Synthetic Vision Technology for Unmanned Aerial Systems: The Real Story

By Jed Margolin
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(Abridged)

Introduction

This is in response to the article **Synthetic Vision Technology for Unmanned Systems: Looking Back and Looking Forward** by Jeff Fox, Michael Abernathy, Mark Draper and Gloria Calhoun which appeared in the December 2008 issue of AUVSI's Unmanned Systems (page 27). *{Ref. 1}*

The AUVSI Authors have used the term "synthetic vision" so loosely that many readers will believe it was invented long before it actually was. This is an important issue. Aerospace is a field where precision and accuracy is critical. There are also patent rights involved. In the interests of full disclosure I am the listed inventor on several patents relating to synthetic vision and there is a patent infringement disagreement between the owner of the patents (Optima Technology Group) and the company that one of the AUVSI Authors is affiliated with (Rapid Imaging Software).

What Is Synthetic Vision?

The term "Synthetic Vision" originally meant anything that you put up on a video display.

For example, there is U.S. Patent 5,593,114 **Synthetic Vision Automatic Landing System** issued January 14, 1997 to Ruhl (Assignee McDonnell Douglas Corporation) where Enhanced or Synthetic Vision is a display of the data from a forward looking radar or equivalent sensor. *{Ref. 2* - Column 2, lines 16 - 27}

This was also the FAA's definition at the time, in their **Synthetic Vision Technology Demonstration, Volume 1 of 4, Executive Summary** *(Ref 3* - PDF page 10 and PDF pages 11,12}

In the AUVSI Authors' own article they equate "pictorial format avionics" with "synthetic vision." [Paragraph 10]:

> Pictorial format avionics (i.e., synthetic vision) formed a key ingredient of the Air Force Super Cockpit concept.

Boeing's report **Multi-Crew Pictorial Format Display Evaluation** describes what Pictorial Format means. {*Ref. 4* - PDF Page 17}:

> In the first of the two PFDE studies, pictorial formats were implemented and evaluated for flight, tactical situation, system status, engine status, stores management, and emergency status displays. The second PFDE study concentrated on the depiction of threat data.

Pictorial Format Avionics is pictures. That explains why it is called **Pictorial** Format Avionics.

Why can't we use the term "Synthetic Vision" to mean anything we want it to mean?

The FAA has a definition for "Synthetic Vision" and if you want an FAA type certificate for your Synthetic Vision product you have to use their definition.

{Ref. 5 – FAA current definition of synthetic vision}

> Synthetic vision means a computer-generated image of the external scene topography from the perspective of the flight deck that is derived from aircraft attitude, high-precision navigation solution, and database of terrain, obstacles and relevant cultural features.

{Ref. 6 – FAA Synthetic Vision is based on a Digital Elevation Database}

> "Everyone gets their data from the same original source."
>
> "If accuracy of data base must be validated then SV is unapproveable."
>
> "Current resolution tends to round-up the elevation data so that small errors are not as significant and on the conservative side."

Therefore, Synthetic Vision means a computer-generated image of the external scene topography from the perspective of the flight deck that is derived from aircraft attitude, high-precision navigation solution, and digital terrain elevation database, obstacles and relevant cultural features.

Implicit in this is that in order for the external scene topography to be viewed from the perspective of the flight deck it has to be a 3D projected view and that the digital terrain elevation database must represent real terrestrial terrain, as opposed to terrain that is simply made up.

Digital Terrain Elevation Database

The **Digital Terrain Elevation Database** is also called the **Digital Elevation Database** or **Digital Elevation Model**. From *Ref. 7*:

