Proceedings of the 2006 Systems and Information Engineering Design Symposium
Michael D. DeVore, ed.

Assessment and Enhancement of Synthetic Vision Systems Experimentation Software

Matthew L. Bolton, *Member, IEEE;* Thomas J. Hagan; Deniz Kustu, *Member, IEEE;* Lancen A. LaChance; Steven S. Li; Ellen J. Bass, *Senior Member, IEEE*

***Abstract*— Synthetic Vision Systems (SVS) are cockpit technologies which depict computer generated perspective displays of terrain surrounding an aircraft in order to prevent incidents of controlled flight into terrain. This paper evaluates a toolset designed to support experiments that assess the ability of different SVS displays to convey spatial awareness by having participants make spatial and temporal judgments after viewing videos of SVS displays in flight. The paper discusses the limitations of this toolset and identifies SVS experiments that the toolset could support. These experiments are used to derive requirements for toolset improvements. The paper then describes the toolset's current implementation status and establishes a trajectory for future development.**

I. Introduction

CONTROLLED Flight Into Terrain (CFIT), where a fully functional aircraft is inadvertently flown into the ground, water, or other terrain obstacle, has been the cause of more than 25% of all fatal accidents in worldwide commercial aviation since 1987, constituting a loss of 3,631 lives and making it the largest source of fatalities in commercial aviation [1]. CFIT accidents are characterized by a loss of situation awareness (SA) in low level flight and low visibility conditions [2].

Synthetic Vision Systems (SVS) are cockpit display technologies designed to prevent incidents of CFIT by using GPS data and onboard terrain databases to create a synthetic, clear-day, perspective view of the world surrounding the aircraft regardless of the visibility conditions [3].

Manuscript received April 10, 2006. This work was supported in part by NIA Rising Star Fellowship for Matthew Bolton, UVA-03-01, Sub-Award Number: 4817-UV

M. L. Bolton is a Ph.D. student at the University of Virginia, Charlottesville, VA 22904 USA (phone: 434-243-2280; fax: 434-982-5393; e-mail: mlb4b@ Virginia.edu).

T. J. Hagan is a undergraduate student at the University of Virginia, Charlottesville, VA 22904 USA (phone: 540-529-3152; e-mail: thagan1@gmail.com).

D. Kustu is an undergraduate student at the University of Virginia, Charlottesville, VA 22904 USA (phone: 434-227-0305; e-mail: denizkustu@ gmail.com).

L. A. LaChance is an undergraduate student at the University of Virginia, Charlottesville, VA 22904 USA (phone: 603-608-7539; e-mail: lancenlachance@ gmail.com).

S. S. Lee is an undergraduate student at the University of Virginia. Charlottesville, VA 22904 USA (phone: 860-917-9698; e-mail: ssl5b@ Virginia.edu).

E. J. Bass, is an Assistant Professor at the University of Virginia, Charlottesville, VA 22904 USA (email: ejb4n@virginia.edu).

Research documented in [4] described an experiment to evaluate the ability of seven different textures and two fields of view (FOVs) to convey three levels of spatial awareness for SVS displays. Spatial awareness was defined as the extent to which a pilot noticed objects in the surrounding environment (Level 1), the pilot's understanding of where these objects were with respect to ownship (Level 2), and the pilot's understanding of where these objects would be relative to ownship in the future (Level 3) [5].

The procedure in [4] had pilots watch five second videos [6] of the SVS display in straight level flight. In each video, a point was identified on the terrain via a yellow cylindrical cone. When the video was over, the display was cleared and pilots were asked to make four judgments related to the relative location of the terrain point. Relative distance, angle, and height judgments evaluated how well a participant was able to assess the spatial location of the terrain point. A time to fly abeam judgment (how long it would take the airplane to fly to the point of closest approach for the terrain point) was used to assess a participant's understanding of the point's relative temporal location. Additionally, at set intervals in the experiment, participants would provide subjective measures for each texture and FOV.

In order to support this procedure, researchers developed three tools [7]: the Flight Plan Generator (FPG) for defining flightplans and the location of terrain points, the SVS Video Recorder for capturing the flightplans to videos (the non-interactive simulations), and the Data Collection Interface (DCI) for ordering the videos into experiments, running these experiments, and collecting participant judgments and subjective measures during experiments.

