14ème 14th SIIV IFIS
Toulouse-France 12-16 Juin/June 2006

Blended Synthetic Vision for Spatial Flight Inspection and Database Verification

Michael Coffman
Federal Aviation Administration
Sensor Fusion Project Manager
Flight Inspection Operations
Oklahoma City, OK USA 73169

Telephone: 405 954 6510
Fax: 405 954 7450
email: michael.coffman@faa.gov

ABSTRACT

The paper will tell how the United States Federal Aviation Administration (FAA) Flight Inspection Organization, the National Aeronautics and Space Administration (NASA), the University of North Dakota (UND), Rapid Imaging Software, INC. (RIS), and Aerospace Applications North America (AANA) entered into a Memorandum of Agreement (MOA) to explore sensor fusion into blended synthetic and live imagery displays (video and infrared camera). This technology can be used to improve flight crew situational awareness, enhance ground and flight safety, and develop control and interface concepts for crewed and non-crewed remote controlled vehicles. Additional uses include flight inspection, verification of spatial databases, and real time identification of vertical obstructions.

The paper will describe how MOA partners are flight-testing the blended synthetic vision system (BSVS) onboard a Challenger 604 to evaluate system performance in both ground taxi and

terminal area environments. The BSVS installed onboard the Challenger 604 is a PC based system using Smartcam 3D software to generate the synthetic image. Smartcam allows overlay of both static imagery and live sensors on the synthetic image as well as spatial data to provide a realistic near 180-degree field of view through 3 flat panel monitors mounted in the cabin of the aircraft.

The goal of the flight test program is to mature the technology to operational standards and allow synthetic flight inspection of vertical obstructions,

spatial coordinates of taxiways and runways, approach trapezoids, and additional point in space coordinates. Further operational aspects will be covered, including ground based technicians evaluating flight inspection missions through a ground based BSVS using near real time data links from UAV's.

Statistical analysis of the BSVS will be commissioned by the University of North Dakota to determine end-to-end accuracy, improved efficiencies of the flight inspection mission, and increased flight safety through database verification.

OVERVIEW

A MOA signed between NASA/JSC, FAA, University of North Dakota and two businesses, Rapid Imaging Software and Aerospace Applications North America, made this opportunity possible. The first phase of testing highlights the shared nature of the MOA as each party is supplying either hardware, software coding ability, flight test experience, aircraft, fuel, pilots, etc.

The overall goal is to create a cost effective, rapid prototyping flight platform that can meet the needs of many partners sharing information and investigating sensor fusion techniques in various flight environments including both atmospheric and space. NASA gains real world flight test experience with this type of system and demonstrates concepts for possible use in Constellation Program assets such as Crew Exploration Vehicle, LSAM, crewed or remote control of rovers from a lunar habitat or ground based MCC, and Unmanned Aerial Vehicles (UAV's). The FAA gains an important research and development knowledge focused on data validation, future synthetic vision technology, and how to handle flight inspection of spatial data.

The basic system consists of PC based CPU's, software package, cameras and an EGI (position & attitude sensor) that generate an out-the-window scene comprised of live video, satellite imagery, approach plate information, and a Heads Up Display (HUD), to create a sensor fused three dimensional like wide field of view display. The information can be viewed and evaluated during approaches to the test airport followed by landing and taxi evaluations.

BSVS SOFTWARE

The goal of Phase 1 testing was to have an environment to evaluate concepts for data validation. MOA partners believed that synthetic vision offered excellent capabilities for that purpose. From a hardware standpoint, a Windows-based PC platform would offer the greatest latitude in developing new software technology, and at the same time is cost effective due to it's less expensive price.

NASA had extensive experience with the SmartCam3D synthetic vision system which had been used for the remote operation of the X-38 Crew Return vehicle during flight-testing at the NASA Dryden Flight Research Center from 1998 to 2001. This software offers the ability to dynamically blend video, infrared, or any NTSC out signal with real-time synthetic vision on low-cost PC hardware. It also offers us the opportunity to build and customize the displays through various application programming interfaces (APIs). This allowed design and testing of display concepts on the fly in near real time.

