Smart Camera System for Aircraft and Spacecraft

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ABSTRACT

This paper describes a new approach to situation awareness that combines video sensor technology and synthetic vision technology in a unique fashion to create a hybrid vision system. Our implementation of the technology, called "SmartCam3D" (SC3D) has been flight tested by both NASA and the Department of Defense with excellent results. This paper details its development and flight test results.

Windshields and windows add considerable weight and risk to vehicle design, and because of this, many future vehicles will employ a windowless cockpit design. This windowless cockpit design philosophy prompted us to look at what would be required to develop a system that provides crewmembers and operations personnel an appropriate level of situation awareness. The system created to date provides a real-time 3D perspective display that can be used during all-weather and visibility conditions. While the advantages of a synthetic vision only system are considerable, the major disadvantage of such a system is that it displays the synthetic scene created using "static" data acquired by an aircraft or satellite at some point in the past. The SC3D system we are presenting in this paper is a hybrid synthetic vision system that fuses live video stream information with a computer generated synthetic scene. This hybrid system can display a dynamic, real-time scene of a region of interest, enriched by information from a synthetic environment system, see figure 1.

The SC3D system has been flight tested on several X-38 flight tests performed over the last several years and on an ARMY Unmanned Aerial Vehicle (UAV) ground control station earlier this year. Additional testing using an assortment of UAV ground control stations and UAV simulators from the Army and Air Force will be conducted later this year.

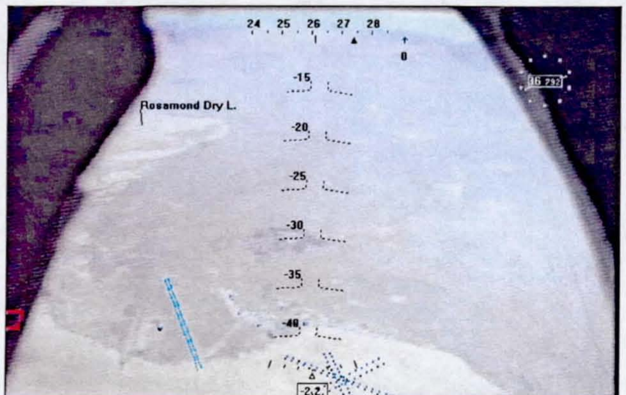

Figure 1: A Smart Camera System in action during Vehicle 131R flight-testing. Here we see video that is augmented with synthetically created runways, buildings, and no-fly zones. We also included a HUD and labeled the Rosamond Dry Lakebed.

We are also identifying other NASA programs that would benefit from the use of this technology.

Keywords: Synthetic vision, simulation, flight visualization, flight guidance, human factors, situation awareness, hybrid synthetic system, UAV visualization, and smart camera systems.

SMART CAMERA SYSTEM CONCEPT

The goal of the SC3D system is to create a system that provides crews and operations personnel with enhanced situation awareness (both for comfort and safety). The X38 program provided an initial testbed for the SC3D system. The X38 program was a NASA effort investigating the requirements to develop a Crew Return Vehicle (CRV) for the International Space Station (ISS). The X38 vehicles employed a windowless cockpit design philosophy. As such, crewmembers onboard would have to rely on technology advancements to provide them with the visualization information required during all phases of their mission. The hybrid system developed augments a live sensor data stream (video in this case) with information from a synthetically created scene. The system provides operators visuals that continue to function under all weather and visibility conditions. In cases of night, poor weather or other limited visibility environments, the operators can utilize the computer-generated synthetic out the window scene. However, if video data is available, it can provide a view that includes transient objects that might not be present in the geographic database. Obstructions, hazards, landing areas, flight paths/corridors, airstrips, and other items can be easily created synthetically and inserted into the live video stream. These synthetically created elements will continue to function, regardless of the quality of video stream. Figure 2 is a depiction that shows the basic components and data flow for the SC3D system system.