Because the procedure supported by this toolset has produced significant results and supports short experiments with many independent variables, researchers at NASA Langley Research Center have shown interest in using this toolset to support the design and execution of future SVS experiments. Unfortunately, because this toolset was designed to support a specific experiment, all future experiments that might utilize it will be constrained by the underlying assumptions of this experiment. This paper identifies the limitations of the current toolset, identifies potential improvements that could be made based on the types of experiments that the toolset may be used to support, and describes progress in the implementation of these improvements.

II. Toolset Limitations

While the toolset proved useful for the purposes of [4], it is limited in its ability to design other experiments, its ability to execute experiments, and its usability.

A. Experimental Design Limitations

One limitation of the toolset is the lack of a shared configuration file. This is a problem because there are two experimental constants that are used by each of the toolset components: airspeed and scenario length. Airspeed controls the airspeed of the aircraft in each scenario and scenario length controls how long the video of the aircraft will play. These values are important to all three toolset components because they impact what the relative position of the terrain point will be at the end of the scenario. Unfortunately, if an experimenter wanted to change any of these values, he or she would have to edit the source code for each of the programs.

Another limitation of the toolset is the restrictions it puts on flightplans. In the current implementation, only straight, level flightplans can be defined using the FPG.

A third limitation is that the toolset always assumes the presence of a terrain point. This has implications for both the FPG and DCI: the FPG requires that all scenarios have a terrain point; the DCI expects scenarios to contain a terrain point so it can collect and calculate the error in participant special awareness judgments. While this is not problematic for running experiments using the same procedure from [3], it would be problematic for procedures not concerned with the relative location of a terrain point.

Another problem is that the current toolset only supports the use of specific SVS display parameters as independent variables (texture and FOV), and only recognizes specific values of these parameters (texture must be one of the textures used in [4], and FOV must be either 30° or 60°). Thus, the current toolset cannot support independent variables (and their levels) not used in [4], making it impossible for researchers to investigate other SVS display parameters (display size, symbology, etc.) using it.

B. Experiment Execution Limitations

Experiment execution occurs exclusively in the DCI. Thus, all limitations to experiment execution occur because of design decisions made for the DCI.

Because the DCI was designed exclusively to support [4], it expects all experiments to follow [4]'s experimental methods. Thus, when running experiments, the DCI will examine the each scenario and determine when to show transition messages (dialog boxes that describe the experiment and give instructions to participants), when to collect judgments, and when to collect subjective measures. If a procedure does not match those used in [4], the software will crash or display incorrect information.

Additionally, the DCI does not give experimenters the ability to determine what types of data will be collected or the ability to specify when specific types of data are collected. This limitation prevents researchers from conducting studies using judgments and measures that are not supported by the toolset.

In order to prevent test participants from inadvertently exiting the program during testing procedures, the DCI will not allow an experiment to be terminated once it has been started. Additionally, because participants are only intended to see each video once, the DCI does not allow videos to be played repeatedly. While these features are advantageous when running participants, they make it very difficult to demonstrate the testing procedure.

C. Usability Limitations

The usability limitations of the toolset stem from a lack of documentation and human-computer interface shortcomings.

The original version of the toolset contains no documentation, having been designed exclusively for use in a single experiment. This makes it extremely difficult to use or modify the tool. This problem is compounded by poor display designs limited input error checking, lack of on-line instructions, and inclusion of legacy functionality.

There are also unintuitive allocations of functionality within software applications. For example, in order to capture a video clip of a saved scenario (created using the FPG), an experimenter must launch the FPG, load the desired scenario, and apply the scenario before using the SVS video recorder to capture video (this process is discussed in [7]). In order to reduce the number of steps in this process, the functionality of the SVS video recorder could be implemented in the FPG. There are also issues with the DCI. The DCI is used to both design experiments and run them, making the DCI larger and more computationally complex than it needs to be to run experiments, and needlessly abstracting two functionalities into a single executable. These problems could be remedied by separating the design of experiments from the running of experiments into separate programs.

III. Potential Uses of the Toolset

In order to predict what modifications to the toolset would be the most advantageous to its users, the authors conducted a requirements analysis to determine types of experiments the toolset could support. The analysis also attempted to define what the requirements of these new procedures would be.