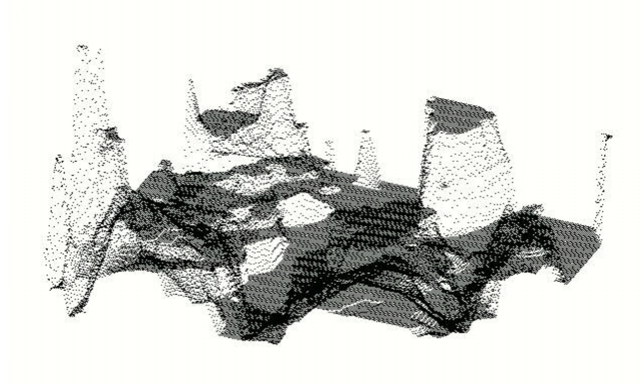
> The USGS Digital Elevation Model (DEM) data files are digital representations of cartographic information in a raster form. DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. These digital cartographic/geographic data files are produced by the U.S. Geological Survey (USGS) as part of the National Mapping Program and are sold in 7.5-minute, 15-minute, 2-arc-second (also known as 30-minute), and 1-degree units. The 7.5- and 15-minute DEMs are included in the large scale category while 2-arc-second DEMs fall within the intermediate scale category and 1-degree DEMs fall within the small scale category - (Source: USGS)

The Digital Elevation Model was substantially improved by STS-99 when Endeavour's international crew of seven spent 11 days in orbit during February 2000 mapping the Earth's surface with radar instruments. *{Ref. 8}*

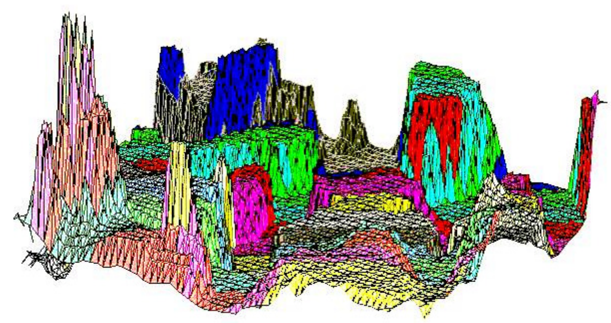
Displaying the Digital Elevation Database

Now that we have a Digital Elevation Database consisting of a sampled array of elevations for a number of ground positions at regularly spaced intervals, what do we do with it? The database is just elevation points.

If you display only points there is no way to remove "hidden points" because there are no surfaces to test them against. (Things can only be hidden behind surfaces.) The result is a jumble which looks like this (the only useful features are the highest peaks):



This picture shows the same scene rendered in polygons. (The polygons are crude because I had only a few colors to work with and there is no clipping, only polygon sorting):



After you have used the digital elevation points to produce polygons you can shade and blend the polygons so that the underlying polygons may no longer be obvious. Honeywell did an excellent job in their IPFD (Instrument Primary Flight Display) *{Ref. 9}*:

NASA HiMAT

The AUVSI Authors have gone to considerable lengths to persuade readers that NASA's HiMAT project was Synthetic Vision [Paragraphs 11 – 14]. It wasn't.

From Sarrafian (*Ref. 11}*

1. "The vehicle was flown with cockpit display instruments until the landing approach phase of the flight when the camera aboard the aircraft was activated to provide the pilot with a television display during the approach."

2. During the operational phase of the HiMAT program, a simulator was used to adjust the control laws for the primary control system. The display presented to the pilot of this simulated system was a display of an instrument landing system (ILS).

3. Separately, a study was undertaken to compare evaluations of pilots using a simulated visual display of the runway scene and a simulated ILS display with the results of actual flight tests, using the HiMAT aircraft as a representative remotely piloted research vehicle.

There is no mention of a terrain database or any suggestion that the simulated visual display of the runway scene was ever used to control a real aircraft. It was never anything other than a simulation.