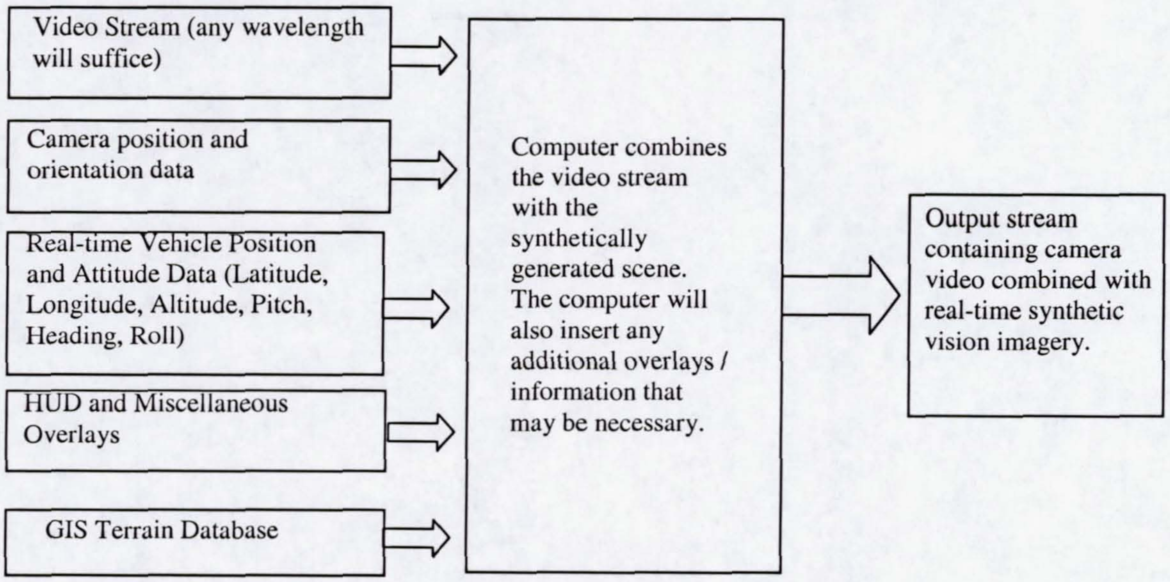

Figure 2: basic Components of the Smart camera System

The notion of a hybrid synthetic vision system is simple. A video camera is mounted on the vehicle in such a manner as to provide the operator with a view of the vehicle flight path. Simultaneously, a computer creates a 3D representation of the current scene that the camera should be viewing. Doing this requires a camera bore-sight calibration procedure that has been developed and verified to co-align the real and simulated cameras views, see figure 2. Once this alignment is performed, the two streams of information (video and synthetic) are overlaid inside the computer and displayed in a Helmet Mounted Display (HMD) or standard display monitor. Figure 3 shows a sample frame from the system that has been developed. Crewmembers and operations personnel assigned to evaluate this display system have noted that the addition of a custom Head-Up Display (HUD) is of great benefit. For pilots of both full scale and remotely piloted aircraft, such a display system would provide a view of the environment, which includes live video and enhanced with outlines of the terrain, other aircraft, landing zones, targets, objects of importance, runway outlines, landing zone markers, building models, no-fly zones, checkpoint flags, landing obstruction markers, hazardous landing areas, and flight path corridors and a custom HUD. The currently implemented HUD includes: an altitude tape, a compass heading indicator, a

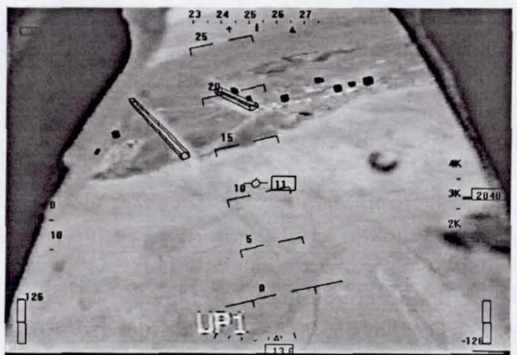

Figure 3: Combined video, synthetic scene, and overlays.

pitch ladder, a bank angle indicator, control surface command and position indicators, and miscellaneous flight data. Furthermore, because the synthetically created objects are generated from digital data, they are not subject to the limitations of visibility inherent to video. While darkness, terrain occlusion, smoke, fog, and haze all impact the video, the synthetically generated items will be unobstructed.

PLATFORM REQUIREMENTS

The SC3D system developed during our initial phase was deployed to the X-38 Remote Cockpit Van (RCV), see reference 3 for detailed description of the RCV, but could be deployed on any platform that meets the SC3D system fundamental requirements. The fundamental requirements include a real-time video stream, position & attitude data for the aircraft, and a graphical information system (GIS) database. This specific vehicle flight data required include: latitude, longitude, altitude, pitch, heading and roll, which we call our 6 degree of freedom (6-DOF) data set. Additionally, if the camera is mounted on a gimbal and has zoom capability, then gimbal angles and zoom setting are also required in the data stream. Realistic performance is achieved if this data is received at a data rate that is greater than 5 Hz. The 6-DOF data allows the software to synthesize a real-time 3D scene to match the camera's view.

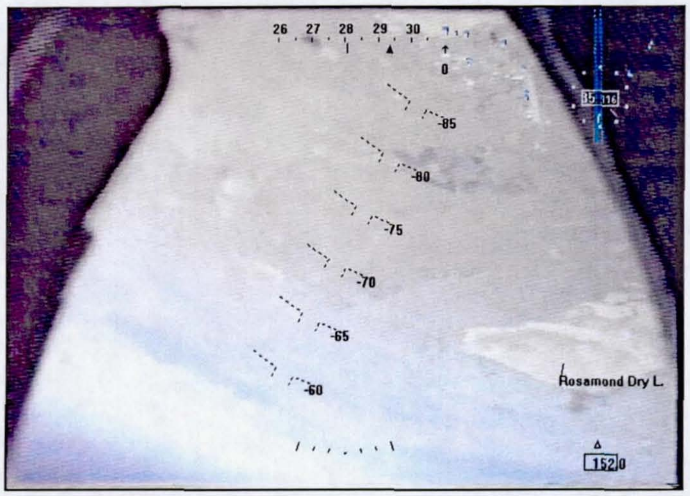

Figure 4: The Smart Camera uses the 3D position and attitude of the vehicle and thus provides situation awareness, regardless of vehicle attitude. Here the vehicle has rolled almost inverted, but the Smart Camera display still correctly marks the location of objects in the scene, like the lakebed.

The term video, as it is used in this discussion, refers to visual wavelength light but could include any wavelength signal from visual wavelength, to Near Infrared (NIR), Long Wave Infrared (LWIR), Forward-Looking Infrared (FLIR), etc. Anything that produces an RS-170 video or a stream of digital images that can be move into computer memory quickly can be utilized as the input video stream into the SC3D system.

The computer inserts information that details the location of landing zones, no-fly zones, runways, obstructions, buildings, topography and other geographic data. Anything with known geographic coordinates can be included in the scene. The synthetic image created exactly matches the theoretical camera view, and is overlaid on the video in real time. Base on our experience, modern laptops can generate these overlays at 5 to 15 frames per second. Figures 4 and 5 show examples frames taken from the first flight test of the X-38 131R vehicle.

