

A TOOLSET TO SUPPORT THE DEVELOPMENT OF SPATIAL AND TEMPORAL JUDGMENT EXPERIMENTS FOR SYNTHETIC VISION SYSTEMS

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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 describes a toolset designed to support an experiment that assessed the ability of different SVS displays to convey spatial awareness (the ability of a pilot to identify terrain, his ability to identify its relative location, and his ability to identify its relative location in the future) using spatial and temporal judgments. This toolset was used successfully to design and conduct this experiment. Work is currently being conducted to generalize the applicability of the toolset so that it can be used to support a wider range of experiments.

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].

SVS have a variety of different display properties that can impact human performance. Two important factors are texture and Field of View (FOV). Texture refers to the imagery drawn on the synthetic terrain in SVS displays. FOV refers to the angular boundaries of the volume of space represented in the SVS display. As part of a research program evaluating the ability of different SVS displays to convey spatial awareness [4], this paper addresses the development of a software toolset built to facilitate the

design, execution, and data collection of SVS experiments.

II. MOTIVATION

The goal of [4] was to evaluate the ability of seven textures (Fig. 1) and two fields of view (FOVs) (30° and 60°) to convey spatial awareness. 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].

Spatial awareness was measured using four judgments made with respect to a point on the synthetic terrain of an SVS display after five second simulations. 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. In addition to these performance measures, several subjective measures were collected for each texture.

To reduce the effect of known spatial biases from impacting the results (see [5]), the experimental trial geometries varied the relative position of the terrain point (Fig. 2). This was done by parameterizing the point's relative angle, distance, and height into two levels each (Table 1). Angles could be large or small, distances could be near or far, and heights could be above or below the aircraft.

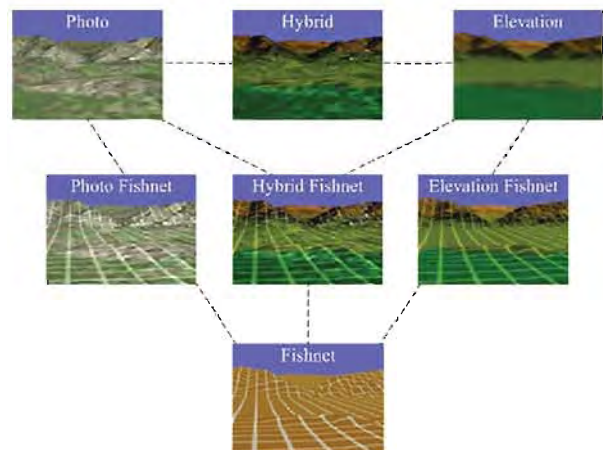


Fig. 1. The terrain textures evaluated in the experiment.

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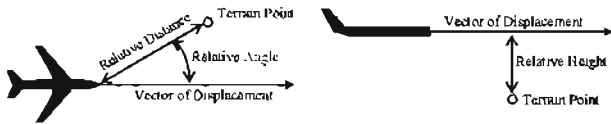


Fig. 2. Parameters of the trial geometries

TABLE I
TRIAL GEOMETRY LEVELS

Geometry	Level	Range	Coded Value
Relative Angle	Low	[0°, 6.5°]	Small
	High	[8.5°, 15°]	Large
Relative Distance	Low	[1 nmi, 3.25 nmi]	Near
	High	[3.75 nmi, 6 nmi]	Far
Relative Height	Low	[-1000 ft, -100 ft]	Below
	High	[100ft, 1000ft]	Above

Thus, in order to run a full factorial experiment where there were two distance levels, two angle levels, two height levels, two FOV levels, and seven texture levels, 112 ($2 \cdot 2 \cdot 2 \cdot 2 \cdot 7 = 112$) trials were required for each participant. Additionally, in order to familiarize participants with the experimental task, and to introduce each texture and FOV, there were 64 training trials. Thus there were a total of 176 trials for each participant.

In order to generate these experimental trials, all of the following were needed: 1) A means of generating multiple, distinct, non-interactive simulations of SVS displays in straight flight; 2) A means of varying terrain texture and FOV between simulations; 3) A means of placing a point on the terrain in the SVS displays at a specific relative position to a flight plan (relative angle, relative distance, and relative height); 4) A means of collecting participant judgment data and subjective ratings at set points between simulations; and 5) Due to the large number of trials and participants, a means of running participants in parallel with as little experimenter involvement as possible.

Unfortunately, such an experiment had never been attempted with SVS displays. Thus, there was very little infrastructure to fulfill these requirements.

