THE USE OF AUGMENTED REALITY IN COMMAND AND CONTROL SITUATION AWARENESS

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Abstract

Augmented reality is not completely new technology, but rather an interesting combination of existing technologies, facilitated by the rapid progress made on ultra-portable devices such as smart cellular telephones. It has the potential to enhance the situation awareness of military operators. This study identifies possible uses of augmented reality in command and control applications with specific attention to situation awareness in the South African context. Applications across the different command and control functions, as well as at the different levels of military operations are considered. The article concludes with some concept definitions for augmented reality applications.

Introduction

Augmented reality applications are becoming more popular due to the remarkable progress in ultra-mobile computing devices such as smart cellular telephones (smartphones), personal digital assistants and lightweight laptop computers (so-called "netbooks"). Ubiquitous internet access, even from mobile devices, fuels the development further with the availability of electronic devices that combine the required technologies into single integrated units.

Typically, an augmented reality application relies on a global positioning system (GPS) device, electronic compass and/or accelerometers, real-time video display and direct access to geo-referenced information. Devices should also be capable of supporting the development of custom applications that allow for the overlaying of synthetic generated scenery, such as animations, call-outs and arrows onto the live video scene display, as depicted in Figure 1 (taken from Shukla[1]).

International companies, such as Google™, Microsoft™ and Yahoo™, and "open" drives, such as the Open Geospatial Consortium®, OpenLayers[2] and OpenStreetMap[3], offer freely available geo-referenced maps, data and information. All of these contribute to the richness a user could experience whilst using an augmented reality application.

Figure 1: Example of augmented reality application[4]

Command and control rely heavily on situation awareness, since decisions have to be made based on the current situation, as well as the anticipated unfolding sequence of events. Two important models are those of Boyd[5], who formulated the observe-orientate-decide-act loop, and Endsley, Bolté and Jones[6] who defined the

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[1] G. Shukla, "Best Augmented Reality Browsers for Android", *ANDROIDOS.in*, Oct 2009, http://www.androidos.in/2009/10/best-augmented-reality-browsers-for.html, accessed on 26 Jan 2010.

[2] From http://openlayers.org, accessed on 26 Jan 2010.

[3] From http://www.openstreetmap.org, accessed on 26 Jan 2010.

[4] Image of Wikitude world browser application in action courtesy, from http://www.mobilizy.com, accessed on 26 Jan 2010.

[5] D.J. Bryant, *Rethinking OODA: Toward a Modern Cognitive Framework of Command Decision Making*, Military Psyhology, Vol 18, No 3, 2006, pp. 183–206.

[6] M.R. Endsley, B. Bolté and D.G. Jones, *Designing for situation awareness: an approach to user-centered design* (Boca Raton: Taylor & Francis, 2003).

three levels of situation awareness – perception, comprehension and projection. Both models emphasise the importance of situation awareness, typically achieved via different modes of interaction and perception, namely direct human interaction, direct and indirect visual observation, and processing of reports, to name but a few.

The premise of this article is that augmented reality can enhance the effectiveness and efficiency of command and control applications. Possible applications are suggested in an attempt to substantiate this point. Initial work on augmented reality in command and control is that of Nilsson, Johansson and Jönsson[7], with the aim to improve collaboration. Rosen, Grigg, Lanier, McGrath, Lillibridge, Sargent and Koop[8] suggest that augmented reality is one of the techniques used in cyber command and control centres to manage information overload on commanders. Instead of displaying all information, augmented reality applications are used to display the information necessary per role and responsibility of an operator only.

After a short overview of augmented reality and related work, the joint command and control functions are used as a guide to discuss possible applications. Attention is paid to situation awareness and three specific functions: planning, current operations and exercise support. Technical challenges are highlighted before the discussion is concluded.

Overview of augmented reality and related work

A summary of the history of augmented reality is provided by Rawlinson[9]. The term *augmented reality* was coined by Caudell and Mizell[10], whilst developing a head-mounted display system at Boeing for efficiency improvements in aircraft

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[7] S. Nilsson, B. Johansson and A. Jönsson, "Design of Augmented Reality for Collaboration", *Proceedings of the 7th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and Its Applications in Industry*, Nr 47, Dec 2008.

[8] J. Rosen, E. Grigg, J. Lanier, S McGrath, S. Lillibridge, D. Sargent and C.E. Koop, "Cyberspace: The Future of Command and Control for Disaster Response", *IEEE Engineering in Medicine and Biology Magazine*, Vol 21, Nr 5, Oct 2002, pp. 56–68.

[9] D. Rawlinson. Augmented Reality Wiki, from http://www.augmentedrealitywiki.com/History_of_Augmented_Reality, accessed on 26 Jan 2010.