FLIGHT TESTING

The X-38 vehicle was equipped with an Embedded GPS/INS system (EGI). The EGI provides vehicle position and attitude information to the flight control system and to the telemetry system that downlinks the data to the engineers performing flight following activities on the ground stations. The onboard telemetry system transmits all of the vehicle parameters, including the vehicles position (latitude, longitude, and altitude) and orientation (pitch, heading and roll) angles and are available for view by engineers and operations personnel in the X38 Mission Control Center at JSC, at the Spectrum Analysis Facility (SAF) at the Dryden Flight Research Center (DFRC), and in the Remote Cockpit Van in the field. Additionally, the X-38 131R vehicle was equipped with a camera mounted on the underside of the nosecone. The video from this camera is also transmitted to the ground. Prior to a flight test, ground crews activate the camera and perform a brief calibration procedure to determine the exact field of view and pointing angles (pitch, reading and roll offsets) for the onboard camera. This bore-sight calibration data is used by the SC3D system to create an identical viewpoint for the synthetic scene as the one being seen by the "real" camera.

The X-38 131R vehicle made three successful free flights at the DFRC. The SC3D system was preloaded with a 3-D topographical model of the flight test area, synthetically created 3D entities, maps/aeronautical charts for the area, and a custom built HUD. The 3-D synthetic entities created for the flight test include: a geographic model of the base, prominent landmarks, and reference points of interest to the mission. Runways, large hangars, towers, and buildings in the geographic model are displayed by the SC3D system and used as landmarks by the crew. Once a landing site has been selected, it is entered into the database and can be used as an aim point during final approach and flare flight phases.

Results from this system have been very encouraging and have emphasized some of the less obvious benefits of the SC3D system. During one of the flights a rapid descent caused ice to form on the vehicle's camera window, partially obscuring the cameras view, see figure 5. Astronauts in the remote cockpit, as seen in figure 6, were able to continue to rely on the display even when the camera had partially failed because of the presence of the synthetic vision overlays still correctly showed the location of landmarks and the landing zone. Free flight 1 also afforded the crew an opportunity to evaluate the display during a 360 degree roll. Because the SC3D system utilizes the real-time vehicle attitude information to synthesize its scene, the display continued to work very well, even at extreme attitudes (upside down at a pitch angle of -70 degrees).

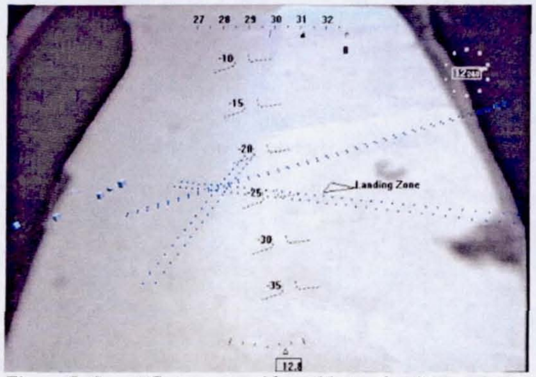

Figure 5: Smart Camera provides additional safety against camera failure. Here the camera window has begun to ice over on the left side of the screen, but the crew is still seeing the synthetic elements of the 3-dimensional scene.

Figure 6: Astronauts in the X-38 remote cockpit using Smart Camera situation awareness technology.

Video and flight data from both a helicopter and a glider have been evaluated in a post-processing regime with equally good results, and some significant discoveries emerged. During testing with an Army UH-1 helicopter it was discovered that gyro lag in older mechanical inertial navigation unit caused a perceptible lag in the angle-dependent elements of the overlay. While perceptible, this problem was mostly aesthetic. Data collected from a glider equipped with an air data system that included a barometric altimeter confirmed that barometric altitude measurements are several times more accurate than GPS altitude measurements.

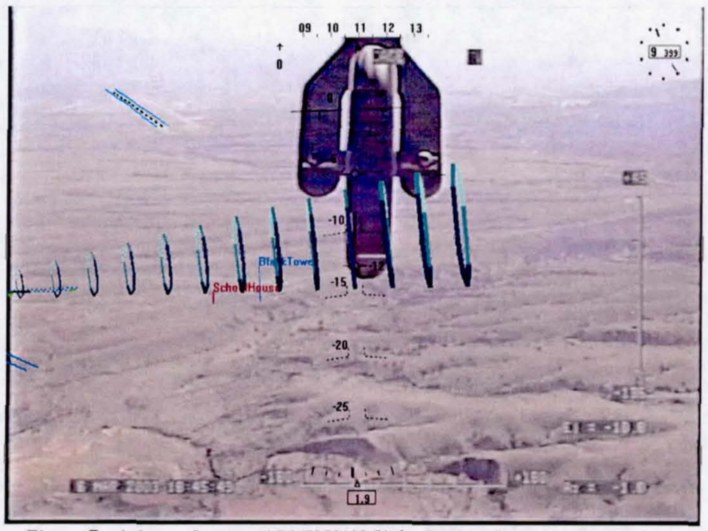

Figure 7: A frame from an ARMY UAV flight display shows the Tactical Automated Landing System (TALS) Acquisition Window as a 3D corridor.

Real time flight-testing on a United States Army Tactical Unmanned Aerial Vehicle (UAV) demonstrated both the feasibility of integrating the SC3D system with currently existing UAV ground control stations and the utility of SC3D system enhanced the situation awareness of the crew and ground control engineers. The flight data showed a good basic match between the synthetic and video scenes with some predictable exceptions. Engineers for the ground control station of the UAV alerted us to some inherent problems that we might encounter because of the UAV model that we would be using. We did encounter those problems and found although distracting at times, did not detract from the usefulness of the SC3D system for UAV operations.