The NASA Supplied SVS simulation (SVS 3.3.2) was capable of displaying varying flightplans with different textures and FOVs. Unfortunately, the simulation had several limitations. Firstly, it was not capable of indicating the position of a point of the terrain. Secondly, the simulation needed to be shutdown and restarted in order to change terrain texture, making it extremely difficult to sequence simulations in rapid succession. This also required a significant amount of experimenter involvement in the testing procedure, making it difficult to run participants in parallel. Thirdly, flightplans had to be manually created by specifying a sequence of waypoints in ASCII files. This made flightplan definition difficult to visualize. Finally, the simulation had no built in mechanism for collecting participant spatial judgments or subjective ratings.

The experimental requirements were fulfilled by modifying the SVS simulator to support the display of objects (for indicating the location of the terrain point), and constructing three tools: 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.

III. MODIFIED SVS SIMULATION

In order to indicate the location of a terrain point in an SVS display, modifications were made to NASA Langley's SVS 3.3.2 simulation. These modifications allow 3D models to be rendered as part of the synthetic display. In order to use these models to indicate a specific location on the terrain, the lateral position of a model can be specified via a configuration file. In order to ensure that the model will be displayed on the terrain, the simulation dynamically queries the terrain database during runtime and adjusts the object's height accordingly. Finally, this height value is written out to a file so it can be used in the computation of experimental parameters.

IV. FLIGHTPLAN GENERATOR

The FPG (Fig. 3) allows experimenters to create experimental scenarios by giving them the means to define straight flight plans, specify the relative location of a terrain point, select SVS display parameters, and reconfigure the SVS simulation to reflect these changes.

The FPG has two windows: the main window ("Flightplan Generator") and the information window ("Information"). The main window depicts an aerial view of the terrain database (a 95 nmi by 95 nmi square plot of land surrounding the Eagle Vail Colorado airport) at a resolution of 47.69 nmi per pixel. The terrain itself is color coded based on its elevation above sea level (a key can be found in the information window).

Flightplans are defined by two points: a start point (the green dot in Fig. 3) and an end point (the red dot in Fig. 3). The start point is set with the left mouse button; the end point is set with the right mouse button. A line connecting these points illustrates the path of the flightplan. The termination point (the yellow dot) is displayed along the flightplan to indicate where the front of the aircraft will be at the end of five seconds.

A terrain point (the blue dot with the white outline) is specified in the main window using the middle mouse button or scroll wheel. A pink line between the termination point and the terrain point visually conveys the relative angle and distance of the terrain point. The actual values of these parameters are displayed in the information window.

The information window serves several purposes: it displays information necessary for specifying flightplans, it

allows all of the other information required for a scenario to be specified, it supports the saving and loading of scenarios, and it supports the ability to apply scenario configuration information to the SVS simulation.

The information window lets experimenters define three scenario related variables: the elevation of the flightplan (in feet above sea level), the object used to indicate the location of the terrain point, and the terrain texture. With a flightplan and these parameters, an experimenter can use the “Apply Scenario” button to configure the SVS simulation to play the scenario.

With a flightplan and terrain point location specified in the main window, the information window displays the terrain point’s relative angle (in degrees) and distance (in nmi). The interface also displays the relative height of the terrain point. However, in order to ensure that this value was accurate, the experimenter would need to apply the scenario and launch the SVS simulation in order to view it. Once the simulation is loaded, the experimenter uses the “←” button to right of “Point Elevation” to import the elevation of the point (in ft above sea level). This process must be repeated every time the location of the terrain point changes.

The experiment described in [4] was concerned with different levels of relative angle (small or large), relative distance (near or far), and relative height (above or below). This information is coded into the “Geometry” field in the display. When the angle is large, a capital “A” is displayed. When the distance is far, a capital “D” is displayed. When the terrain point is above the flightplan, a capital “H” is displayed. When an angle is small, the distance is near, and the terrain point is below the aircraft, an X is displayed.

Scenarios can be saved and loaded. Saved scenarios are used by the data collection interface when running an experiment.

V. SVS VIDEO RECORDER

The SVS video recorder launches and automates the SVS simulation and third party video capturing software. In order to record video of the SVS simulation flying flight plans defined by the FPG.

Once a scenario has been saved and applied using the

FPG, the experimenter can capture it to video using the SVS video recorder.

The experimenter runs the SVS video recorder using the “Launch” button to execute the SVS simulation (with the most recently applied scenario) and video capturing software. The experimenter then uses the “Prime” button to set the SVS simulation to its initial playback position. At this point, if the experimenter wants to change the FOV represented in the SVS display, he would need to select it within the SVS simulation. The experimenter uses the “Record” button to set the simulation in motion and start the recording process in the video capturing software. Once five seconds of video is recorded, the SVS video recorder stops the recording process.