One of the ways this toolset could be used would be in variations of the experiment conducted in [4], where participants view video clips of SVS displays in flight and make spatial awareness judgments. There are a variety of different experimental variations that a researcher might wish to explore. For example, in addition to textures and FOVs not tested in [4], there are SVS display parameters that may impact spatial awareness. These include: display size, atmospheric perspective, the size of the grid used in fishnet based textures, and the type of symbology superimposed on the SVS display. Experimenters may also wish to change the airspeed and scenario length. If the toolset were to support such variables, it would require a way for the researchers to specify their values for each scenario in the FPG, and have these values be recognized by the DCI.

Because almost 70% of the CFIT incidents occur during the approach and landing phases of flight [2], researchers may wish to use the toolset in an experiment assessing spatial awareness for descending and curving flightplans as well as for flight plans with turns.

There are other SVS experiments that might be well suited to the procedure supported by this toolset. For example, researchers have investigated the use of SVS to display the position of nearby aircraft [9]. Researchers could use the toolset to conduct experiments where participants are asked to judge the relative spatial and temporal location of air traffic in SVS displays.

SVS research has also investigated different types of symbology and instrumentation for use in SVS displays [10][11]. Experimenters may wish to use the procedure supported by the toolset to test new symbology and instrumentation concepts.

For symbology and air traffic research, modifications will likely need to be made to the SVS simulation, and the relevant parameters for defining scenarios would need to be accessible through the FPG. Additionally, the DCI would need to be able to support any data collection capabilities required by these experiments.

IV. Requirements Analysis and Implementation Suggestions

Since it is impossible to anticipate exactly which variables experimenters may wish to vary between experimented trials, and what data collection capabilities every future experiment will employ, the authors attempted to develop requirements for the improvement of the toolset that would accommodate as many unknowns as possible. Each of the following requirements specifically addresses problems with the toolset and proposes solutions that are compatible with the toolset's anticipated uses.

A. Documentation

In order to facilitate the development and usability of the toolset, documentation should be developed for each of the toolset's components. This documentation should describe how each of the tools is used and functions. This documentation should be updated with each incremental improvement of the toolset to assist future developers and users.

B. Redistribution of Toolset Functionality

The SVS video recorder should be integrated into the FPG in order to reduce the number of steps required to number of steps to capture video of a scenario. The experimental design component of the DCI should be separated from the DCI and reconstituted as a separate application (referred to as the experiment builder).

C. Shared Configuration File

A configuration file should be created that defines all of the shared variables (such as airspeed and scenario length) for the toolset's programs. Each of the programs should be modified to use this file.

D. Flexible Terrain Point Assumption

The FPG should allow experiments to be run without including a terrain point in a scenario. This will support experiments that are not concerned with collecting spatial awareness judgments with respect to the ground.

E. More Complex Flight Plans

The FPG should be modified to allow for flightplans that support curves, assent, and descent. This will allow experimenters to define scenarios that imitate the approach and landing phases of flight.

F. Demonstration Utility

A demonstration utility should be created that would support all of the following: playing each video in a continuous loop; playing, pausing, and traversing between videos; allowing the size of the video playback to be scaled to accommodate different display sizes and resolutions; and launching the data collection interface used in the experiment. The demonstration utility should make no assumptions about the underlying experimental design.

G. Scenario Associated Configuration Files

Almost all of the SVS simulation configuration parameters can be controlled via configuration files. In order to give experimenters as much control over experimental variables as possible, the FPG will associate each scenario with these configuration files. The FPG will provide users with the means to edit the parameters to these files, and allow their data to be saved as part of a single scenario file. When a scenario is applied, the FPG will replace the appropriate configuration files in the SVS simulation.

This modification allows the toolset to support all of the following: SVS display parameters not supported by the current toolset; different SVS simulations; and modifications to SVS simulations whose new variables are reflected in configuration files.

In order to allow data in these configuration files to be recognized by the DCI, the FPG must provide a means for users to specify important values from each configuration file that will be recognizable by named variables by the DCI and experiment builder.

H. Video Recording Scripting

To allow the toolset to support as many SVS simulations as possible, the SVS video recorder functionality (now in the FPG) should support a scripting system that will allow users to define how the toolset will launch and automate the SVS simulation and synchronize its playback with the video capturing software.