[10] T.P. Caudell and D.W. Mizell, "Augmented Reality: An Application of Heads-Up Display Technology to Manual Manufacturing Processes". *Proceedings of the Twenty-Fifth Hawaii International Conference on System Sciences*, Vol 2, Jan 1992, pp. 659–669.

manufacturing. Milgram and Kishino[11] introduced a more generic term, *mixed reality*, and defined a continuum for mixed reality. On the one extreme of the continuum, the real environment persists, whereas on the other extreme, only the virtual environment persists. Augmented reality and augmented virtuality then constitute mixed reality between these two extremes. The first lies towards the reality side of the continuum, and the latter to the virtual side.

Azuma[12] defines three requirements for augmented reality applications:

1) real and virtual aspects must be combined;
2) the application must be real-time and interactive; and
3) the visual display must be registered in the three dimensional (3D) world.

Although the term *augmented reality* was derived from the aircraft manufacturing industry, diverse applications quickly arose. Early simulators are cited as examples of augmented reality, but the study on which this article is based, only considered applications that combine real and virtual scenery in a display. A simulator typically combines physical interfaces, such as cockpits, handles and levers – representing the real world – with virtual displays. Head-mounted displays on the other hand represent augmented reality applications since information is projected in such a way that an operator can observe the real world directly – sometimes through some kind of visor. Milgram and Kishino[11] provide an excellent overview of all possible modes of augmented reality applications. Livingston, Swan, Julier, Baillot, Brown, Rosenblum, Gabbard and Höllerer[13] summarise some performance measurements for augmented reality applications, including perceptual and cognitive measures, and then continue to do a heuristic evaluation of an augmented reality experiment. Aspects evaluated are drawing styles, opacity, intensity, target position, ground plane, stereo vision and repetition.

Turunen, Lankila, Pyssysalo and Roning[14] briefly discuss augmented reality applied for personal navigation, and provide some performance requirements for position and orientation accuracy.

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[11] P. Milgram and F. Kishino, "A Taxonomy of Mixed Reality Visual Displays", *IEICE Transactions on Information Systems*, Vol E77-D, Nr 12, Dec 1994.

[12] R.T. Azuma, "A Survey of Augmented Reality", *Teleoperators and Virtual Environments*, Vol 6, Nr 4, Aug 1997, pp. 355–385.

[13] M.A. Livingston, J.E. Swan II, S.J. Julier, Y. Baillot, D. Brown, L.J. Rosenblum, J.L. Gabbard and T.H. Höllerer, "Evaluating System Capabilities and User Performance in the Battlefield Augmented Reality System", *Performance Metrics for Intelligent Systems Workshop*, Gaithersburg, Aug 2004.

[14] T. Turunen, T. Lankila, T. Pyssysalo and J. Roning, "Realization of Mobile Augmented Reality-Based Personal Navigation Services in 3rd Generation

Billinghurst, Grasset and Looser[15] define augmented reality as an attempt to map user input onto computer output using some interaction metaphor. They also propose the term *tangible augmented reality* when a visual display is coupled to a physical device (interface).

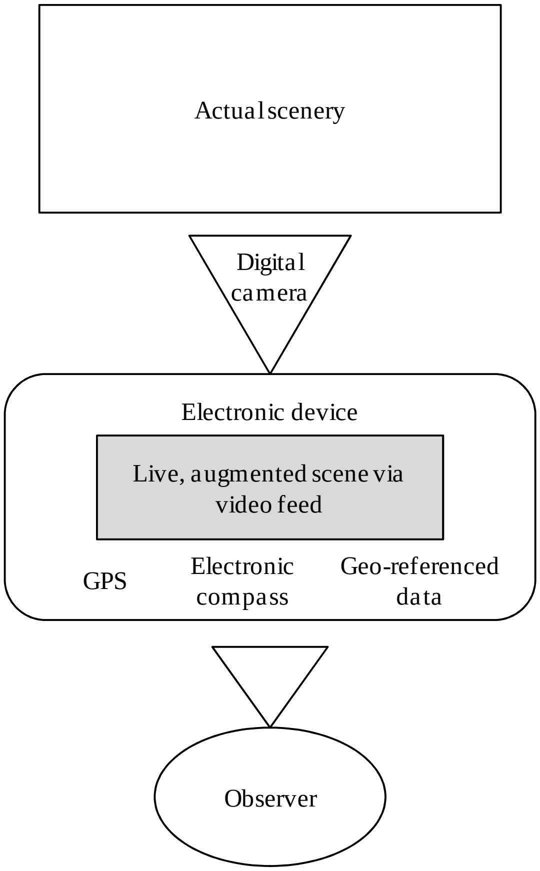

Figure 2: Conceptual model of an augmented reality application

Cellular Networks", *Conference Record of EUROCOMM 2000: Information Systems for Enhanced Public Safety and Security*, Munich, May 2000, pp. 100–105.

[15] M. Billinghurst, R. Grasset and J. Looser, "Designing Augmented Reality Interfaces", *Computer Graphics SIGGRAPH Quarterly*, Vol 39, Nr 1, Feb 2005, p. 17–22.