This process produces an uncompressed 30 frames per second Audio Video Interleave (AVI) file of the SVS display in flight. These uncompressed AVI files are large which inhibits accurate playback. In order to resolve this, the files should be compressed using a third party codec. The experiment described in [4] utilized Microsoft’s Windows Media Encoder 9 to compress the videos into Window Media Video files. However, any video codec supported by Direct X is supported by the toolset.

VI. DATA COLLECTION INTERFACE

The DCI allows videos to be paired with their configuration information (scenario files from the FPG). This pairing is called a trial. In addition to the pairing, a researcher specifies which FOV was used when capturing the video and whether or not to use the trial for training. Trials can be sequenced and saved for use in an experiment.

The DCI also runs experiments: giving instructions to participants, playing the videos, collecting participant judgments, collecting participant subjective ratings, and generating data output.

A researcher can run an experiment by entering a participant identification number and selecting a trial order file. For [4], trials were grouped together based on FOV, and by texture within each FOV. Thus, participants would see all of the trials with one FOV before seeing any trials with the other FOV.

In [4] participants completed training, experimental trials,



Fig. 3. The Flightplan Generator.

TABLE II
EXPERIMENT PROCEDURE

	1st FOV	2nd FOV
1st Texture	12 Training Trials	12 Training Trials
	8 Experimental Trials	8 Experimental Trials
	DAC ^a ratings	DAC ratings
2nd Texture	4 Training Trials	4 Training Trials
	8 Experimental Trials	8 Experimental Trials
	DAC ratings	DAC ratings
3rd Texture	4 Training Trials	4 Training Trials
	8 Experimental Trials	8 Experimental Trials
	DAC ratings	DAC ratings
4th Texture	4 Training Trials	4 Training Trials
	8 Experimental Trials	8 Experimental Trials
	DAC ratings	DAC ratings
5th Texture	4 Training Trials	4 Training Trials
	8 Experimental Trials	8 Experimental Trials
	DAC ratings	DAC ratings
6th Texture	4 Training Trials	4 Training Trials
	8 Experimental Trials	8 Experimental Trials
	DAC ratings	DAC ratings
7th Texture	4 Training Trials	4 Training Trials
	8 Experimental Trials	8 Experimental Trials
	DAC ratings	DAC ratings
SA-SWORD	21 Comparisons	21 Comparisons

^a Demand, Awareness, and Clutter

and provided subjective ratings (Table II). For each FOV, participants completed trials for one texture type at a time. Training trials with feedback were completed for each texture type with twelve training trials for the first texture and four for the others. Each trial included one of the five second videos. The videos depicted an SVS primary flight display (Fig. 4). An airspeed dial, altitude dial, and a FOV indicator were also displayed. During each trial, a yellow cylindrical cone was used to identify the terrain point. At the end of the five seconds, the simulation would freeze for one second before the display was cleared. The judgment collection interface was then presented to collect the three spatial awareness judgments (Fig. 5).

Relative distance and angle judgments are made by placing a yellow X on the display (using the mouse) corresponding to the location of the terrain point relative to the aircraft (left side of Fig. 5). A yellow line on the navigation-like display connects the center of the X to the front of the aircraft. To aid in making the judgments, text values for relative angle and distance are displayed next to the X as the mouse is moved. Relative distance is displayed in

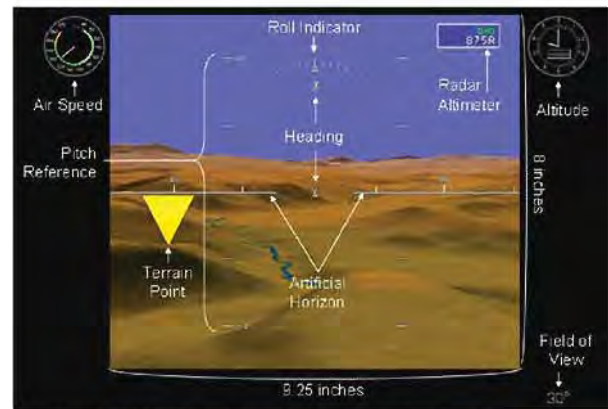


Fig. 4. The SVS display from the data collection interface

nautical miles from the aircraft along the connecting yellow line. Relative angle is displayed in degrees from the aircraft's vector of displacement (the magenta line).

For the relative height judgment, a yellow X is placed on a vertical scale (using the mouse) corresponding to the relative height of the terrain point (right side of Fig. 5). A yellow line connects the center of the X to the aircraft's flight level (the magenta line). To aid participants in making the judgment, the relative height is displayed in feet next to the X as it is moved.