From NASA's description of the HiMAT project *{Ref. 10}*:

> **Highly Maneuverable Aircraft Technology**
>
> From mid-1979 to January 1983, two remotely piloted, experimental Highly Maneuverable Aircraft Technology (HiMAT) vehicles were used at the NASA Dryden Flight Research Center at Edwards, Calif., to develop high-performance fighter technologies that would be applied to later aircraft. Each aircraft was approximately half the size of an F-16 and had nearly twice the fighter's turning capability.

and, later:

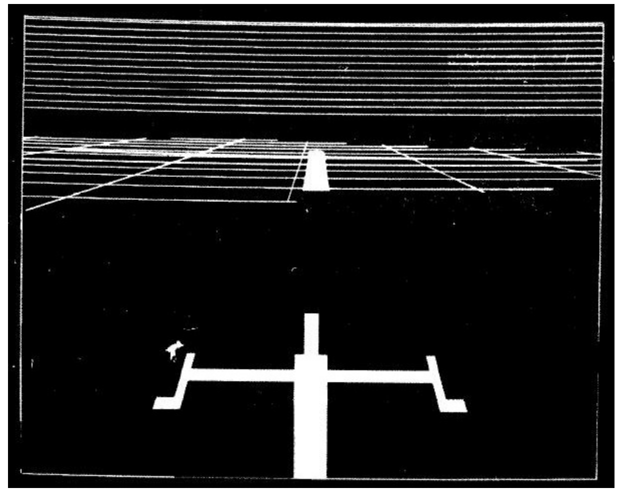
> The small aircraft were launched from NASA's B-52 carrier plane at an altitude of approximately 45,000 feet. Each HiMAT plane had a digital on-board computer system and was flown remotely by a NASA research pilot from a ground station with the aid of a television camera mounted in the cockpit. There was also a TF-104G chase aircraft with backup controls if the remote pilot lost ground control.

NASA's article says it was flown remotely by a pilot using a television camera in the aircraft. It does not say it was flown using what is now known as synthetic vision. (As previously explained, the definition of the term "synthetic vision" has changed over the years.)

The AUVSI Authors cite the report by Shahan Sarrafian,**"Simulator Evaluation of a Remotely Piloted Vehicle Lateral Landing Task Using a Visual Display."** There are two Sarrafian reports with that title, one dated May 1984; the other dated August 1984. See *Ref. 11* which contains links to the reports as well as to mirrored copies. The August 1984 report has been converted to text to make it easy to search and to quote from.

The title of the Sarrafian report gives an accurate description of his project, "**Simulator Evaluation of a Remotely Piloted Vehicle Lateral Landing Task Using a Visual Display**."

There is no mention of a terrain database or any suggestion that the simulated visual display of the runway scene was ever used to control a real aircraft. It was never anything other than a simulation.



The following is a picture of the image Sarrafian produced in his simulator (*Figure 9 - Simulated landing approach conditions on glideslope*):

The display was created with an Evans and Sutherland Picture System *{Ref. 16}* using a calligraphic monitor. The term ***calligraphic*** means that the system only drew lines and dots. This type of system is also called ***Random Scan*** because the electron beam in the CRT can be moved anywhere on the screen, as opposed to a Raster Scan system, which draws a raster. Atari's term for ***Random Scan*** was ***XY*** or ***Vector*** and was used in several games in the late 1970s and early 1980s such as Asteroids, BattleZone, and Star Wars.

The solid areas are filled-in by drawing lots of lines.

The lines above the horizon are presumably meant to indicate the sky. The grid lines are presumably meant to indicate the ground. There is no suggestion that the grid lines are produced from a digital elevation database. There would be no reason to use a digital elevation database because the system was used only to simulate landings. (Indeed, the name of the study is "Simulator Evaluation of a Remotely Piloted Vehicle Lateral Landing Task Using a Visual Display.")

The AUVSI Authors have reproduced a picture in their article with the caption, “The HiMAT RPV remote cockpit showing synthetic vision display. Photo courtesy of NASA.”

This picture is identical to the picture in Sarrafian Figure 5 {Ref. 11}, August 1984, PDF page 10} but the Sarrafian picture has a different caption. It says, “ HiMAT simulation cockpit.”

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

ECN 22757

Fig. 5 HiMAT simulation cockpit.

The monitor shows a picture of the kind shown in Sarrafian Figure 8 or Figure 9 (along with a considerable amount of what appears to be reflected glare). The picture was produced by an Evans and Sutherland Picture System which requires a calligraphic monitor.

Here's the thing. "The vehicle was flown with cockpit display instruments until the landing approach phase of the flight when the camera aboard the aircraft was activated to provide the pilot with a television display during the approach."