I. Experiment Scripting System

In order to relax the assumptions associated with experimental design, the experiment builder and DCI will support a scripting system that will allow experimenters to define each experiment in a sequential manner.

This scripting language will allow experimenters to specify when a video is played, how playback is terminated (clear, pause then clear, do not clear, etc.), when prompts (if any) are showed to participants, what the contents of the prompts are, and what data collection interfaces to show.

In order to give experimenters as many data collection options as possible, the scripting language will support the ability to launch external applications. When appropriate, experimenters will be able to pass variable values from scenario files to these programs via command line arguments.

V. Progress to Date on Toolset Enhancements

Based upon the requirements analysis, the authors highlighted a group of potential project objectives. These ideas were ranked in a trade study. The criteria the team used in ranking potential project ideas were based on its applicability, practicality, scope, and accessibility to resources. The trade study concluded with the following project objectives:

- Create software documentation for the toolset
- Create a utility to demonstrate the functionality of the toolset
- Modify the FPG to allow non-constant elevation flight plans (i.e., climbing and descending flight plans)

A. Documentation

The original toolset lacked any documentation with regards to the three individual tools, installation requirements, and hardware system requirements. If future researchers wish to continue work with the toolset, then software documentation is essential. Software documentation was created with the following sections:

- Purpose and Architecture of the Toolset
- System Requirements
- Installation Procedures
- Individual tool functionality and operation
- SVS 3.3.2 Tips and Tricks
- Directory Structure

The documentation begins with an overview of the toolset and its components. The system requirements section enumerates the hardware and software specifications for the computers running SVS toolset. Because the toolset assumes a directory structure, the file organization of the software was described. An installation package was created and an installation protocol was developed in order to standardize the installation process. The protocol instructed users where and when to copy specific files.

B. Demonstration Utility

The main objective behind the demonstration utility is to provide a flexible program that supports demonstrations of the toolset capabilities. The demonstration utility (Figure 1) allows for the playback of any previously generated scenario, with its corresponding judgment collection interface.

Figure 1. Demonstration Utility Computer Interface

The scenario playback is viewable on Windows Media Player. The user is able to view the list of scenarios using the demonstration utility. The user can also navigate through the scenarios via forward and backward buttons on the media player, which will cycle through a drop down list. The demonstration utility allows the user to play, pause, stop, and loop the video. The demonstration utility window is resizable to cater towards larger and smaller presentations. The demonstration utility allows the user to toggle between each respective data collection interface and its corresponding scenario playback.

C. Flight Plan Assent and Descent

The original Flight Plan Generator (FPG) only allowed a user to define flight plan scenarios with constant flight path elevations. The authors proposed the enhancement of the FPG so a user can define flight plan scenarios with non-constant elevations. Thus, he or she will be allowed to specify start point elevations and end point elevations of his or her flight plan scenarios.

The major change to the FPG graphical user interface was the replacement of the "Path Elevation" dialogue box with start elevation and end elevation dialog boxes. In order to create ascending and descending flight plan scenarios, the user must enter start and end elevations into the corresponding FPG dialog boxes. An ascending flight plan is defined by the end elevation being higher than the start elevation. A descending flight plan is defined by the start elevation being higher than the end elevation.

D. Usability Analysis

A usability test was designed in order to evaluate the effectiveness of the software modifications and documentation in order to identify potential usability issues. The project plan is for the study to be completed by mid-May 2006. Using task analysis techniques, the team identified a set of tasks supported by the capabilities of the experimental toolset. Based on the modifications made to the software, the team decided that the subset of tasks to include in the usability experiment was: creating and modifying a flight plan scenario in the FPG and viewing a flight plan scenario using the SVS Video Recorder.

The dependent measures of the usability test are: the time required by a participant to complete a task, the number of times the participant refers back to the software documentation, the experiment administrator's subjective observations of the participant, and the participant's responses to a post questionnaire.

The usability test protocol guides the participant through the software toolset. To help with the participants' understanding of the software, the participant will read the documentation prior to using the software. Participants will be free to ask questions or make notes regarding confusing aspects of the text, and the experimenter will note any questions or issues during the task. The participant will be referring back to the documentation throughout the experiment, so it is important he or she becomes familiar with the text.