Some augmented reality configurations use head-tracking devices, similar to those used for immersive virtual reality applications and head-mounted displays. This means the operator is free to move his/her head around, typically unrestricted in a confined area, whilst looking at a fixed display console. The graphics on the display console will be orientated in real-time to provide the correct viewing angles of the displayed scene. The augmented reality technique assumed in this article for command and control applications relies on a handheld electronic device. The electronic device may be moved around and orientated, as depicted in Figure 1. The display is therefore not in a fixed position as with the immersive virtual reality case. The observer is still free to move his/her head unrestricted, but now unconfined. The display is determined by the position and orientation of the device, rather than the position and orientation of the observer's head. In reality, the position of the electronic device is limited to signal reception. In the case of a cellular telephone, this is determined by the coverage of the cellular telephony service provider.

Figure 2 presents a conceptual model of an augmented reality application. The observer views reality via a live, augmented video feed. At any point in time, the observer may switch between using the device to view the scenery or to view the scenery without the device.

Although augmented reality applications mainly arose from the manufacturing and military industries, a proliferation of applications is experienced in the interactive and information entertainment markets. Dumas[16] lists the seven best augmented reality applications, Inbar[17] lists the ten best games using augmented reality, and Thompson[18] discusses how James Cameron used augmented reality as a pioneering technology in film making, most notably with the movie *Avatar*.

Command and control

Command and control in the South African National Defence Force context, addresses all levels of military operations, as well as all the functions

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[16] D. Dumas, "7 Best Augmented Reality Apps", *Wired Magazine*, Vol 17, Nr 12, Dec 2009, from http://www.wired.com/magazine/2009/12/st_augmented_reality_apps, accessed on 28 Jan 2010.

[17] O. Inbar, "Top 10 Augmented Reality Demos that will Revolutionize Video Games", *Games Alfresco*, March 2008, from http://gamesalfresco.com/2008/03/03/top-10-augmented-reality-demos-that-will-revolutionize-video-games, accessed on 28 Jan 2010.

[18] A. Thompson, "View from the Brink", *Popular Mechanics,* South African Edition, Vol 8, No 7, Feb 2010, pp. 41–47.

necessary to conduct operations. Activities central to operations are planning, tasking and control, supported by situation awareness.

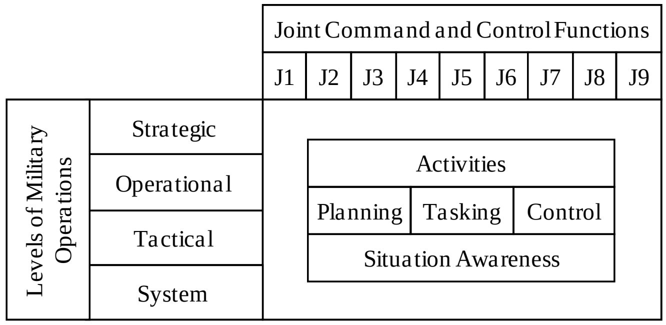

Figure 3: Command and control[19]

Figure 3 depicts command and control in the joint operations context across the different levels of military operations and joint command and control functions[19]. The functions are J1 (Personnel), J2 (Intelligence), J3 (Operations), J4 (Logistic Support), J5 (Planning and Future Operations), J6 (Communications and Information Systems), J7 (Training and Exercises), J8 (Civil-Military Cooperation) and J9 (Host-nation Support). From reports in the open literature, augmented reality shows promise in all of these functions.

To support Personnel functions, applications exist that identify a person, and then provide additional information regarding the person, such as The Astonishing Tribe's Augmented Identification application. Similar applications could be useful in the intelligence domain, while there could be applications that provide additional information for specific locations. Applications for Operations (J3), Planning (J5) and Communications (J6) are addressed later in this article.

Caudell and Mizell's original work is in the aircraft manufacturing industry to assist technicians with locating positions of holes and rivets that require precision and accuracy. It could easily be extended to logistical support where a technician uses an augmented reality application to identify a part so that it could be

[19] Discussions with H.J. Harris; W.H. le Roux, "Interoperability Requirements for a South African Joint Command and Control Test Facility", *Proceedings of the 2008 European Simulation Interoperability Workshop*, Edinburgh, Jun 2008, pp. 87–96; A.C. Kalloniatis, I.D.G. Macleod and P. La, "Process versus Battle-Rhythm: Modelling Operational Command and Control", *Proceedings of the 18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation*, Cairns, July 2009, pp. 1622–1628.

replaced with the correct one. These types of applications typically require accurate operator tracking, or tracking of a pointing device.

Personnel information, location information and performance tracking would provide valuable tools for Training (J7). If a trainer could view additional information of a trainee, such as previous performance statistics, whilst engaging with the trainee, more effective alternatives could be selected. This would rely on similar applications as reported by Dumas. Other possibilities include training and logistics for maintenance, as reported by Schwald and De Laval[20] for the industrial domain. Accurate head tracking is a requirement here.