In order to display the video from the camera aboard the aircraft, the Ground Cockpit that controlled the aircraft had to have a raster-scan monitor.

Raster-scan monitors and Calligraphic monitors are incompatible.

The picture shows the Simulation Cockpit, and the Simulation Cockpit could not be used to control the aircraft.

Why did the AUVSI Authors change the caption?

Visual-Proprioceptive Cue Conflicts in the Control of Remotely Piloted Vehicles, Reed, 1977

In paragraph 9 the AUVSI Authors state:

> 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.

Ref. 14 provides the link to the Reed report.

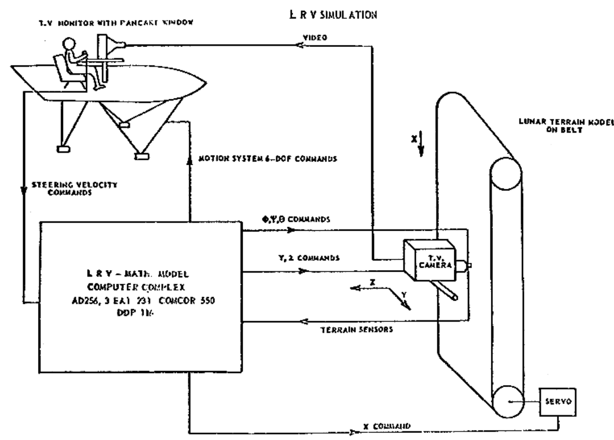
This is what the Reed report was about. From page 5 (PDF page 8):

An operator is asked to maneuver a remotely piloted vehicle (RPV) from an airborne control station (a mother ship). This station is equipped with a television monitor, control stick, and other controls and displays necessary to maneuver the RPV through a specified course. The RPV, containing a television camera mounted in its nose, relays an image of the terrain to be displayed on the television monitor in the control station. Thus, the visual scene displayed to the operator represents the scene viewed by the camera. The task of the operator is to use the controls and displays to "fly" the RPV in much the same way he would fly a conventional aircraft.

And from page 7 (PDF page 10):

Visual system. The visual system consisted of a three-dimensional terrain model (a modified SMK-23 Visual Simulator, The Singer Company), television camera and optical probe, and three monochromatic television monitors. The terrain model provided "real-world ground cues for visual tracking over the surface. The real-world to terrain model scale was 3,000:1 and represented a six by twelve-mile (9.65 by 19.3 km) area. The model was mounted on an endless belt that was servo-driven to represent the continuous changes in scene as the simulated RPV traveled along north-south directions. A television camera viewed the terrain model through an optical probe that contained a servoed mechanical assembly to permit the introductions of heading, roll, and pitch. Both the camera and probe were mounted on a servo-driven carriage system that moved across the terrain model to simulate movement of the RPV along east-west directions and in and out to simulate altitude changes.

The SMK-23 was also used in The Lunar Roving Vehicle (LRV) simulator *{Ref. 15}*. This shows what an SMK-23 looks like.



The SMK-23 used a television camera with an optical probe to fly over the terrain model contained on a servo-driven endless belt.

If Reed had had *synthetic vision* why would he have used the SMK-23 mechanical contraption?

The only link between Reed and HiMAT is that the HiMAT aircraft could be landed by either a ground-based pilot or an airborne controller (the backseat chase pilot in the TF-104G aircraft). While HiMAT might have used the results of the Reed report to select the airborne controller (the backseat chase pilot in the TF-104G aircraft) Reed did not use synthetic vision and neither did HiMAT.

Simulators

The AUVSI Authors describe several flight simulators, such as the RC AeroChopper by Ambrosia Microcomputer Products [Paragraphs 15 and 16] and Bruce Artwick's "Flight Simulator" for the Apple II, which ultimately became Microsoft Flight Simulator. [Paragraph 5]

RC AeroChopper was developed by David R. Stern at Ambrosia Microcomputer Products. The following is from an email correspondence with Mr. Stern:

Question 1: Did AeroChopper use a 3D terrain database?