The FPG tasks require the participant to launch the application, locate specific points on the terrain, create or modify a flight plan, and save and apply the flight plan. The participant will be given specific terrain point coordinates to ensure a consistent experience among test subjects. To test the SVS Video Recorder, the participant will view the scenario he or she generates in the FPG. Using the SVS display, the subject will answer a series of questions regarding the requirements of the scenario. Based upon the answers to those questions, the subject will return to the FPG and make changes.

Following the completion of the experimental protocol, the participant will complete a post-experiment questionnaire. The questionnaire asks the participant to describe the features of the documentation and software that were vague or confusing. The participant will be asked to identify and suggest areas for improvement.

VI. Future Work

This project has currently yielded five major deliverables: SVS experimental toolset requirements analysis, SVS experimental toolset documentation, enhanced FPG, demonstration utility and the design of a usability test.

Future work will involve the execution of the designed usability test with human subjects in order to evaluate the toolset and the documentation. Researchers will be directed to areas of the software requiring further development based on the results of the usability test.

In the summer of 2006 the toolset will be delivered to NASA Langley Research Center. In addition, a NASA technical report concerning the toolset as well the details of the experiment in [4] will be delivered.

VII. Acknowledgements

The authors would like to thank all the members from NASA Langley Research Center and the National Institute of Aerospace who attended and contributed in the brainstorming meeting on September 16, 2005. Specific thanks to: Trey Arthur, Dan Burdette, Ray Comstock, Richard Hayes, and Linda Kramer.

References

[1] Boeing Commercial Airplanes. (2005, May). *Statistical summary of commercial jet airplane accidents: World wide operations 1959 – 2004.* Available: http://www.boeing.com/news/techissues/pdf/statsum.pdf

[2] Flight Safety Foundation. (1999, February). *Killers in aviation: LFSF task force presents facts about approach-and-landing and controlled-flight-into-terrain accidents.* Flight Safety Digest. Volumes 17-18. Available: http://www.eurocontrol.int/safety/gallery/content/public/Level_bust/ResPool/FS_Kill.pdf

[3] R. V. Parish, D. G. Baize. and M. S. Lewis, "Synthetic Vision," in *The Avionics Handbook*, C. R. Spitzer, Ed. Boca Ratton: CRC Press, 2001, pp. 16-1–16-8.
[4] M. L. Bolton, "An investigation of the effects of texture and field of view on spatial awareness in synthetic vision head-down displays," M.S. thesis, Dept. Systems and Information Eng., Univ. of VA, Charlottesville. VA, 2006.
[5] C. D. Wickens, "Spatial awareness biases," Tech. Rep. ARL-02-6/NASA-02-4, Savoy, IL, 2002.
[6] M. L. Bolton, E. J. Bass, and J. R. Comstock, "Using video simulations to support the analysis of spatial awareness in synthetic vision displays" in *2006 IEEE International Conference on Systems. Man. and Cybernetics*, this volume.
[7] M. L. Bolton. E. J. Bass. and J. R. Comstock, "A toolset to support the development of spatial and temporal judgment experiments for synthetic vision systems", in *2006 IEEE Systems and Information Engineering Design Symposium*. to be published.
[8] M. A. Vidulich, "Testing a subjective metric of situation awareness," in *Proceedings of the Human Factors and Ergonomics Society 35th Annual Meeting*, San Francisco, CA, 1991.
[9] M. U. de Haag, R. Thomas, and J. Rankin, "Initial flight test results of Ohio University's 3-dimensional cockpit display of traffic information 2002", in *IEEE 2002 Position Location and Navigation Symposium*, April, 2002.
[10] L. J. Kramer, L. J. Prinzel, J. J. Arthur, and R. E. Bailey, "Pathway design effects on synthetic vision head-up displays", in *Proceedings of the 2004 SPIE Conf. on Enhanced and Synthetic Vision*, Orlando, 2004, pp. 61-72.
[11] M. A. Takallu, D.T. Wong, A.P. Bartolone, M.F. Hughes, and L. J. Glaab. "Interaction between various terrain portrayals and guidance/tunnel symbology concepts for general aviation synthetic vision displays during a low en-route scenario", in *Proceedings of the 2004 Digital Avionics Systems Conf. (DASC)*, Salt Lake City, October, 2004.