DEVELOPMENT PLANS

An early version of the SC3D system demonstrated the usefulness of such a system using various "hardware mixer" boxes to perform the overlay operation. While this was useful in demonstrating the basic concept, the achievable accuracy, large form factor, and high cost made this option less desirable than a software only solution that would run on a desktop PC. NASA's Integrated Video program started in 2001 and aims to achieve the software overlay capability, add support for multiple cameras, and incorporate various display technologies (i.e. a Helmet Mounted Display) into the SC3D system system. Flight testing will proceed along with development. More extensive data collection with fixed wing aircraft, the remote cockpit, and various simulators will be conducted this coming year.

ENHANCED UAV DISPLAY

Unmanned Aerial Vehicles (UAVs) often have on-board cameras, which transmit live video during flight to the control stations on the ground. As such, they can benefit significantly from the SC3D system technology. There are several improvements in the effectiveness of UAVs for combat applications for this technology.

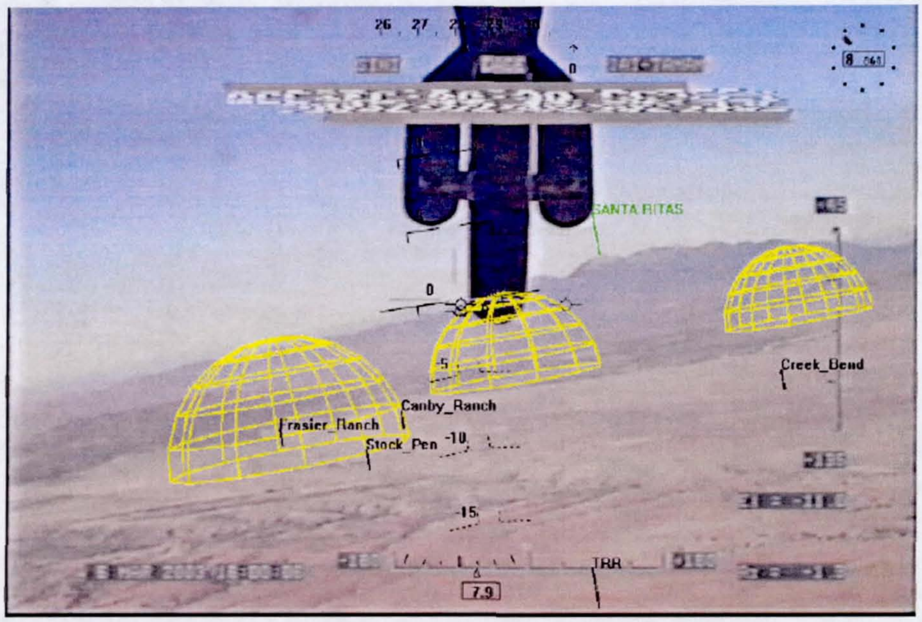

Figure 8: Video camera frame taken in the downrange portion of the flight shows yellow no fly markers over courtesy no-loiter zones. Imaging target locations are indicated in black, as is the SmartCam3D HUD.

- The SC3D system makes it easier for operators to identify known friendly force locations in the video scene.
- The synthetic vision system is based on VisualFlight, which is already compatible with most NIMA data formats including DTED, ADRG, CADRG, CIB, etc., so the necessary geographic data is already abundantly available.
- The system aids operators in avoiding anti-aircraft weapons and small arms fire from known enemy locations - these can be shown as threat domes and are more easily avoided by the operator.
- Safer vehicle operation at night and in limited visibility situations (sandstorms, dust, smoke, etc.). The SC3D system provides a synthetic vision component that is not affected by visibility conditions.
- Finally, users will better utilize UAV video data because landmarks and reference points are clearly identified in the scene.

STUDENT PILOT FLIGHT REVIEW SYSTEM

The SC3D system could become an important tool for the general aviation industry, as a student pilot flight review system. In this application a training aircraft would be outfitted with the Smart Camera System including video camera, recorder, and computer laptop. The annotated video recorded during the flight would be reviewed with the student during debriefing.

The student could also take a copy of the tape with him or her for later review. This would provide considerable benefit to the student by leveraging every hour of airtime into 2 or more hours of learning experience. Any available digital avionics information deemed critical to the lesson (airspeed, descent rate, pitch angle) would be displayed on the 2-D overlay to aid post-flight review, see figure 9.

RECONNAISSANCE, MISSION PLANNING, AND MISSION OPERATIONS:

As military special operations, RECON, and other forces operate in geographically unfamiliar territory, the SC3D system will provide them with instant terrain familiarity. A man-portable SC3D system can be engineered to support field operations and provide operatives an increased level of situation awareness. Figure 10 shows an example of such a system in operation. Tags are used to indicate the location of significant landmarks, structures, and the positions of known friendly and enemy forces. The location of air strike or artillery aim-point coordinates can be viewed in three dimensions in advance of the strike, permitting the observer to confirm that the impact point is correct. An interactive system will permit the user to interrogate the database through the camera to obtain information about objects, which are in the scene and in the 3-D database.