Possible applications for Civil-Military Cooperation (J8) and Host-nation Support (J9) are similar to people identification, site information and in the case of different cultures working together, possibly background information. For civil-military operations, different applications could be used to provide capability-specific information. To illustrate, a military operator will view a situation using military symbols, whereas the civilian operator will view the situation using another set of symbols. Johansson and Nilsson[21] report applications in the Civil-Military Cooperation (J8) domain, where a military commander can rely on an augmented reality application instead of having to explain a military symbol to a civilian. The latter's work mainly focuses on achieving shared understanding, an important constituent of shared situation awareness, with augmented reality.

Situation awareness

Situation awareness is crucial to most military operations, but has different requirements across the different levels of military operations and the different functions (J1 to J9). Although the initial focus of this work will be on Operations (J3) at the tactical level, some of the concepts are also applicable to the Planning (J4) and Communications (J6) functions. Situation awareness in context of command and control, is addressed as a collaborative action by Riley, Endsley,

[20] B. Schwald and B. de Laval, "An Augmented Reality System for Training Assistance to Maintenance in the Industrial Context", *Proceedings of the 11th International Conference in Central Europe on Computer Graphics*, Visualization and Computer Vision, Plzen, Feb 2003.

[21] B.J.E. Johansson and S. Nilsson, "Augmented Reality as a Tool to Achieve Common Ground for Network-Based Operations", *Proceedings of the 13th International Command and Control Research and Technology Symposium*, Seattle, Jun 2008.

Bolstad and Cuevas,[22] who analysed a complex planning and course of action development. Challenges to planning were identified by using cognitive task analyses, namely:

1) rapid development of plans and dissemination of plans;
2) visualisation of plans and tracking of deviations to plans;
3) contingency planning;
4) distributed collaborative planning; and
5) plan rehearsal.

The challenges listed above were identified from a land-battle scenario. Similar challenges may be identified for the rest of the activities indicated in Figure 3. Tasking has more of a hierarchical nature than planning – orders permeate down the hierarchical structure to result in a concerted operation. Some challenges are:

1) rapid dissemination of orders;
2) acknowledgement of received orders together with execution confirmation (can or cannot comply); and
3) cancellation or modification of orders or new orders.

Control can best take place if constant monitoring is possible, and not just the monitoring of intermediate control points. Some challenges are:

1) increased loading on operators to provide status reports;
2) dissemination of status reports;
3) aggregation of status reports and data to prevent overload at higher level control points; and
4) delays between the status report processing and plans and orders revisions – i.e. how long after a status report was received can plans and orders be revised and disseminated to rectify a situation.

Initially, augmented reality applications aiming to solve the above challenges focus on plan rehearsal, visualisation and collaboration trying to solve challenges such as the dissemination of plans and orders do not seem appropriate. Situation awareness differs between the different levels, functions and services of a defence force. To illustrate this, consider the situation awareness requirements of a dismounted soldier in an urban operation. Knowing which route is optimal and where all his/her team members are at all times, are crucial. Knowing the intent of all operators in his/her direct vicinity is equally important. The commander of a

[22] J.M. Riley, M.R. Endsley, C.A. Bolstad and H.M. Cuevas, “Collaborative Planning and Situation Awareness in Army Command and Control”, *Ergonomics*, Vol 49, Nr 12–13, Oct 2006, pp. 1139–1153.

Joint Operations Centre providing support to an operation-other-than-war, such as a large sports event, has different needs. Managing diverse resources and diverse threats requires accurate tracking. Situation awareness is less visual and more focused on reports in this situation. Augmented reality applications would therefore also be diverse and dedicated to specific activities – a catch-all application is not easily attainable.

Augmented reality applications

In previous sections, examples of possible augmented reality applications were offered for some of the Joint Command and Control functions. The following sections provide some application concepts for the remaining functions: Operations (J3), Planning (J5) and Communications (J6). Additional concepts are also defined for Exercise Support (J7)

Proposed augmented reality applications — Planning (J5)

Planning is a complex military process designed for rigour and robustness. Various phases and activities are performed by various operators. Boukhtouta, Bedrouni, Berger, Bouak and Guitouni[23] surveyed various planning systems and processes in the Canadian Air Force context with some mention of naval and joint systems. Aspects mentioned are deployment and battle operations, automated planning, development and execution, analysis and re-planning tools, anticipatory planning support, collaboration support, action planning, adaptive resource management agents, decision scheduling, mission control, flight planning, strategic planning, and planning architectures. Boukhtouta[23] summarises the military planning process from the Canadian Forces Operational Planning Process[24] as initiation, orientation, courses of action development, plan development, plan review and the generation of operational orders for deliberate plans.