The abeam time judgment is entered in minutes and seconds using the keyboard (bottom right side of Fig. 5). To support this time judgment, a yellow dot on the relative distance and angle judgment collection interface indicates the abeam point based on the relative distance and angle judgment.

For training trials, feedback relating to the relative distance, angle, and height judgments is provided as text and as blue Xs on their corresponding judgment interfaces (Fig. 6). The actual time to fly abeam to the terrain point is displayed in blue next to the participant's judgment. The actual abeam point for the terrain point is displayed as a blue

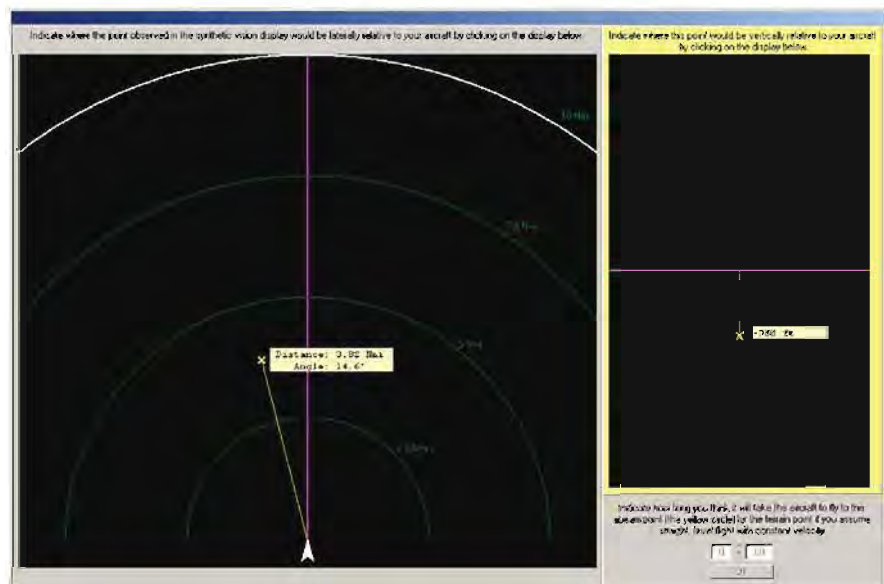


Fig. 5. Judgment collection interface

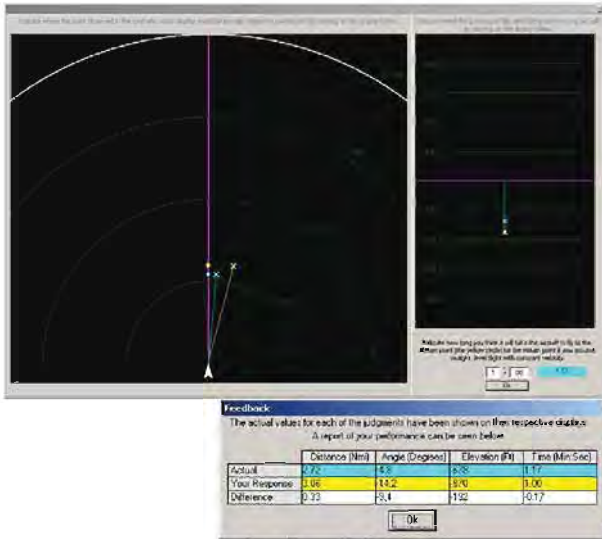


Fig. 6. Judgment collection interface with feedback

dot on the relative distance and angle judgment interface. A summary of the differences between the participant's judgments and the actual values appears in a popup dialog box. This box shows the correct response for each value in blue, the participant's response in yellow, and the difference in white.

In addition to the judgment values, the DCI collects several subjective measures. Demand, Awareness, and Clutter (DAC) ratings are collected after each texture block (Fig. 7). Each of these scores is recorded as an integer value on a scale of 0 to 100. SA-SWORD [6] pair-wise comparisons are collected after each FOV block. Participants are asked to rate their level of spatial awareness for each pair of textures (on a 17 point scale) based on their relative ability to provide spatial awareness (Fig. 8).

