AFRL-HE-WP-TP-2006-0038

AIR FORCE RESEARCH LABORATORY

Evaluation of Synthetic Vision Overlay Concepts for UAV Sensor Operations: Landmark Cues and Picture-in-Picture

Mark Draper
Gloria Calhoun
Jeremy Nelson

Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433-7022

Heath Ruff

General Dynamics
5200 Springfield St., Suite 200
Dayton OH 45431

February 2006

20060403508

Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
February 2006

2. REPORT TYPE
Technical Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Evaluation of Synthetic Vision Overlay Concepts for UAV Sensor Operations: Landmark Cues and Picture-in-Picture

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER
7184

5e. TASK NUMBER
09

5f. WORK UNIT NUMBER
72

6. AUTHOR(S)
Mark Draper, Gloria Calhoun, Jeremy Nelson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Materiel Command
Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433-7022

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/HECI

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-HE-WP-TP-2006-0038

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
This will be published in the Proceedings of the Human Factors & Ergonomics Society Annual Meeting. The clearance number is AFRL/WS-06-0571, cleared 28 February 2006.

14. ABSTRACT

Of all the information displays in an Unmanned Aerial Vehicle (UAV) control station, video imagery from UAV-mounted cameras is particularly valuable. Pilots use imagery from UAV cameras to verify a clear path for ground operations, scan for air traffic, and identify navigational landmarks, and potential obstructions. Sensor operators use video imagery from a UAV gimbal-mounted camera to conduct a wide variety of intelligence, surveillance and reconnaissance activities as well as to support combat operations. Video imagery quality, however, can often be compromised by narrow camera field-of-view, datalink degradations, poor environmental conditions, bandwidth limitations, or a highly cluttered visual scene (e.g., in urban areas or mountainous terrain).

15. SUBJECT TERMS
Unmanned Aerial Vehicle (UAV)

16. SECURITY CLASSIFICATION OF:

a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
UNC	UNC	UNC	SAR	8

19a. NAME OF RESPONSIBLE PERSON
Mark Draper

19b. TELEPHONE NUMBER *(include area code)*
(937) 255-5779

EVALUATION OF SYNTHETIC VISION OVERLAY CONCEPTS FOR UAV SENSOR OPERATIONS: LANDMARK CUES AND PICTURE-IN-PICTURE

INTRODUCTION

Of all the information displays in an Unmanned Aerial Vehicle (UAV) control station, video imagery from UAV-mounted cameras is particularly valuable. Pilots use imagery from UAV cameras to verify a clear path for ground operations, scan for air traffic, and identify navigational landmarks and potential obstructions. Sensor operators use video imagery from a UAV gimbal-mounted camera to conduct a wide variety of intelligence, surveillance and reconnaissance activities as well as to support combat operations. Video imagery quality, however, can often be compromised by narrow camera field-of-view, datalink degradations, poor environmental conditions, bandwidth limitations, or a highly cluttered visual scene (e.g., in urban areas or mountainous terrain).

Synthetic vision technology (also termed augmented reality) has the potential to ameliorate negative video characteristics and enhance UAV operator interpretation of the imagery. With this technology, spatially-relevant information, constructed from databases (e.g., terrain elevation, maps, photo-imagery, etc.) as well as networked information sources, can be represented as computer symbology and overlaid conformal, in real time, onto a dynamic video image display. This computer-generated symbology appears to 'co-exist' with real objects in the visual scene, highlighting points of interest to operators.

Presentation of a synthetic visual overlay in a conformal manner with sensor imagery has been demonstrated to reduce scanning time, reduce the need to mentally integrate spatial information from disparate sources, and facilitate attentional management (Wickens & Long, 1995). To date, research has primarily focused on how synthetic overlays can aid piloting tasks during manned flights (e.g. Prinzel, et al., 2002). For instance, flight guidance overlay symbology can be provided for reduced visibility conditions, especially during landings.

It is anticipated that a synthetic visual overlay could also benefit UAV missions (Calhoun, Draper, Abernathy, Delgado, & Patzek, 2005). It could improve operator situation awareness by highlighting elements of interest within the video image such as threat locations, key landmarks, emergency airfields, etc. Secondly, it can assist the operator in maintaining situation awareness of an environment if the video datalink is temporarily degraded. Synthetic vision overlays could also serve to facilitate intuitive communications of spatial information between geographically separated users.