Two modes of using augmented reality are foreseen for planning. The first is to provide a means for easier collaboration and shared awareness between operators, when they are not necessarily at the physical location of the operations. The traditional sandbox, paper-based maps or even computerised maps may be used for planning with devices to augment the scenarios being discussed. Additional

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[23] A. Boukhtouta, A. Bedrouni, J. Berger, F. Bouak and A. Guitouni, “A Survey of Military Planning Systems”*, Proceedings of the 9th International Command and Control Research and Technology Symposium,* Copenhagen, Sep 2004.

[24] Canadian National Defence, *The Canadian Forces Operational Planning Process*, edition 2, ratification draft, B-GJ-005-500/FP-000, Oct 2002.

information used to augment the view can be text, animations or graphics. These may provide information on alternatives, such as alternative routes by means of symbols, intelligence data on opposing forces in the form of geo-referenced text, or even what-if simulations. Figure 4 depicts a sandbox studied by Lyndon Johnson (second from left) and others with a few augmented reality concepts superimposed on it. The figure attempts to show what the first person (the photographer) would see through his augmented reality-capable device. The two coloured lines and two callout boxes represent the augmentation. The electronic device needs to be aware of the position and orientation of the real sandbox, which could be achieved via some markers, electronic or otherwise.

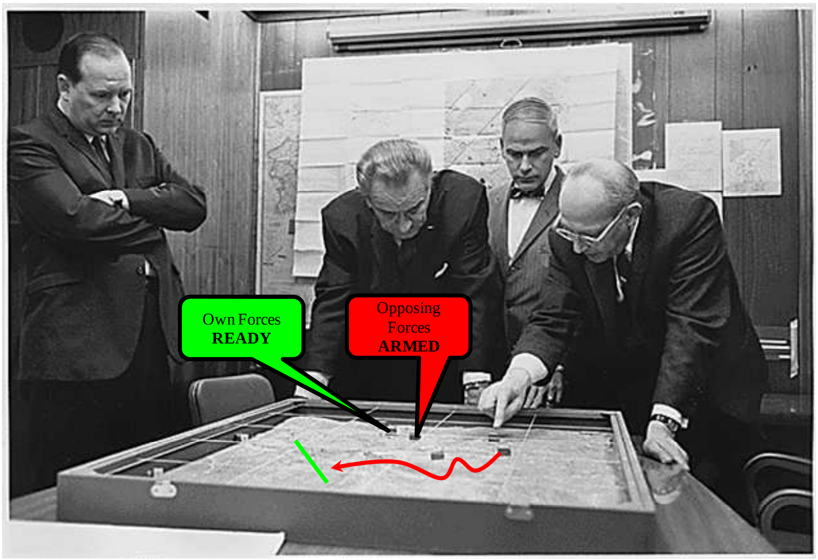

Figure 4: A sandbox with augmented reality[25]

The second mode attempts to augment visuals when physically at the area of operations. This may be part of site reconnaissance or intelligence operations. The latter is typically for an operation, whereas the former would be to prepare for an exercise. Access to sites for operations may not always be possible before an operation commences. In any case, information that could be displayed based on the

[25] Photo taken and adapted from http://en.wikipedia.org/wiki/Military_simulation, accessed on 8 Feb 2010.

geo-referenced position and orientation of an augmented reality device includes the following:

1) elevations may obscure parts of the terrain – these may be highlighted in such a way that the operator is aware of the obscuration;
2) visual or radio frequency line-of-sight can be visualised between different locations;
3) anticipated attack directions of opposing forces;
4) geo-referenced intelligence data, displayed as text boxes at the appropriate locations;
5) meteorological information, such as the prevailing wind direction;
6) planned placement and movement of own or other forces could be played out as animations or shown as static graphics;
7) mobility issues due to terrain, not visible from the current position, may be highlighted with animations;
8) the impact (footprint) of a planned deployment on the terrain – this can be done in such a way that operators could move between virtual buildings to assess logistical, efficiency or other impacts on the placement of important resources; and
9) planned areas of responsibility, surveillance and effecting arcs, effective volumes and ranges of sensors and effectors.

It is anticipated that once an augmented reality application that enables some of the functionalities listed above is evaluated, new requirements will quickly emerge.

Proposed augmented reality applications – Operations (J3)

Operations may be visualised in similar ways as the on-site visualisation concepts discussed in the previous section. In addition to the display of planned information, current information, as part of current operations, can be displayed against, among others, planned information to ascertain deviations. Similar visualisations are applicable to exercises. Real-time visualisations of opposing force developments may be shown, especially if an operator is observing the progress of an operation away from his/her normal situation awareness support systems.