> Mr. Stern: I guess it did, although the ground was a plane with 3D objects (and a 2D runway) scattered around (trees, pylon, towers with crossbar to fly under).

Question 2: If so, did it represent real terrestrial terrain?

> Mr. Stern: No.

RC AeroChopper was a significant achievement for the home computers available at the time and was a highly regarded simulator {*Ref. 17*} but:

1. It did not use a digital elevation database; "... the ground was a plane with 3D objects (and a 2D runway) scattered around (trees, pylon, towers with crossbar to fly under)," and thus, did not represent real terrestrial terrain.

2. It did not provide a computer-generated image of the external scene topography from the perspective of the flight deck that is derived from aircraft attitude, high-precision navigation solution, and database of terrain, obstacles and relevant cultural features.

It was not synthetic vision. It was a simulator.

Now, let's discuss Microsoft Flight Simulator {Ref. 18}. Flight Simulator 5.1 was released in 1995. Microsoft Flight Simulator did not start using 3D terrain until Flight Simulator 2000 Pro, released in late 1999 {Ref. 19}. Even then, it is not clear if the terrain database represents real terrain or is made up.

The article mentions the new GPS feature which is part of the simulated 737 control panel. There is no suggestion that a physical GPS unit can be connected to the program.

A simulator is not synthetic vision. A simulator might do a good job simulating synthetic vision. It might even use a Digital Terrain Elevation Database representing real terrestrial terrain, but that does not make it synthetic vision. It is a simulator. If it does not control a physical aircraft it is not synthetic vision.

When Did NASA Start Working on Synthetic Vision?

From Ref 20:

> **NEWS RELEASE**
>
> May 28, 1999
>
> **Synthetic Vision Could Help General Aviation Pilots Steer Clear of Fatalities**
>
> Hampton, Virginia -- Research Triangle Institute and six companies are teaming up to develop revolutionary new general aviation cockpit displays to give pilots clear views of their surroundings in bad weather and darkness.

See Ref. 20 for the remainder of the news release and Ref. 21 for NASA's news release.

When did NASA first use synthetic vision to control a UAV?

It was in the X-38 project. See Ref 22: "Virtual Cockpit Window" for a Windowless Aerospacecraft from the January 2003 issue of NASA Tech Briefs.

The Press Release from Rapid Imaging Software, Inc., which did the synthetic vision work for the X-38, states {Ref. 23}

> On December 13th, 2001, Astronaut Ken Ham successfully flew the X-38 from a remote cockpit using LandForm VisualFlight as his primary situation awareness display in a flight test at Edwards Air Force Base, California. This simulates conditions of a real flight for the windowless spacecraft, which will eventually become NASA's Crew Return Vehicle for the ISS. We believe

that this is the first test of a hybrid synthetic vision system which combines nose camera video with a LandForm synthetic vision display. Described by astronauts as "the best seat in the house", the system will ultimately make space travel safer by providing situation awareness during the landing phase of flight.

Other References cited by the AUVSI Authors

"Pathway-in-the-Sky Contact Analog Piloting Display," Knox and Leavitt, 1977

In the article the AUVSI Authors state in Paragraph 7:

> 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.

The complete Knox report is *Ref. 24*.

Everything comes together in Knox Figure 4, which shows the Airplane track-angle pointer and scale, the Airplane symbol with shadow superimposed, the Flight-path-angle scale, the Flight-path prediction vector, the Earth horizon, the Roll pointer, the Airplane altitude deviation from path, the Airplane flight-angle bars, the Programmed path-angle indicator, the Potential flight-path-angle box, and the Programmed flight path.