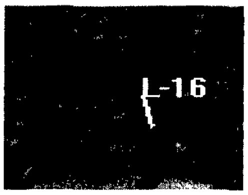
It remains to be demonstrated, however, that this technology does indeed benefit UAV operations. It also needs to be determined to what extent the overlay increases the potential for attention/cognitive tunneling to occur in UAV control tasks. Cognitive tunneling occurs when the operator becomes fixated on the synthetic cue itself (or objects to which attention is directed by the synthetic cue) to such an extent that other, un-cued events known to be of importance are not attended to (Yeh & Wickens, 2001). In the case of UAVs, this may result in the failure to detect unexpected, high priority targets.

Two synthetic vision overlay concepts are believed to be particularly valuable for improving UAV operator performance in finding ground targets with a UAV-mounted video camera. The first concept involves the simple highlighting of key landmarks in a scene with computer generated symbology, thus drawing operator's attention towards those areas. The second is termed 'picture-in-picture' (PIP), whereby synthetic-generated imagery surrounds the real video imagery on the display. This concept affords virtual expansion of the available sensor field-of-view well beyond the physical limits of the camera, potentially improving large area situation awareness.

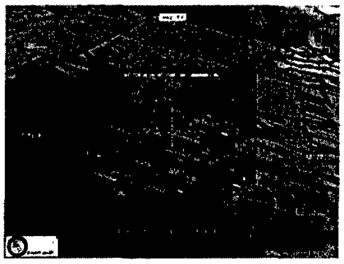
OBJECTIVE

The objective of this experiment was to evaluate synthetic visual symbology concepts overlaid on the camera display in a high-fidelity teleoperated UAV control station simulator. Participants performed a representative sensor operator task (searching for ground landmarks), utilizing the following synthetic overlay concepts:

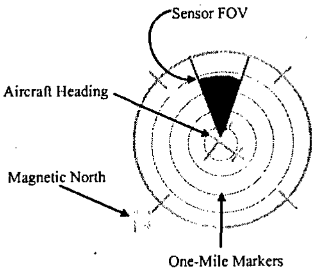
1. **Virtual Flags** (white) that point to key landmarks within the scene.



2. **Picture-in-Picture (PIP)** whereby the UAV camera video was bordered by a synthetically-generated scene of the surrounding area, thus expanding the visible field-of-view virtually.



3. **Spatial Orientation Symbol:** always fixed (not scene-integrated) in bottom right corner of the camera display, indicating current UAV & sensor orientation as well as horizontal sensor coverage.



METHOD

Experimental Design. The Spatial Orientation Symbol was present during all trials. Thus, only subjective data was analyzed to determine if participants found the symbol useful. The two other overlay concepts were experimentally manipulated: PIP (on, off) and Virtual Flags pointing to landmarks (on, off). Additionally, the positional accuracy of the camera's initial automated slew to the vicinity of the landmark was examined (low, high). For some trials the camera automatically slewed to a point fairly close to the landmark (i.e., the landmark was viewable on the screen at slew completion). For other trials the camera viewpoint ended up further away from the landmark (approximately 1.5 screen lengths away from the landmark) and the participant had to search a wider area in order to find it. This factor reflected the variable accuracy of targeting coordinates in real-world applications. With two replications, there were 16 experimental trials to examine these variables. An additional 8 trials were included to explore other effects, to be addressed in the full paper (see table below).

Number of Trials	Trial Type
16	**Experimental:** PIP (on/off), Flags (on/off), Camera Slew Accuracy (low/high), & Repetition (2)
2	**Unexpected Target:** one trial in Flags-On block, one trial in Flags-Off block to test cognitive tunneling effect: are unexpected targets more likely to be missed when flags are present?
4	***Recall:** one trial in each of four PIP/Flag blocks. Repeat of experimental trial to test if PIP and/or Flags increases situation awareness (SA), speeding up completion of recall tasks.
2	***Slew error:** one in PIP/Flag-On block & one in PIP/Flag-Off block. Camera slewed to opposite quadrant to test whether symbology reduces time to detect slew error.

* Results for these two tasks will be covered in full paper.

