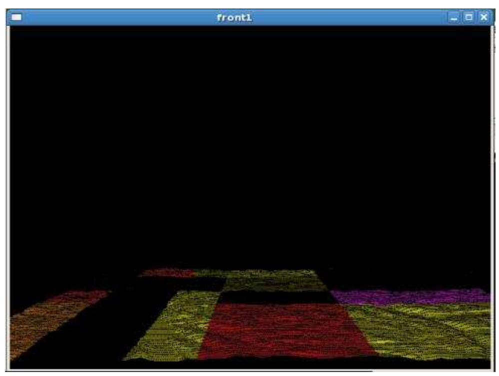

Figure 11. A screen shot illustrates the terrain map highlighted with different colours accordin to probabilities.

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 color will be given to the borders of the section (the wire frame method) as shown in Figure 12.a and Figure 12.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.

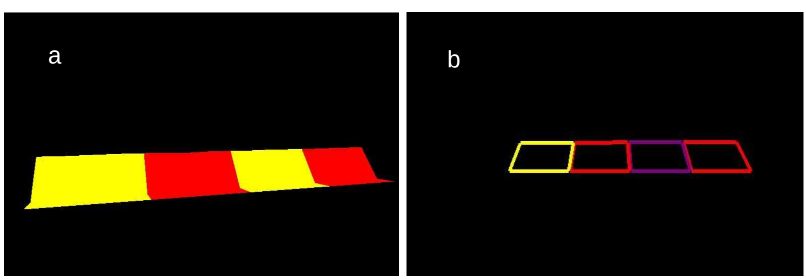

Figure 12. (a) Different areas highlighted with the shading method (b) Different areas highlighted with the wireframe method.

For flexible effects to cope with variations in lighting and terrain coloring, the ability to blend the transparent object's color with the real world behind it is important. When an object is rendered on the screen, an RGB color 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 [29]. OpenGL blending is used with these alpha parameters to make areas of interest appears transparent to enhance visibility and clarity for the search.

3.4 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.

3.4.1 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 large immersive projection environment to simulate the cockpit view 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 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 colors will be different e.g. people, cars, pets, etc. When a participant sees a target he 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.

3.4.2 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 Figure 13. As in the simulation the navigation data and the time will be recorded. Also the information about the target type will be recorded.

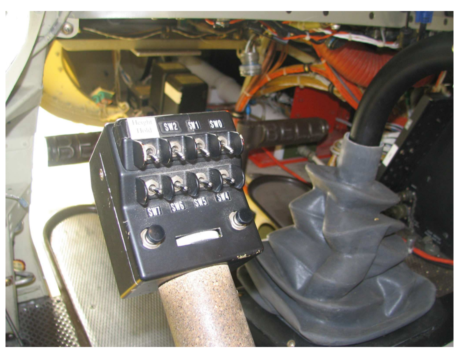

Figure 13. The switches in Bell 412 helicopter which will be used in the detection and discrimination process.

4. Discussion

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 scan behavior 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.

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