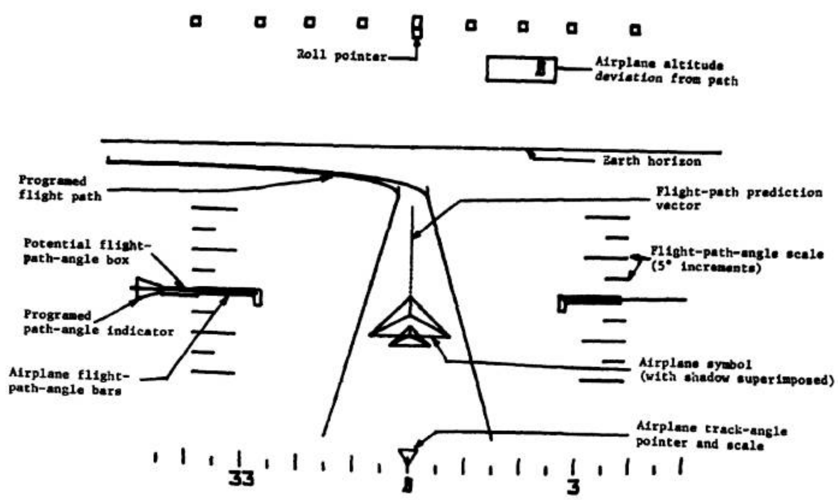


Figure 4.- The PITS contact analog display symbology.

The Programmed flight-path consists of two three-dimensional lines showing the predicted flight path of the airplane. Knox and Leavitt's work is significant but there is no terrain, there is no digital elevation database. There is no synthetic vision.

"The Electronic Terrain Map: A New Avionics Integrator", Small, D.M., 1981 {Ref 25}

In the article the AUVSI Authors state in Paragraph 8:

> 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.

No, Small did not describe “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.”

The Small report discusses the concept of a digital Electronic Terrain Map (ETM) and proposes that it be used for Navigation; Terrain Following/Terrain Avoidance (TF/TA); Threat avoidance, analysis, warning, and display; Terrain Masking; Weapon delivery; and Route planning.

For Navigation Small gives a choice between Radar-scanned terrain and finding your location on a map using an undefined method of adding a correlator to the avionic suite and using the on-board sensors together with the Electronic Terrain Map (ETM).

Small’s failure to mention omission of Terrain Referenced Navigation and Tercom is puzzling since both existed at the time he write the report.

He does say, “An electronic map subsystem can generate perspective scenes, which are essentially computer generated images of the surrounding area, and an electronic map should be much easier to interpret,” but the statement must be understood according to the meaning it would have had at the time the article was written (circa 1981) and wishing for a desired result is not the same as teaching how to do it.

In the 1980s (and well into the 1990s) the conventional wisdom was that Real 3D graphics was too computationally intensive to do in real time without large and very expensive hardware.

Honeywell was the leader in avionics. Harris was probably a close second. They both spent the 1980s and 1990s competing with each other to see who could do the best fake 3D.

There is Honeywell’s U.S. Patent 5,179,638 **Method and apparatus for generating a texture mapped perspective view** issued January 12, 1993 to Dawson, et al. *{Ref. 32}*

It even has the word “perspective” in the title, but the perspective it produces is a trapezoidal perspective, not a real 3D projected perspective.

A real 3D perspective is a 3D projection.

Anything else is Fake 3D.

If you think Fake 3D is just as good as Real 3D then the next time someone owes you money tell them that it’s ok to pay you in fake dollars.

There is also the matter that Small is only wishing for a desired result. Wishing for a desired result is not the same as teaching how to do it.

Not only did Small not teach it, he was not clear in saying what he was wishing for.

VCASS: An Approach to Visual Simulation, Kocian, D., 1977

In the article the AUVSI Authors state in Paragraph 6:

> 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).

The Kocian report is available in *Ref. 34*.

Kocian is about using a Helmut Mounted Display (HMD) with a Head Position Sensing System to replace large expensive hemispherical display systems used in simulators. The simulator is used to develop the visual interface used by crew members to control advanced weapon systems. This visual interface can then be used in airborne operations.

During simulation a representative visual scene is generated by the graphics or sensor imagery generators but, from Paragraph 11:

> **For an airborne VCASS capability, it is only necessary to install the VCS components along with a small airborne general purpose computer in a suitable aircraft and interface a representative programmable symbol generator to an on-board attitude reference system in order to synthesize either airborne or ground targets**.