A within-subjects design was utilized with 16 participants. For the 16 experimental trials, trials with each PIP level were blocked, with participants receiving both Flag and Slew Accuracy levels (two reps each) with one PIP level prior to experiencing the other PIP level. Order of PIP level was counterbalanced across participants. The order of the Slew Accuracy level was randomized with the constraint that the Low and High Accuracy trials occurred an equal number of times across the 16 participants in the first, second, etc. blocks of experimental trials per participant. For each of the eight orders of experimental trials, the recall, unexpected target, and slew error trials were next sequentially inserted, with the insertion point randomly determined with the constraint that none were the first trial in a block and the recall trial was separated from the experimental trial recalled by either one or two other trials.

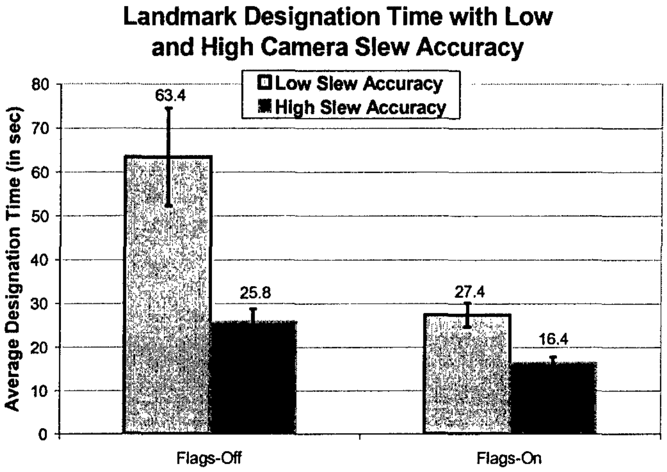
Simulation Environment. The UAV sensor operator workstation had upper and head-level 17" color displays, as well as two 10" head-down color displays (HDDs). A map (north-up) was shown on the upper display, with symbology identifying current UAV location, flight corridor, and numerical labels representing landmark locations. The head-level camera display presented simulated video imagery from the UAV's gimbaled camera, along with head-up display sensor symbology. The simulated imagery was a realistic database model of southern Nevada. The HDDs presented subsystem information. Participants used the keyboard for data entry and manipulated the right and left joysticks to control the camera's orientation and zoom factor, respectively.

Tasks. There was no flight control task; the UAV automatically loitered in a racetrack pattern. The participants' task was to manually control the camera orientation to locate, zoom in on, and designate specific landmarks. Participants completed practice trials until performance stabilized. For each trial, the experimenter issued a landmark number and then participants: 1) reviewed descriptive information regarding that landmark, 2) pressed a key to auto slew the camera to landmark area, 3) pressed a key to resume manual camera control, and 4) located/designated landmark (centering crosshairs on landmark and pressing joystick button). Participants were also instructed: a) if they saw a high priority fuel truck, they were to designate it instead of the landmark, and b) if the camera slew oriented the view to the wrong quadrant, they were to press a 'reset' key.

RESULTS

Time to designate landmarks was measured as well as the number of unexpected targets detected. Subjective ratings were obtained via post-trial and post-experiment questionnaires. Results are presented below by overlay concept.

Virtual Flags: Average landmark designation time (measured from manual control of the camera to designation of the landmark) was significantly faster when virtual flags overlaid the imagery (F(1,15)=14.104, $p<0.005$) and when the slew accuracy was high (F(1,15)=18.785, $p<0.005$). Moreover, a significant interaction of these two variables (F(1,15)=7.255, $p<0.05$) suggests that the flags were particularly beneficial with low slew accuracy, decreasing the difference between low and high slew accuracy by a factor of 2.3. Subjective data indicated that workload was lower and that flags were useful for finding landmarks (all $p<0.01$).


Landmark Designation Time with Low and High Camera Slew Accuracy

The number of unexpected targets detected with Flags-Off was not significantly different from the number detected with Flags-On (p=0.580, paired samples t-test) indicating that the overlaid symbology did not promote cognitive tunneling. However, participants' comments indicated that the flags could pose a problem in this way (e.g, "...with flags...less likely to look for...").

Picture-in-Picture (PIP): It was hypothesized that the use of PIP during low camera slewing accuracy would result in faster landmark designation times due to more of the environment being displayed instantaneously. However, results failed to show any significant effects (PIP (p=0.685), PIP x Slew Accuracy (p=0.176), PIP x Flag (p=0.763)). In the subjective data, participants were divided on PIP's benefit. Some felt that PIP was distracting, had potential alignment problems, and was overly cluttered (the synthetic imagery consisted of a multi-color aerial map of the region). Others felt that PIP was useful if flags were also available, as having the flags in both views helped relate the views and locate the landmark.