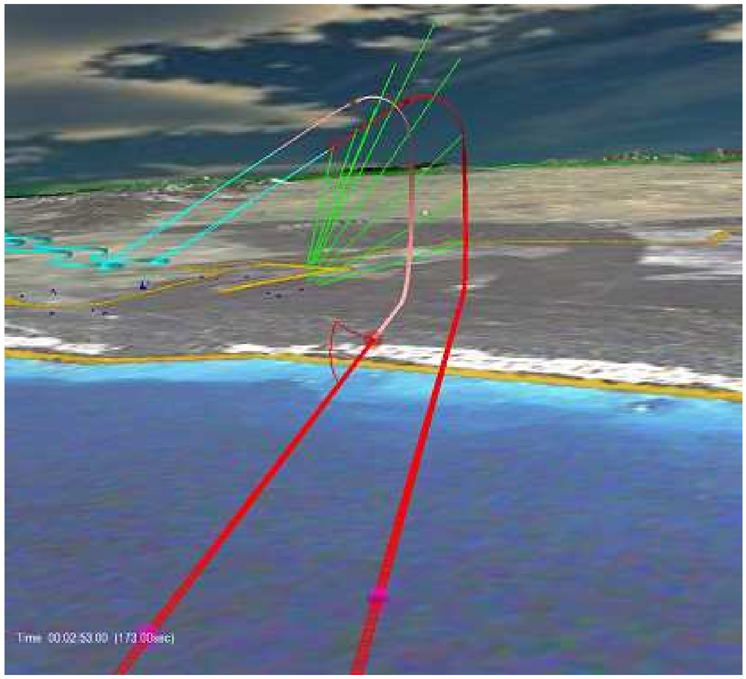

Figure 5: Simulated sequence of events[26]

Figure 5 depicts a scenario where planned flight profiles are indicated as blue lines, and the progress of the aircraft as red sections over the blue, planned lines. Green lines indicate possible effector trajectories. Although the figure shows a simulated terrain, it is intended to be the actual terrain observed via an augmented reality device. The orange lines draped onto the terrain depict fire arcs of some of the deployed effectors in the scenario.

Proposed augmented reality applications — Communications (J6)

Communications operators always face a problem when they cannot directly observe a communications link. This holds for the status of a link as well. Consider the scenario where an operator is charged with maintaining a number of links to different geographic sites. Instead of being tied to a console where he/she

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[26] Three-dimensional scenario generated with a simulation environment developed and used at the Council for Scientific and Industrial Research.

can observe the status of each link, or to continuously enquire via radio whether a link is operational, an augmented reality application displays links as geo-referenced lines between sites, with a colour that is significant in terms of status. This allows the operator to roam freely, whilst being able to observe links' status easily.

Proposed augmented reality applications — Exercise Support (J7)

As mentioned previously, deviations from trained profiles can be visualised by comparing planned and actual data. Another possibility for exercise support is found where operators, observers or stakeholders are present at an exercise covering larger geographic areas, or where the terrain is such that entities that need to be visible to the observers are too far away or obscured. Anyone who has been to a field exercise where combat aircraft were deployed could attest to the difficulty of visually acquiring and tracking these aircraft.

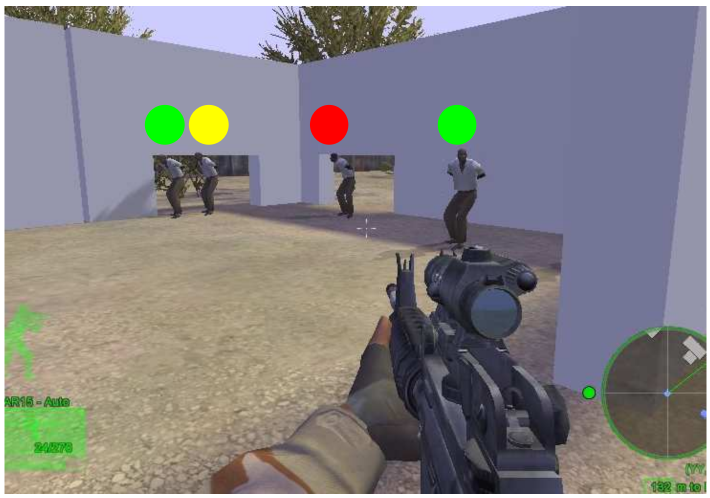

Figure 6: Special operations augmented reality concept[27]

Augmented reality devices linked to the telemetry systems of the test range could then cue observers visually. A second supporting scenario is for special operations exercises, where multiple force affiliations are represented – the participants should not be aware, at least visually, of the affiliations of all those

[27] The scene was generated with a first-person shooter simulation environment, Virtual Battle Space-2®.

present, but to external observers it usually is necessary. Affiliations could be displayed with an augmented reality application.

Figure 6 portrays an augmented reality concept where the coloured circles indicate the affiliations of the exercise participants.

Technical challenges

Various technical challenges exist for the different modes of augmented reality applications. For the mode described in this article, where an electronic device is used, some challenges are discussed in the following paragraphs.