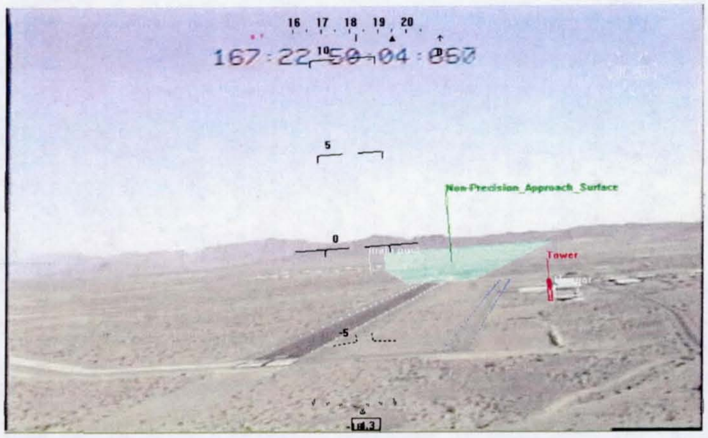

Figure 9: Student Pilot flight review system shows the FAA non-precision approach surface.

Figure 10: A portable smart targeting system may help Special Forces personnel in unfamiliar terrain make reliable targeting decisions.

CONCLUSION

The NASA Smart Camera System has been developed to substantially enhance the information density and usefulness of video imagery. The SC3D system has been implemented using inexpensive off-the-shelf hardware and software, and it's utility has been demonstrated during flight tests of the X-38 vehicle, flight test of an Army UAV, UH-1 flight testing, glider testing, and in the remote cockpit van (RCV). Future development will make the technology even simpler and more useful. A multiple camera feature, that will provide users with a live data 360 by 360 degree field of view of the area, will be incorporated this coming year. Additional testing will also be performed to determine if the technology can be used in several other application areas.

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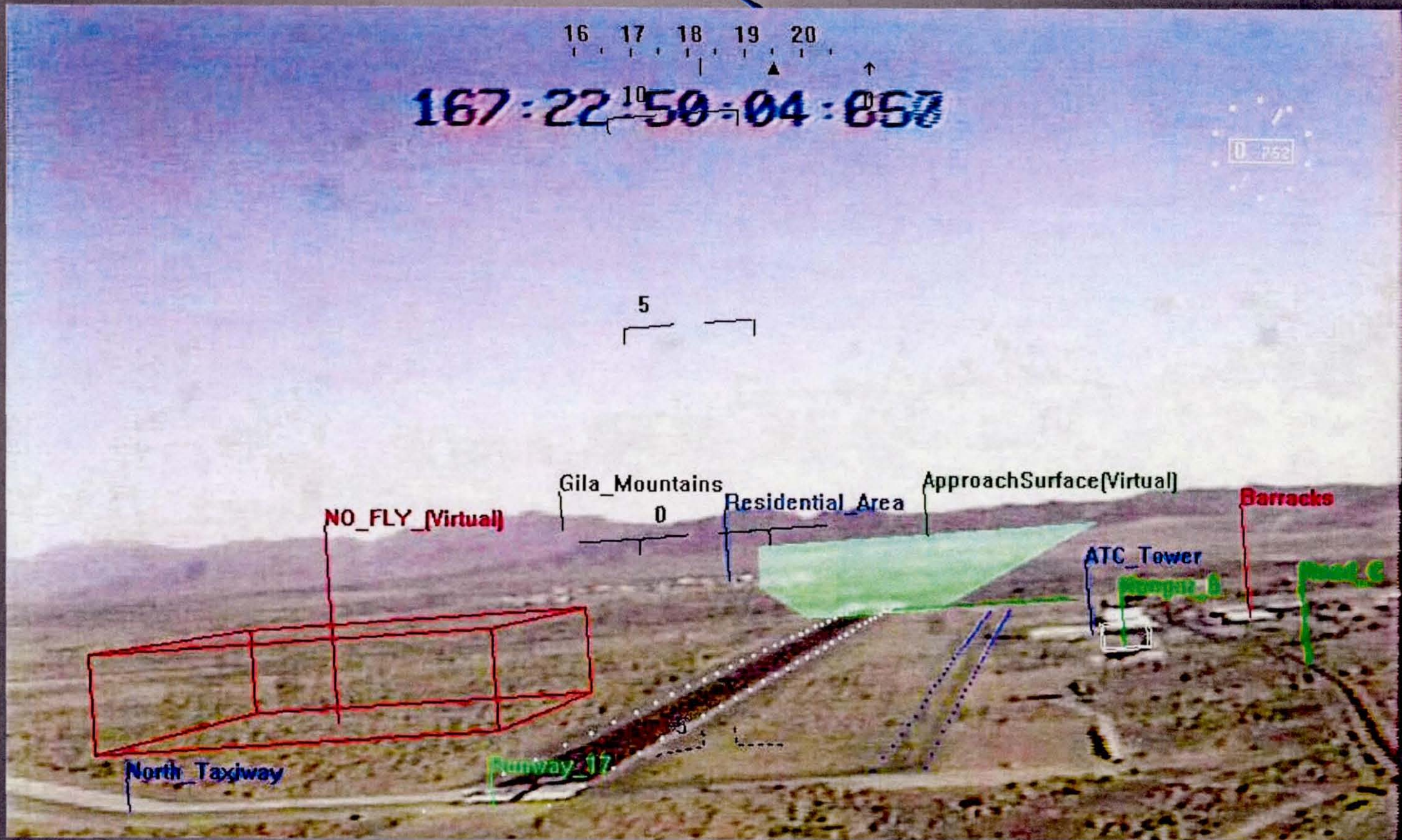
April 21, 2003