The airborne version does not synthesize a visual scene, so it is not synthetic vision.

U.S. Patent 5,566,073 **Pilot Aid Using A Synthetic Environment** issued October 15, 1996 to Margolin

This patent was not mentioned by the AUVSI Authors.

Abstract

> A pilot aid using synthetic reality consists of a way to determine the aircraft's position and attitude such as by the global positioning system (GPS), a digital data base containing three-dimensional polygon data for terrain and manmade structures, a computer, and a display. The computer uses the aircraft's position and attitude to look up the terrain and manmade structure data in the data base and by using standard computer graphics methods creates a projected three-dimensional scene on a cockpit display. This presents the pilot with a synthesized view of the world regardless of the actual visibility. A second embodiment uses a head-mounted display with a head position sensor to provide the pilot with a synthesized view of the world that responds to where he or she is looking and which is not blocked by the cockpit or other aircraft structures. A third embodiment allows the pilot to preview the route ahead or to replay previous flights.

It teaches what is now known as synthetic vision in sufficient detail that it may be practiced by a *Person having Ordinary Skill In The Art* without undue experimentation. A Person having Ordinary Skill In The Art (POSITA) is a legal term that is often fought over during patent litigation.

This patent is a continuation of Application Ser. No. 08/274,394, filed Jul. 11, 1994, which is its filing priority date. The earliest known description of the invention is in *Ref. 35*.

For those unfamiliar with Patent Law, the Claims are the legal definition of the invention. The purpose of the Abstract is to provide search terms only.

See *Ref. 36* for the patent. (I am the inventor named in the patent.)

U.S. Patent 5,904,724 **Method and apparatus for remotely piloting an aircraft** issued May 18, 1999 to Margolin

This patent was also not mentioned by the AUVSI Authors.

Abstract

A method and apparatus that allows a remote aircraft to be controlled by a remotely located pilot who is presented with a synthesized three-dimensional projected view representing the environment around the remote aircraft. According to one aspect of the invention, a remote aircraft transmits its three-dimensional position and orientation to a remote pilot station. The remote pilot station applies this information to a digital database containing a three dimensional description of the environment around the remote aircraft to present the remote pilot with a three dimensional projected view of this environment. The remote pilot reacts to this view and interacts with the pilot controls, whose signals are transmitted back to the remote aircraft. In addition, the system compensates for the communications delay between the remote aircraft and the remote pilot station by controlling the sensitivity of the pilot controls.

It teaches the use of synthetic vision (as the term is currently used) for remotely piloting an aircraft. It teaches it in sufficient detail that it may be practiced by a Person having Ordinary Skill In The Art without undue experimentation.

This patent was filed January 19, 1996, which is its priority date.

For those unfamiliar with Patent Law, the Claims are the legal definition of the invention. The purpose of the Abstract is to provide search terms only.

See *Ref. 37* for the patent. (I am the inventor named in the patent.)

U.S. Patent Application Publication 20080033604 **System and Method For Safely Flying Unmanned Aerial Vehicles in Civilian Airspace**

In the interests of full disclosure I have the following patent application pending: U.S. Patent Application Publication 20080033604 **System and Method For Safely Flying Unmanned Aerial Vehicles in Civilian Airspace.**

Abstract

A system and method for safely flying an unmanned aerial vehicle (UAV), unmanned combat aerial vehicle (UCAV), or remotely piloted vehicle (RPV) in civilian airspace uses a remotely located pilot to control the aircraft using a synthetic vision system during at least selected phases of the flight such as during take-offs and landings.

See *Ref. 38* for the published patent application. (I am the inventor named in the application)

The Future of Synthetic Vision

This is what the AUVSI Authors have said about synthetic vision [Paragraph 2]:

> More recently it has evolved away from being a piloting aid to a potentially powerful tool for sensor operators.

and [Paragraph 22]:

> 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.

While I have no doubt that synthetic vision is very useful to the sensor operator, the news that its use in piloting UAVs is on its way out came as a big surprise to me.