SmartCam3D is adapted to use on Unmanned Aerial Vehicles (UAV's), like the Shadow and Predator, where issues of data latency and timing become very important. This is also desirable, as the option of performing approach inspections using unmanned vehicles will be desirable in certain environments. Another desirable feature of SmartCam3D is its ability to support gimbaled or moveable sensors rather than being limited to cameras mounted in a stationary place on the airframe, as a moveable sensor may be a desirable option in data validation.

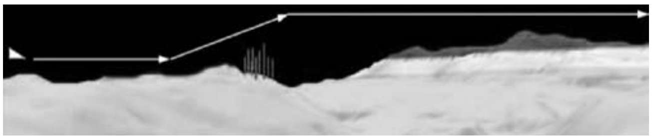
(Figure 1) (5-monitor sit-up)

SmartCam3D also supports a panoramic display mode (see Figure 1), in which multiple views can be strung together. 3 to 5 monitors are configured around the observer to form a virtual cockpit window. The idea here is not simply to display synthetic vision but rather to match the synthetic vision to the viewer's eye position so that the displayed geometry exactly matches the geometry of the scene if the user were looking out a glass window at the scene. In other words, the angular size of the synthetic scene matches the angle of the user's eye with respect to the monitors. It's believed that wider peripheral vision will be important in data validation because features misplaced by incorrect data may otherwise be undetectable.

The SmartTopo technology is still under development, but it holds the promise that it may be used to detect obstructions and aid the process of approach inspection using inexpensive video and computer equipment. The safe design of airports requires that the approach paths taken by arriving and departing aircraft be free of obstructions, which penetrate the minimum safe altitude that the aircraft may fly during the approach. This minimum safe altitude constitutes an invisible floor above, which aircraft may safely operate in instrument or limited visibility conditions.

However, it is sometimes difficult to identify all obstructions that might affect an approach. Water and communication towers and their associated guy wire represent a potential hazard to flight. Large cranes may appear in the vicinity of the airport for temporary construction projects and will naturally not be listed in obstruction databases. The technique of flying these approaches and visually inspecting them is currently used, however, a more quantitative answer is available using the SmartTopo technology.

The SmartTopo technology is currently implemented as software running on a WINTEL PC computer (or laptop) and processing live video coming from a camera mounted on the aircraft and looking down (in LVLH coordinates) from the aircraft. The aircraft must also be equipped with some kind of attitude detection system like an EGI or AHRS. SmartTopo acts something like a radar altimeter and reports the distance to objects below the aircraft. The best most accurate results are obtained for the area directly beneath the airplane but data can also be obtained for across the camera field of view. The concept is new, but very promising. This process creates a map of obstruction heights for the area traversed by the aircraft. This map is like a terrain map, containing latitude, longitude and altitude for points surveyed. So if the aircraft flies the approach path, the safe altitude can be evaluated.



(Figure 2) (SmartTopo vertical display)

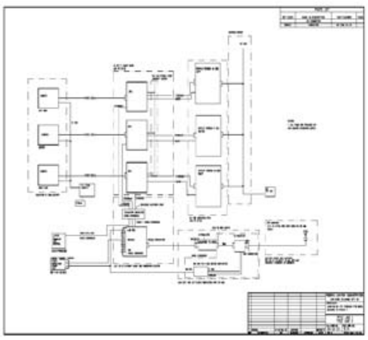
The vertical situation display (see Figure 2) offers the potential of being an excellent tool for confirming the location of obstructions detected during an inspection.

CHALLENGER 604 BSVS INSTALLATION

FAA's Challenger 604(see Figure 3) was selected as the test platform for the blended synthetic vision system. The system (see Figure 4) consists of three CPUs loaded with SmartCam 3D

(Figure 3) (Challenger 604)

visualization software, three Sony mini cameras, three 17-inch monitors, and an EGI system. The system is totally self-contained and does not interface with any of the 604 systems except for 24-volt power requirements and a GPS antenna for the EGI system.



