Synthetic Vision Technology for Unmanned Aerial Systems: *Looking Back and Looking Forward*

By Jeff Fox, Michael Abernathy, Mark Draper and Gloria Calhoun

Using computers and terrain databases to generate a simulated, real-time, three-dimensional view of an environment—otherwise known as synthetic vision—has been applied to unmanned aircraft systems for three decades.

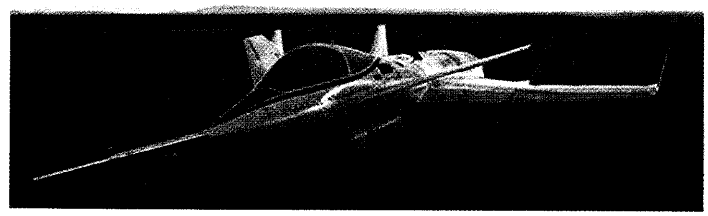
More recently it has evolved away from being a piloting aid to a potentially powerful tool for sensor operators. Technology observers expect it can help offset many factors that currently compromise the usefulness of UAS video imagery: narrow camera field of view, degraded datalinks, poor environmental conditions, limited bandwidth and highly cluttered visual scenes such as those found in urban areas.

With synthetic vision technology, information can be pulled from databases (of terrain elevation, cultural features, maps, photo imagery) and combined with data from networked sources, all of which can be represented as computer-generated imagery and symbology and overlaid on a dynamic video image display. The imagery and symbology appears to coexist with real objects in the scene, allowing an operator to cut through the clutter and maintain situational awareness of the environment.

There is a large body of research from the 1970s to the present that addresses the application of synthetic vision to manned and unmanned aircraft. In the interest of brevity, this article will focus on select systems that were important enablers toward UAS synthetic vision systems.

The story begins in the 1970s when the use of computers to create 3D real-time, out-the-window synthetic environments was beginning to see wide acceptance for training pilots of manned aircraft. Computer graphics company Evans and Sutherland (E&S), of Salt Lake City, Utah, had seen the commercial potential for flight simulation and had introduced special-purpose graphics computers, like their Picture System, which transformed and projected 3D terrain data as simple 3D polygons to a pilot's perspective view in real-time. In 1975, an engineering student named Bruce Artwick wrote "Flight Simulator" for the Apple II computer. He formed a company and in 1980 marketed the product that ultimately became Microsoft Flight Simulator.

This emergence of computer flight simulation in the 1970s appears to have sparked a monumental amount of research. The U.S. Air Force began its Visually Coupled Airborne Systems Simulator (VCASS) program, with a particular eye toward future-generation fighter aircraft ("VCASS: An Approach to Visual Simulation," Kocian, D., 1977). NASA was developing synthetic vision for the Super Sonic Transport and for its High Maneuverability Aircraft Testbed (HiMAT) remotely piloted vehicle (RPV) program. Educational institutions studied the limitless new possibilities for virtual reality human-machine interfaces. By the mid-1980s, synthetic vision for RPV simulation was even commercially available for radio control aircraft hobbyists.



NASA's HiMAT remotely piloted vehicle after flight at Dryden Flight Research Center. Photo courtesy of NASA.

In 1977, NASA researcher Charles Knox published "Pathway-in-the-Sky Contact Analog Piloting Display," which included a complete design for a synthetic vision system. It featured a computer that projected a 3D view of the terrain given an aircraft's position and orientation. This out-the-window perspective view was displayed on a CRT type display. Such displays were called "Pictorial Format" avionics systems, but we recognize them as containing all of the essential elements of a modern synthetic vision display.

In 1979, the U.S. Air Force completed its "Airborne Electronic Terrain Map Applications Study" and in 1981 published "The Electronic Terrain Map: A New Avionics Integrator" describing how a computerized terrain database could be displayed as an out-the-window 3D view allowing the pilot to "see" even at night and in other limited visibility situations.

Also in 1979, the Air Force published research identifying human factors problems that would have to be overcome in RPV cockpit design ("Visual-Proprioceptive Cue Conflicts in the Control of Remotely Piloted Vehicles" by Reed in 1977). NASA would use this in the design of the HiMAT RPV 3D visual system in 1984.

Pictorial format avionics (i.e., synthetic vision) formed a key ingredient of the Air Force Super Cockpit concept. This program included a bold future vision in which "the pilot need not be present in the actual vehicle which he is piloting since with the appropriate data links a 'remote' super cockpit would provide the visual and aural 'telepresence' cues as if he were located in the vehicle," according to Air Force researcher Tom Furness.