The AUVSI Authors have an ulterior motive in making the statements. Their real objective is to make people believe synthetic vision no longer has value in controlling Remotely Piloted Vehicles (aka UAVs) and that a Remotely Piloted Vehicle that is flown using an Autonomous control system is no longer a remotely piloted vehicle and therefore a sensor operator may use synthetic vision without infringing U.S. Patent 5,904,724. See *Ref. 39* for the response Rapid Imaging Software's attorney sent to Optima Technology Group in 2006.

The statements made by the AUVSI Authors form a distinction without a difference unless there is a wall between the sensor operator and the pilot that results in the sensor operator having no influence on how or where the UAV is flown, regardless of whether it is flown with a human pilot or a machine pilot.

There are legal and political ramifications to this.

Someone has to be responsible for the operation and safety of the flight. The FAA defines "Pilot in Command" as *{Ref. 5}*:

> *Pilot in command* means the person who:
>
> (1) Has final authority and responsibility for the operation and safety of the flight;
> (2) Has been designated as pilot in command before or during the flight; and
> (3) Holds the appropriate category, class, and type rating, if appropriate, for the conduct of the flight.

It is unlikely that FAA will allow this responsibility to be delegated to a machine anytime soon. That's where the political ramifications come in. A UAV (especially a completely autonomous UAV) that injures or kills civilians would ignite a political firestorm that would ground the entire UAV fleet.

Frankly, it is stupid to cripple the utility of a UAV system in order to avoid paying a small patent licensing fee. Besides, the '724 patent is for the use of synthetic vision in a Remotely Piloted Aircraft. It is not limited to the use of synthetic vision by the crew member designated as the Pilot.

An autonomous pilot would have to be really good.

Even after 100 years of aviation, pilots still encounter situations and problems that have not been seen before. The way they deal with new situations and problems is to use their experience, judgment, and even intuition. Pilots have been remarkably successful in saving passengers and crew under extremely difficult conditions such as when parts of their aircraft fall off (the top of the fuselage peels off) or multiply-redundant critical controls fail (no rudder control). Computers cannot be programmed to display judgment. They can only be programmed to display judgment-like behavior under conditions that have already been anticipated. UAVs should not be allowed to fly over people's houses until they are at least smart enough to turn on their own fuel supply.

[On Apr. 25, 2006 the Predator UAV being used by the U.S. Customs and Border Protection agency to patrol the border crashed in Nogales, Ariz. According to the NTSB report (NTSB Identification CHI06MA121) when the remote pilot switched from one console to another the Predator was inadvertently commanded to shut off its fuel supply and "With no engine power, the UAV continued to descend below line-of-site communications and further attempts to re-establish contact with the UAV were not successful." In other words, the Predator crashed because the system did not warn the remote pilot he had turned off the fuel supply and it was not smart enough to turn its fuel supply back on. *{Ref. 40}*]

An autonomous UAV assumes the computer program has no bugs.

Complex computer programs always have bugs no matter how brilliant or motivated the programmer(s). As an example, look at almost every computer program ever written.

An autonomous Unmanned Combat Aerial Vehicle (UCAV) will have little chance against one flown by an experienced pilot using Synthetic Vision until Artificial Intelligence produces a sentient, conscious Being. At that point, all bets will be off because a superior sentient artificial Being may decide that war is stupid and refuse to participate. It may also decide that humans are obsolete or are fit only to be its slaves.

I propose yearly fly-offs:

1. A UCAV flown and fought autonomously against an F-22 (or F-35).

2. A UCAV flown and fought by a human pilot using synthetic vision against an F-22 (or F-35).

3. A UCAV flown and fought by a human pilot using synthetic vision against a UCAV flown and fought autonomously.

And that is the future of Unmanned Aerial Systems.

References

Reference 1 - ***Synthetic Vision Technology for Unmanned Systems: Looking Back and Looking Forward*** by Jeff Fox, Michael Abernathy, Mark Draper and Gloria Calhoun, AUVSI's **Unmanned Systems**, December 2008, pages 27-28.

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