(Figure 4) (BSVS System Diagram)

Attitude and Position data is derived from the EGI unit through a blending of GPS and INS solutions. This allows the BSVS system to be independent of the Challenger 604's navigational data stream solutions.
The three Sony mini cameras (see Figure 5) were installed on the dash of the Challenger 604 to provide the live sensor overlay. These cameras are commercial off the shelf units that utilize simple 12-volt power. The Sony cameras were picked based on cost, resolution, and field of view match to the hardware and software system. The cameras did pose a field of view limitation, that dictated that the 604 be put into the Experimental category during the flight-testing of the system, but the benefits of the sit-up out-weighed the negative impact.

(Figure 5) (Installed Sony Cameras)

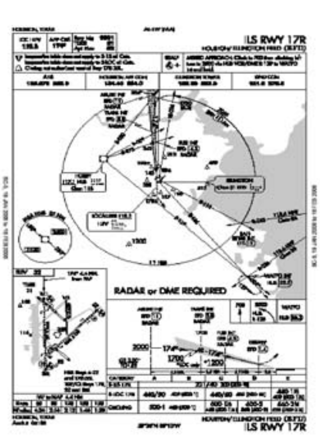
The CPUs running the SmartCam3D software are commercial off the shelf units made by XC Cube with 3.6 gigabyte Intel P4 processors. 2 gigabytes of ram were required to process the large image files.
The three 17-inch monitors installed in the mid-cabin area is the focal user station for the BSVS. The three monitors are near-perfectly aligned with the Sony mini camera mounted on the flight deck dash. The alignment issue requires the cameras to be both aligned with the horizontal level of the aircraft and with each of the three camera's field of view. To obtain the near 180 degrees sight pictures seen by the pilots in the 604, it was determined that both the port and starboard cameras needed a 40.2 degree offset angle for the center camera. This same offset was translated to the mid-cabin monitors in a three-panel wrap-around design. (see Figure 6)

(Figure 6) (604 three Panel Displays)

The eye viewpoint for the best representation of reality is 17.5 inches from the center monitor base on triangulation of the three center points of the monitors drawn back on a straight line.

PHASE 1 FLIGHT TESTING

NASA, RIS, AANA, and the FAA teamed up for a series of flight tests in March of 2006 centered on Ellington Field (KEFD) in Houston, Texas. The purpose of this series of testing was to demonstrate the concept of using BSVS to validate data, and specifically spatial data in the three dimensions of the synthetic world. This concept would require that aeronautical databases to be generated in X, Y, Z coordinates and viewed



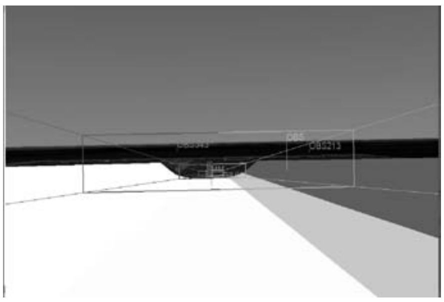
(Figure 7) (KEFD ILS 17R)

against reality, with the live video sensor overlay. In theory, the comparison of reality against the synthetic world should highlight errors in data such as obstacle penetration of the approach trapezoid, uncharted vertical obstructions, inaccurate runway coordinates, airspace conflicts, etc.

KEFD ILS 17R (see Figure 7) was the basis of all approaches flown by the Challenger 604 during the March 2006 flight tests. NASA personnel modeled the entire approach in SmartCam3D software and uploaded it into the BSVS. The results were synthetic entities in X, Y, and Z coordinates that simulated the two-dimensional charts currently published by the FAA.

The BSVS system consists of multiple layers of data that provided the fusion of sensors and databases into one display providing greatly enhanced situational awareness. The basic layer of data is United States Geological Survey (USGS) terrain elevation data that provides the canvas that all subsequent data is placed upon. Satellite imagery is anchored to the USGS data through geo-referenced points to provide visualization of the ground environment of the test airport. FAA XML data was used to model spatial entities including the ILS corridor, DME arc, final approach fix, missed approach point, vertical obstructions, and the holding pattern. A heads-up display can be inserted as another layer of information to enhance situational awareness. The Sony mini cameras provided the final layer of reality used for comparison against synthetic world.

The approach trapezoid depicting the protected airspace (see Figure 8) around the approach was modeled to test the concept of detecting obstacle penetration.