Geo-location accuracy

As indicated, the augmented reality application relies on a GPS device to determine the current position of the device. Even though GPS technology is much more advanced now, Yoshimura, Nose and Sakai[28] report errors between approximately 1 m and 30 m, depending on the quality of the unit and the antenna configuration. However, with ultra-mobile units, an assisted GPS device is used. Zhao[29] provides an overview of assisted GPS, and cites accuracies of better than 20 m in 67% of cases in unobstructed areas. Errors in this range are acceptable for large, outdoor areas, such as the combat aircraft example described earlier. However, for applications such as the sandbox in Figure 4, it is unacceptable. In such cases, additional or alternative positioning schemes will be necessary – these could be pattern recognition-based if visual markers are used (registration), or electronically based, if transponders are used. In general, the better the location accuracy, the better the end-results will be. Current entertainment electronic devices such as the Nintendo® Wii[30], provide very accurate tracking of orientation and movement of the game devices. It is also possible to customise these devices for other uses, such as reported by Rickard and Davis,[31] to track an object.

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[28] T. Yoshimura, M. Nose and T. Sakai, "High-end GPS vs. low-end GPS: Comparing GPS Positional Accuracy in the Forest Environment", *Proceedings of the International Precision Forestry Symposium*, Stellenbosch, Mar 2006, pp. 429–436.

[29] Y. Zhao, "Standardization of Mobile Phone Positioning for 3G Systems", *IEEE Communications Magazine*, Vol 3, Nr 7, Jul 2002, pp. 108–116.

[30] See http://www.nintendo.com/wii for more information, accessed on 12 Feb 2010.

[31] I.F. Rickard and J.E. Davis, "Self-Calibrating Optical Object Tracking using Wii Remotes", *Proceedings of Sensors, Cameras, and Systems for Industrial/Scientific Applications X*, Vol 7249, Jan 2009.

Uenohara and Kanade[32] discuss a vision-based system for an augmented reality application in the medical domain that overcomes the problem of prior scenery knowledge by using geometric models of objects. However, this will remain a problem in diverse scenarios, where objects to be recognised are not known beforehand. Vision-based systems have the advantage that they normally include the orientation requirement for augmented reality applications.

Cho, Kang, Park, Park and Kim[33] present a radio frequency-based system for indoor localisation with an accuracy of 1.8 m. This system relies on a mobile unit to determine position. Priyantha[34] proposes a radio frequency beacon with ultrasound that also estimates the orientation of the unit being tracked to an accuracy of 5 cm for location and 3 degrees for orientation. From an intuitive point of view, an accuracy of 1.8 m is not sufficient for the sandbox scenario depicted in Figure 4, but the accuracy of 5 cm is. The implication of localisation accuracy on system performance is dependent on the application as well as the mode – an outdoor system to visualise combat aircraft trajectories has less stringent requirements than an indoor, sandbox system. However, a sensitivity analysis will be necessary for a given application to determine usability.

Orientation and direction accuracy

Ultra-mobile electronic devices with high orientation accuracy are widely available, ranging from cellular telephones to entertainment devices. Some of these are so accurate that it is possible to play a completely computerised version of the ever-popular hand-held mini ball maze game, as depicted in Figure 7.

Depending on the augmented reality mode, direction may also be required in addition to orientation. This especially holds for applications such as the combat aircraft exercise scenario example. Various electronic devices such as cellular phones have electronic compasses. The accuracy of electronic compasses are

[32] M. Uenohara and T. Kanade, “Vision-Based Object Registration for Real-Time Image Overlay”, *Computers in Biology and Medicine*, Vol 25, Issue 2, Mar 1995, pp. 249–260.

[33] H. Cho, M. Kang, J. Park, B. Park and H. Kim, “Performance Analysis of Location Estimation Algorithm in ZigBee Networks using Received Signal Strength”, *21st International Conference on Advanced Information Networking and Applications Workshops*, Vol 2, Ontario, May 2007, pp. 302–306.

[34] N.B. Priyantha, “The Cricket Indoor Location System”, PhD thesis, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Jun 2005.

typically less than 5° (Cox, Scalf, Jamison and Lutz[35]), where, again, the influence of this error can only be determined given the augmented reality application mode and function.