Because the DCI was designed to support the procedure in [4], the software is able to detect transitions in experimental conditions by examining the trials. Such transitions include changes between FOVs, textures, and training and non-training runs. This allows the software to show each of the data collection interfaces at the appropriate time. The software also informs the participant of each

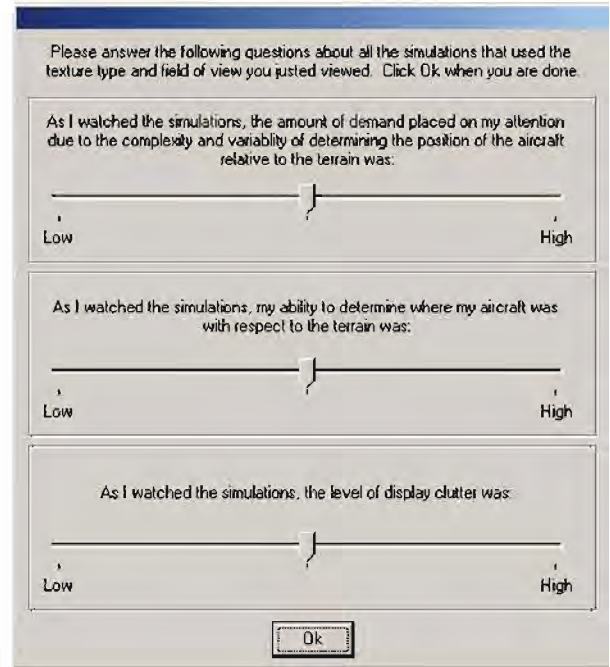


Fig. 7. Demand, awareness, and clutter rating collection interface

transition. This allows multiple test subjects to be run in parallel.

All data collected from a participant is serially saved to an output file to insure the minimum loss of data in case of a power outage or system crash. When an experiment is completed, all of the data relevant to the experiment is written to a tab delimited ASCII file. This file contains the configuration information for each trial, participant judgments, errors in participant judgments, DAC ratings, and computed SA-SWORD scores.

VII. DISCUSSION

The toolset met all of the requirements of [4] it was designed to support: 1) The FPG coupled with SVS video recorder provides the means of generating multiple, distinct, non-interactive simulations of SVS displays in straight flight; 2) The FPG and modified SVS simulation provide the means to vary terrain texture and FOV between simulations;

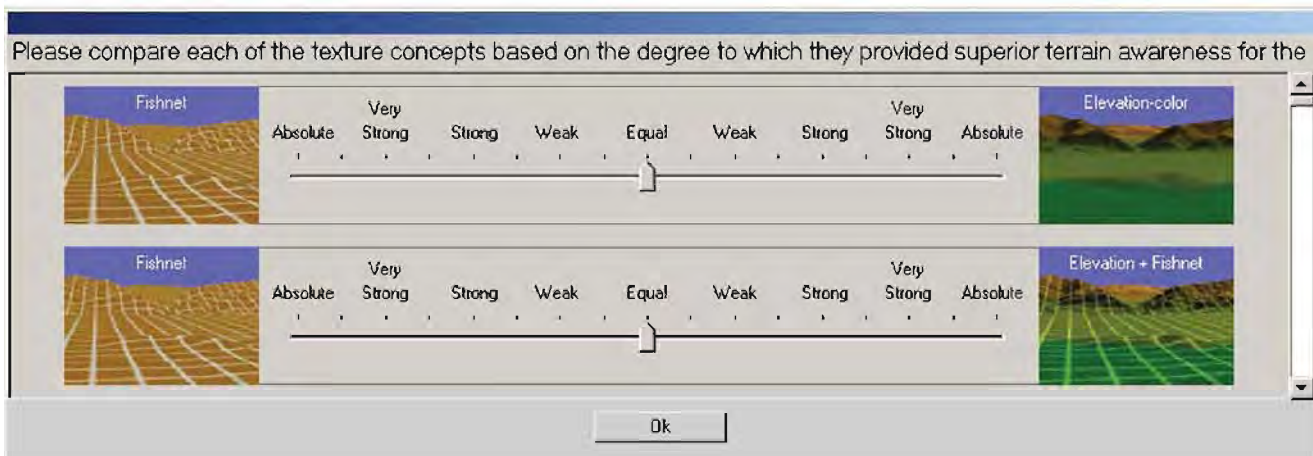


Fig. 8. The SA-SWORD collection interface

3) Modifications to the SVS simulation and the FPG provide the means to place a point on SVS terrain at a specific relative position to a flight plan; 4) The DCI provides the means for collecting participant judgment data and subjective ratings; and 5) The DCI provides the means to run participants in parallel with nearly no experimenter involvement.

This toolset was successfully used to conduct the research discussed in [4]. A variety of significant results were obtained for both the judgment values and the subjective measures.

Ultimately, this toolset has proven itself to be useful for the procedure it was designed to support. With minor modification, it is possible that the toolset could be used to support future SVS experiments. Work is currently being conducted to investigate what modifications will improve its ability to support future SVS research.

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