(Figure 8) (Approach Trapezoid)

No obstacle penetration was expected or occurred, but the synthetic modeling of the concept was tested. The DME arc was modeled as a series of 1000ft. diameter spheres spaced at 1 nautical mile intervals and the ILS corridor was depicted as a rectangular entities based on the dimension tolerances of the approach. Vertical obstructions were simple synthetic vertical sticks, and all other points in space were modeled as simple tagged points. Runway 17R and the parallel taxiway at KEFD was highlighted in high visibility yellow to provide maximum visual cues in reduced visibility.

Thirty-three approaches were flown to runway 17R at KEFD during 11 sorties. NASA mangers and astronauts evaluated each sortie to provide feedback on the BSVS and it's sensor fusion concept in both potential atmospheric and space flight. Even though the March 2006 flight tests were a proof of concept mission, it never the less resulted in the discovery of incorrect published longitude and latitude for the step down approach fixes of ETIME and TRAPS for KEFD ILS 17R. GIKAW, the Missed Approach Point for KEFD ILS 17R, was offset from the final approach course by 0.05 nautical miles.

PHASE 2 EVENTS

Future flight-testing of the BSVS system will begin in the summer of 2006. The goal is to move from the proof of concept mission of Phase 1 to the research and development of BSVS to enhance the capabilities of FAA Flight Inspection. The enhancement of capabilities will focus on verification of spatial data, the determination of accuracy required for databases that populate enhanced and synthetic vision systems, and how to begin the transition, for the flight inspection community, of measuring data instead of signal.

Unmanned Aerial Vehicle (UAV) testing is also scheduled for Phase 2 of this effort. The BSVS used in this research allows for a monitor ground station to be easily set up for constant flight monitoring of UAV assets in hostile areas for flight inspection purposes.All that needs to be down linked for near real time monitoring of world wide assets is the position and attitude of the UAV, and a real time sensor feed that provides reality for comparison validation of spatial data and the navigation state of the craft. Analog signal sensors would still be required in an attachment pod configuration, but as the airspace system of the world relies more heavily on spatial data for navigation, then the possibility of a UAV carrying out a flight inspection mission with only a BSVS system on board becomes a greater possibility.

The University of North Dakota will commission a study to look at the current structures of aeronautical databases to determine the accuracy of the data currently available. The ultimate goal of this study will be to provide accuracy guidance for the origin, structure, and validation of spatial data for use by enhance and synthetic vision systems utilized by industry.

CONCLUSION

BSVS is a way at looking at the flight inspection mission in a different capacity. We are currently in a transition period between analog signal and spatial data. As the proliferation of advanced vision technology increases at an ever-faster pace, then the flight inspection community must adapt to this technology to provide a safe airspace system. Now is the time to explore and adapt this technology to the flight inspection mission, before industry takes a quantum leap ahead of our capability. We are on the verge of seeing a great technology that can enhance the safety of aviation. The question remains, will the spatial data need to populate these systems be accurate enough to allow for the widespread certification of such systems.

A special thanks to the following individuals for making this project possible

AUTHORS:

- Lt. Col. Eric Boe, NASA Astronaut, (281) 244-8229, eric.a.boe@nasa.gov
- Jeffery L. Fox, NASA BSVS Project Coordinator Engineer, (281) 483-4465, jeffrey.l.fox@nasa.gov
- Donald E. Reed, NASA Flight Test Operations, (281) 483-4454, donald.e.reed@nasa.gov
- Rob Rivers, NASA Staff Pilot, (281) 244-9511, robert.a.rivers@nasa.gov
- Michael Coffman, FAA BSVS Project Manager,(405) 954-6510, michael.Coffman@faa.gov
- Dr. Shanaka L. de Silva, UND Space Studies Department Chair, (701) 777-3558, desilva@space.edu
- Pablo De Leon, UND Research Associate, (701) 777-2369, deleon@space.edu
- Michael Abernathy, RIS, INC, (505) 265-7020, mikea@landform.com

Patrick LaPort, AANA President, (832) 755-6725, patrick.p.laport@nasa.gov
- Tim Verborgh, AANA Vice President, (832) 755-6725, tverborgh@aerospaceapplications-na.com