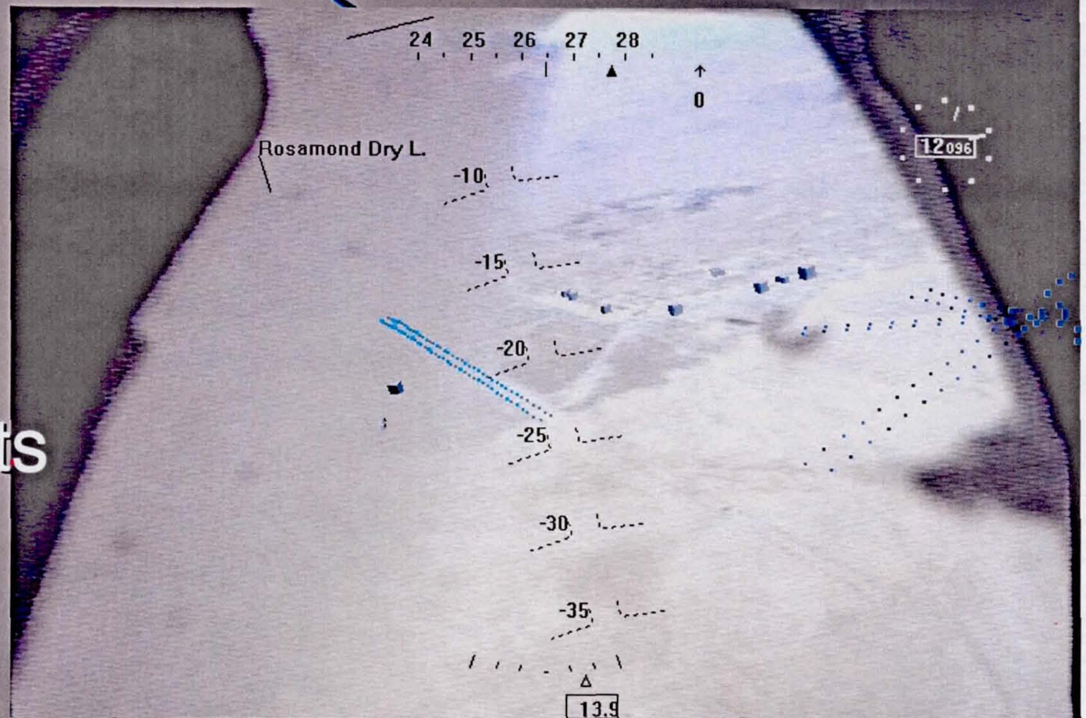
SPIE AeroSense

Enhanced Situation Awareness through Hybrid Synthetic Vision

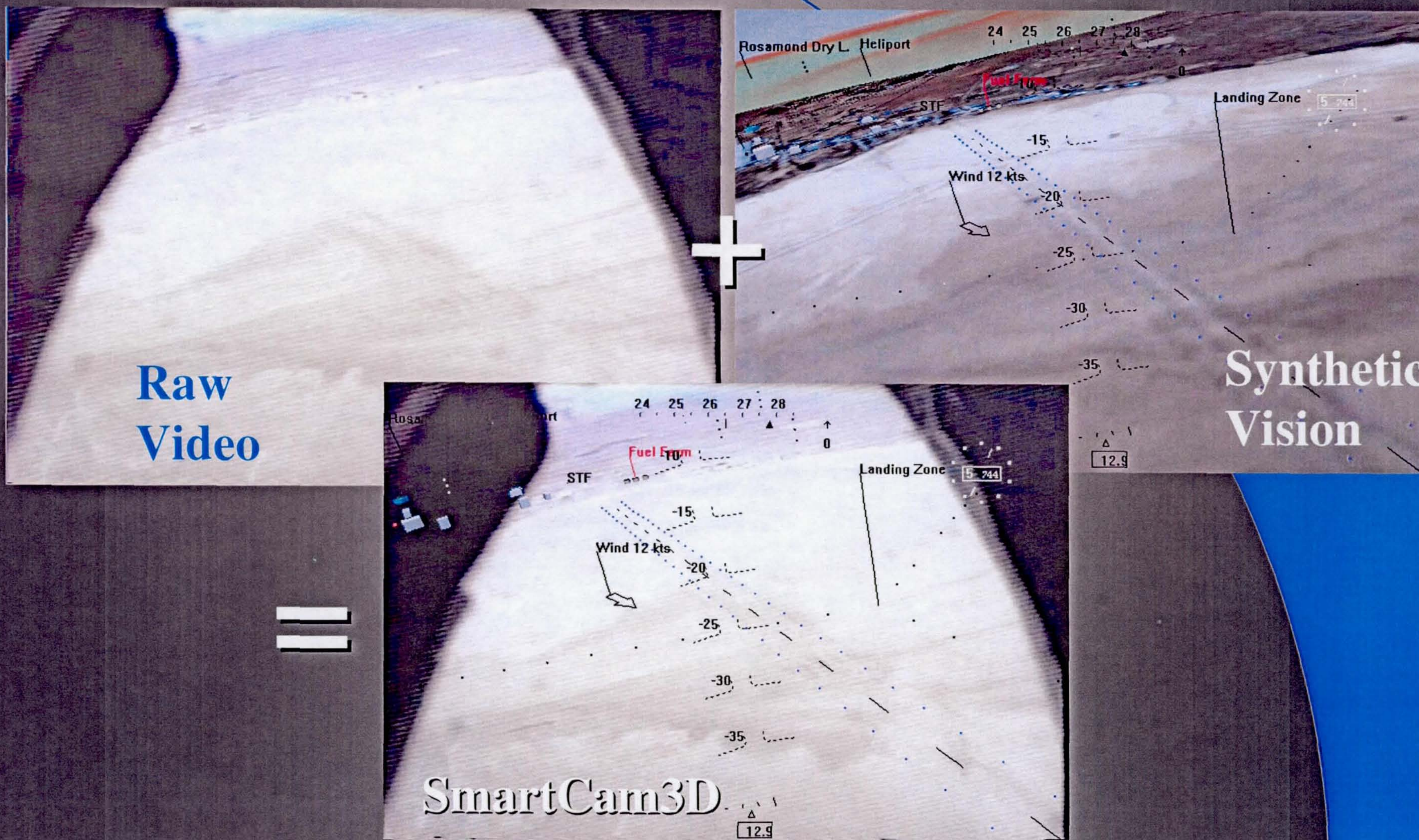


Hybrid Synthetic Vision Overview

- Concept
- Background
- System
- Benefits
- Flight Test Results



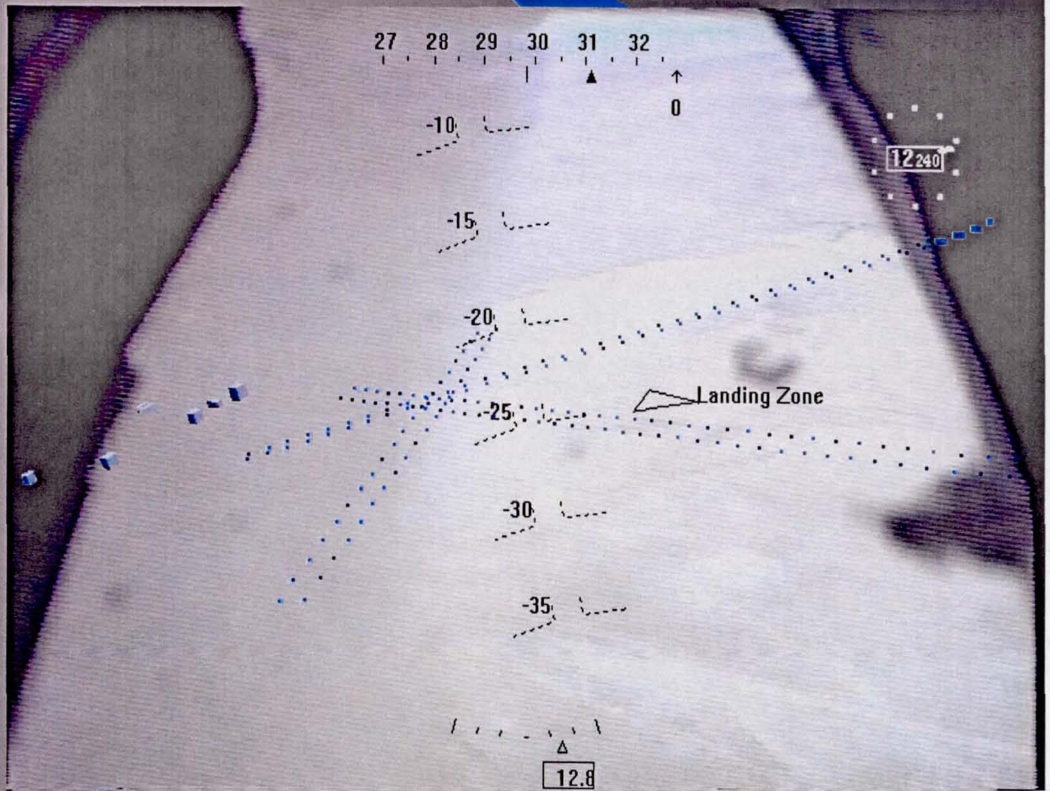
SmartCam System Concept



SmartCam Background

Future spacecraft feature windowless cockpit

- Maintain situation awareness
  - Real-time flight information
  - Real-time operations information
- Enhance crew safety / comfort



SmartCam Background

- Began in 1999 with NASA X-38 Remote Cockpit development
- Based on the LandForm synthetic vision system from RIS
- UAV initiative supported by Deputy Under Secretary of Defense Advanced Systems and Concepts (DUSD AS&C)
- UAV Flight Data Collection by ARMY UAVS PMO