Spatial Orientation Symbol: All 16 participants responded that this symbol was helpful for locating targets. However, their specific comments indicated that they only used the compass points for maintaining situation awareness, not the sensor coverage information.

(Significant results for recall and slew error tasks will be covered in full paper.)

CONCLUSIONS

The overlay of virtual flags onto landmarks definitely improved performance and was favorably rated by all participants. The flag overlay significantly reduced landmark designation time and served to mitigate the negative effect of low camera slew accuracy, speeding landmark designation by over 50% for this condition. It is anticipated that the flag overlay will be especially beneficial in highly cluttered imagery or when landmarks are less salient. These data also did not show any cognitive tunneling effects due to the existence of virtual flags. Follow-on research is underway to further examine this synthetic vision overlay concept and to also test the implications of symbology update rate driven by UAV positional data.

Contrary to expectations, PIP was not found to improve landmark searches. The most likely explanation relates to the visual clutter in the synthetic imagery, from incorporating the same detailed map that was used in the upper map display. It was initially believed that using the same map across displays would facilitate situation awareness (visual momentum). However, the degraded resolution and visual clutter created by overlaying this map likely made perception of the small virtual flags difficult. The type and amount of visual information to display in the PIP region will be addressed in future research, as will other alternative implementations of this basic concept.

Although the participants rated the Spatial Orientation Symbol as useful, it appears elements other than the compass points were not beneficial for this particular task. Future research will develop a tailored display to better support large area searches by UAV sensor operators.

The results of the present study indicate that the synthetic information overlaid on the camera display has strong potential for enhancing imagery interpretation. It is suspected that the advantage of overlaid symbology for landmark/target designation and its ability to mitigate the effects of unreliable camera slew will make UAV operations more robust under a wide variety of situations. This, in turn, should increase UAV mission effectiveness substantially.

REFERENCES

Calhoun, G.L., Draper, M.H., Abernathy, M.F., Delgado, F., & Patzek, M. (2005). Synthetic vision system for improving unmanned aerial vehicle operator situation awareness. *Proceedings of SPIE 5802*, 219-230.

Prinzel, L.J., Kramer, L.J., Comstock, J.R., Bailey, R.E., Hughes, M.F., & Parrish, R.V. (2002). NASA Synthetic vision EGE flight test. *Proceedings of the Human Factors and Ergonomics Society*, 135-139.

Wickens, C.D., & Long, J. (1995). Object versus space-based models of visual attention: Implications for the design of head-up displays. *Journal of Experimental Psychology: Applied*, 1(3), 179-193.

Wickens, C.D., Thomas, L.C., & Young, R. (2000). Frames of reference for the display of battlefield information: Judgment-display dependencies. *Human Factors*, 42(4), 660-675.

Yeh, M., & Wickens, C.D. (2001). Display signaling in augmented reality: Effects of cue reliability and image realism on attention allocation and trust calibration. *Human Factors*, 43(3), 355-365.

Additional Short Abstract Required:

EVALUATION OF SYNTHETIC VISION OVERLAY CONCEPTS FOR UAV SENSOR OPERATIONS: LANDMARK CUES AND PICTURE-IN-PICTURE

UAV video imagery quality can be compromised by narrow field-of-view, environmental conditions, bandwidth limitations, or a highly cluttered scene. Synthetic vision overlay technology (i.e., augmented reality) can potentially ameliorate video characteristics and enhance UAV operations. This study evaluated three synthetic visual overlay concepts for improving the situation awareness of a UAV sensor operator. Sixteen participants searched for ground landmarks using a UAV-mounted gimbal camera simulation. Synthetic overlay concepts evaluated included virtual flags on landmarks, a synthetically-generated imagery border (picture-in-picture), and a display-fixed spatial orientation symbol. Results indicated that the three synthetic overlay concepts evaluated show promise for improving UAV operations. In particular, virtual flags reduced landmark search times by 40-58%. Although the picture-in-picture concept did not improve search times, performance and comments suggest an alternative instantiation of the concept to improve utility. Actual or potential applications of this research include control of unmanned vehicle systems and other teleoperated control applications.