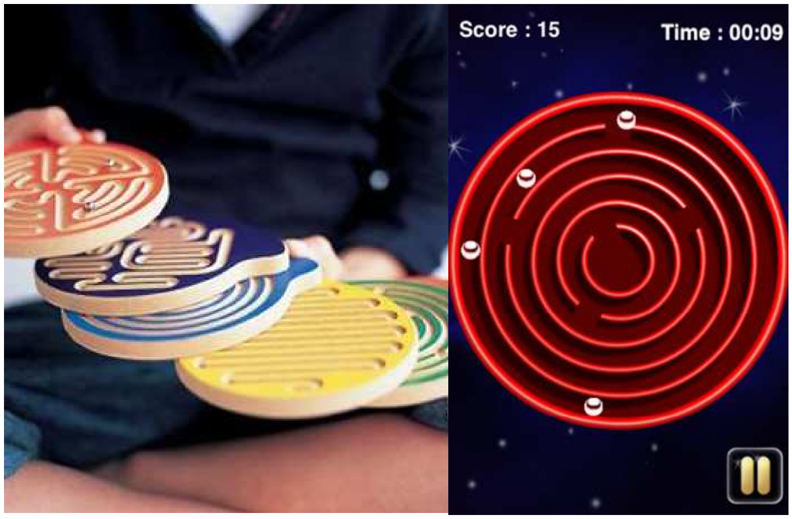

Figure 7: Mini ball maze game, wooden[36] and electronic[37] versions

Turunen *et al*. provide guidelines for orientation accuracy, depending on the augmented reality application type. For personal navigation, an orientation accuracy of 2° is specified, for context awareness 5°, and for telepresence 0.5°. Command and control applications will have similar requirements. In the case of the combat aircraft scenario, a ±5° orientation error, if you are an observer, will not have serious performance effects; however, if you are an operator that has to acquire an aircraft in the shortest possible time, it will detrimentally affect system performance.

Although humans are more than capable of correcting, or ignoring for that matter, image registration errors, operators tend to expect a certain level of

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[35] R.R. Cox (Jr.), J.D. Scalf, B.E. Jamison and R.S. Lutz, "Using an Electronic Compass to Determine Telemetry Azimuths", *Wildlife Society Bulletin*, Vol 30, Nr 4, 2002, pp. 1039–1043.

[36] Image taken from http://www.whippetgrey.co.uk, accessed on 12 Feb 2010.

[37] Image taken from http://iphront.com/numazelite-games, accessed on 12 Feb 2010.

performance. Visual errors are also easily detectable, even by the untrained eye, whereas other more deep-seated technical errors are more difficult to detect. Correcting for certain errors in real-time is technically and computationally challenging and does not necessarily justify the functional gain, but in spite of this, operator satisfaction goes a long way to accept new technologies.

Real-time video display

A key facet of augmented reality is the direct or indirect observation of reality. Here, an indirect mode is proposed where the operator observes reality via a real-time video display. It can be anticipated that this will occur in parallel, or with frequent switching between direct and indirect observation, since the devices are relatively small compared to the available field-of-view of the operator. This is demonstrated in Figure 1, where the operator can view both the real-time video display on the device at the same time as the real scenery in front of it. It is also likely that allowing switching, at the will of the operator, will be preferred in the command and control context. This enables the operator to use whichever mode is appropriate in a given situation and to re-orientate. With other modes, this may not be always possible and may result in resistance to the technology.

Most cellular telephones and other ultra-mobile devices have real-time video capabilities to allow video telephone calls and video recording. The remaining technical challenge is the availability of appropriate tools and utilities for application development. Open operating systems, such as Android™, for mobile devices, provide these tools, specifically to stimulate third-party application development[38].

Connectivity and access to geo-referenced information

Connectivity is rapidly advancing to levels where it is almost ubiquitous, at least in the developing and first world countries. Bandwidth is sufficient to provide route navigation on devices that rely on internet connections for map data (see for example Google™ Maps[39]). Similar services could potentially provide geo-referenced data and content. To illustrate, information regarding a current location could be retrieved from OpenStreetMap[40], in the form of a street name. This represents the geo-reference data aspect. User content, also geo-referenced, may be geo-tagged digital photographs downloaded from an appropriate location. The data and content are then combined for some purpose, e.g. a restaurant review could be

[38] For more information, see http://www.android.com, accessed on 16 Feb 2010.
[39] For more information, see http://www.google.com/mobile/maps/index.html, accessed on 16 Feb 2010.
[40] http://www.openstreetmap.org, accessed on 16 Feb 2010.

displayed whilst pointing the device camera at the actual restaurant. Both the data and content may be provided via dedicated, custom databases, accessible via secure links. In case of the combat aircraft scenario at a test range, the data is obtained via the telemetry systems of the test range. Content information is retrieved via dedicated information sources.

For augmented reality applications in the command and control context, security issues are almost always raised when relying on internet connections. This can be solved by either providing a dedicated capability or secure links. Other connectivity options, such as wireless networking or Bluetooth® can be considered, but this limits the range between the augmented reality device and its access point.

Similar to connectivity, geo-referenced information is becoming so widely and freely available that the challenge is not a technical one, but rather how and which information sources are used. Geo-referenced data spans diverse domains, including almost anything that could potentially be linked to a geographic point, area or place of interest. Internet-based crowd sourcing and social networking are combined to spread the burden of geo-referencing data across hundreds of millions of internet users. This of course, may result in inconsistencies and errors.

Conclusion and future challenges

The article investigated the use of augmented reality in the command and control domain. It addressed joint command and control functions on a higher level. It is clear that augmented reality can contribute to the situation awareness of some operators in the domain but that each specific application needs its own evaluation.

Therefore, some concept demonstrators need to be implemented to further the process. Future work will have to include reporting on these results. Additional aspects to consider in the environment are opposing electronic and information operations that may influence the effectiveness of augmented reality applications, specifically during tactical operations.