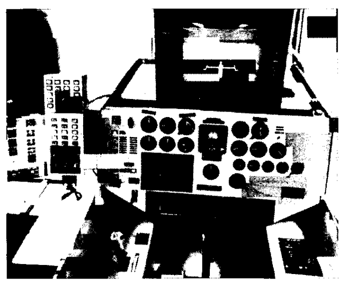
CONTINUED ON PAGE 28

HiMAT: RPV with Synthetic Vision

In 1984, NASA researcher Shahan Sarrafian published research that investigated synthetic vision for lateral control during RPV landings. These tests featured the HiMAT vehicle, flown at Dryden Flight Research Center. These aircraft were dropped from a B-52 and remotely piloted from a ground station to a landing on the lakebed. The vehicle had a nose camera which produced video that could be shown in the remote cockpit, allowing the comparison of nose camera imagery versus synthetic vision during pilot testing.

Vehicle position was computed using radar computations along with a radio altimeter. Electro-mechanical gyroscope systems were installed onboard the aircraft and measured the three-dimensional attitude of the vehicle. The position and attitude were down-linked from the aircraft to a remote cockpit, and pilot control inputs were up-linked from the remote cockpit via the radio communication system.

The remote cockpit included a joystick and rudder controls connected to the computer and control signals were uplinked to the UAV. The computer compensated for delays in the control/ communications loop.



The HiMAT RPV remote cockpit showing synthetic vision display. Photo courtesy of NASA.

The Edwards Air Force Base dry lake bed and runway were represented in three dimensions in the terrain database as polygons (triangles and rectangles). An E&S Picture System computer transformed the terrain in the database into a projected 3D out-the-window view at the pilot cockpit. Finally, the projected 3D view was displayed on an E&S Calligraphic video display system capable of 4000 lines of resolution. According to the pilots participating in the study, the synthetic vision compared well to the nose camera view. By the mid 1990s, NASA had migrated the RPV synthetic vision concept used on HiMAT to PC computers for the X-36 and X-38 flight demonstration vehicles.

One of the early uses of synthetic vision for UAVs—then most often called RPVs—was recreational simulation. In 1986, Ambrosia Microcomputer Products of Willowbrook, Ill., introduced RC AeroChopper, a radio controlled aircraft simulator which enabled pilots to learn to fly a remotely controlled aircraft, without risk to their actual vehicle. According to the "AeroChopper Owner's Manual" (Stern, 1986), the product accepted aileron, elevator, rudder, and throttle pilot inputs via joysticks to control the simulated aircraft. The product also contained data files containing a 3D terrain database provided with AeroChopper representing the earth's surface as well as buildings and obstructions.

The software was run on a computer (an Amiga for example) and was connected to the flight controls and communicated the aircraft position and attitude to the user. The computer used the terrain data to create a projected view of the aircraft and its environment in three dimensions. Like most visual simulations of its time, the program used relatively few polygons to represent the terrain and man-made objects and so looks crude by today's standards.

Synthetic Vision for Sensor Operations

Although most of the historical focus with synthetic vision has been on aiding flight management, recent efforts have focused on how synthetic vision can aid UAS sensor operator functions.

Ongoing research at the U.S. Air Force Research Laboratory's Human Effectiveness Directorate is exploring how to improve the usefulness of video imagery to UAS sensor operators. The overall objective is to determine the value of combining synthetic vision imagery/symbology with live camera video presented on a UAS control station camera display.

One research study evaluated the utility of computer-generated video overlays for four different task types: controlling the camera to locate specific ground landmarks in the 360 degree area surrounding the loitering UAV; designating multiple ground targets marked with synthetic symbology; tracing a synthetically highlighted ground convoy route with the UAV camera boresight; and reading text from synthetic overlaid symbology.

The UAS telemetry update rate was manipulated from 0.5 Hz to 24 Hz. The results indicated the potential of synthetic symbology overlay for enhancing situation awareness, reducing workload and improving the designation of points of interest at nearly all the update rates evaluated and for all four task types. However, data across the task types indicated that update rates greater than 2-4 Hz generally resulted in improved objective performance and a subjective sense that the symbology was useful.

A second research area focused on a picture-in-picture (PIP) concept where video imagery is surrounded by a synthetic-generated terrain imagery border on the physical camera display, increasing the operator's instantaneous field-of-view. Experimental data showed that the PIP helps mitigate the "soda-straw effect," reducing landmark search time and enhancing operator situation awareness. In an evaluation examining the impact of PIP display size and symbology overlay registration errors, results indicated that performance on a landmark search task was particularly better with the more compressed video imagery, reducing average designation time by 60 percent. Also, the registration error between the virtual flags and their respective physical correlates was less critical with the PIP capability enabled. The details were published in "Picture-in-Picture Augmentation of UAV Workstation Video Display" by Gloria Calhoun and others in 2007.

The recent availability of sophisticated UAS autopilots capable of autonomous flight control has fundamentally changed the paradigm of UAS operation, potentially reducing the usefulness of synthetic vision for supporting UAS piloting tasks. At the same time, research has demonstrated and quantified a substantial improvement in the efficiency of sensor operations through the use of synthetic vision sensor fusion technology. We expect this to continue to be an important technology for UAS operation.

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