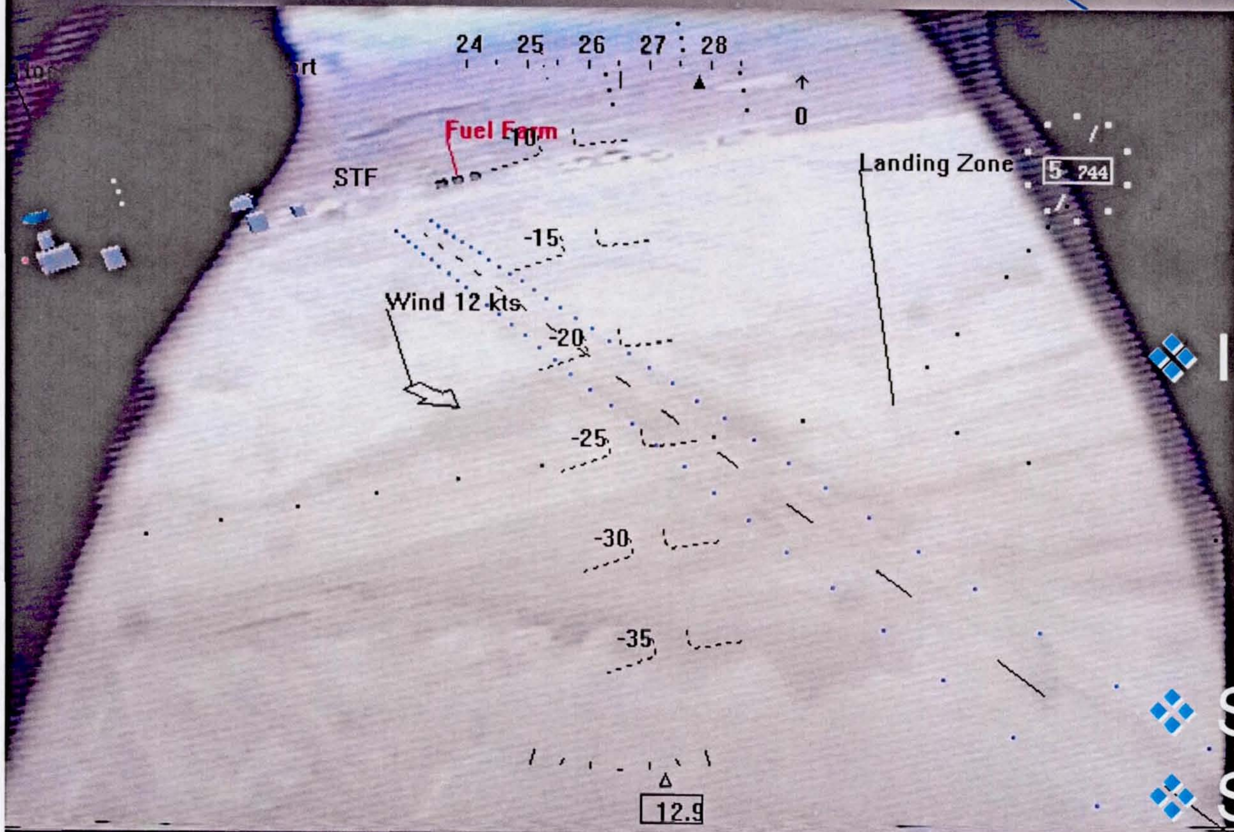
NASA

LANDFORM
Rapid Imaging Software

ADVANCED CONCEPT TECHNOLOGY DEMONSTRATIONS
DUSD/AS&C

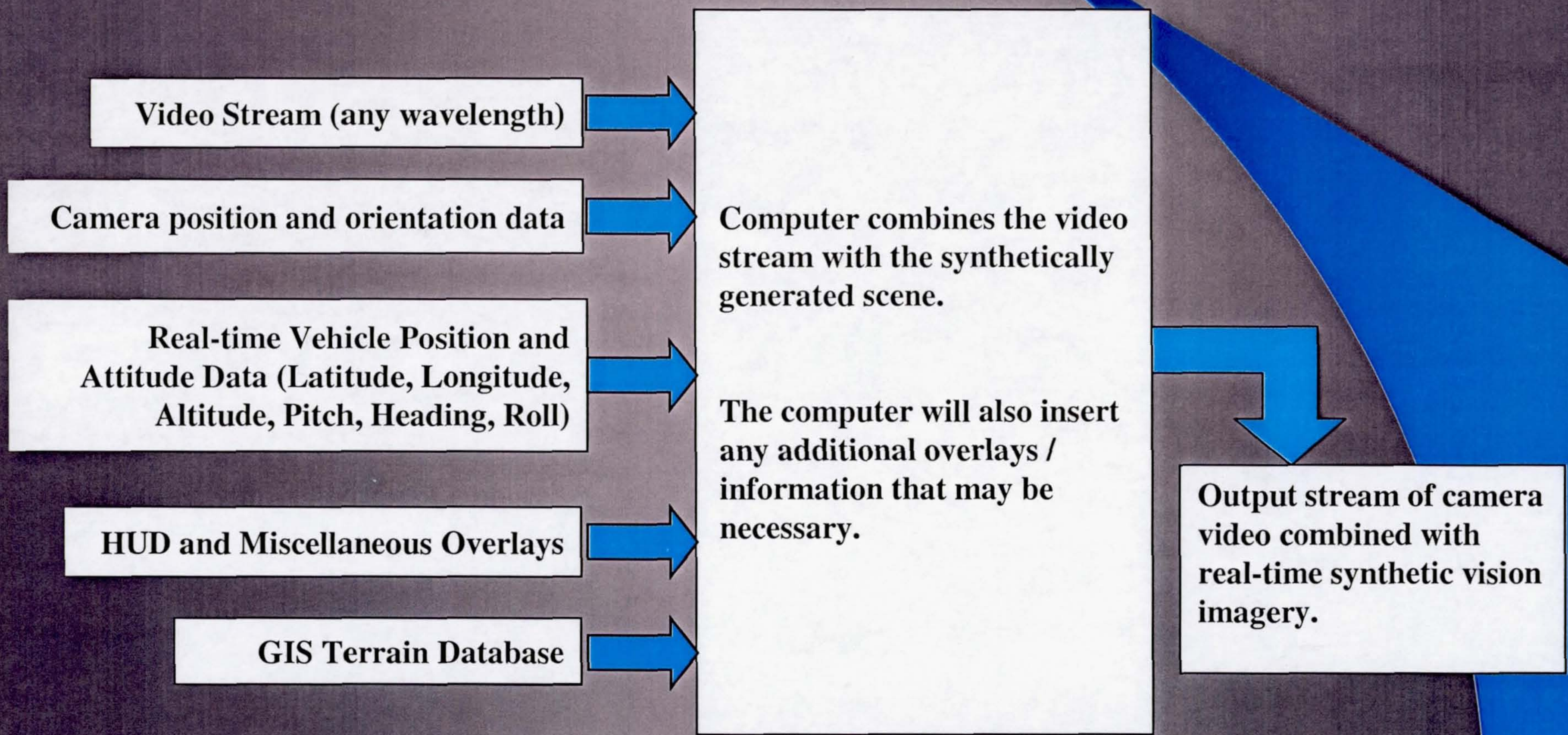
US ARMY TUAV PROGRAM MANAGEMENT OFFICE

SmartCam System

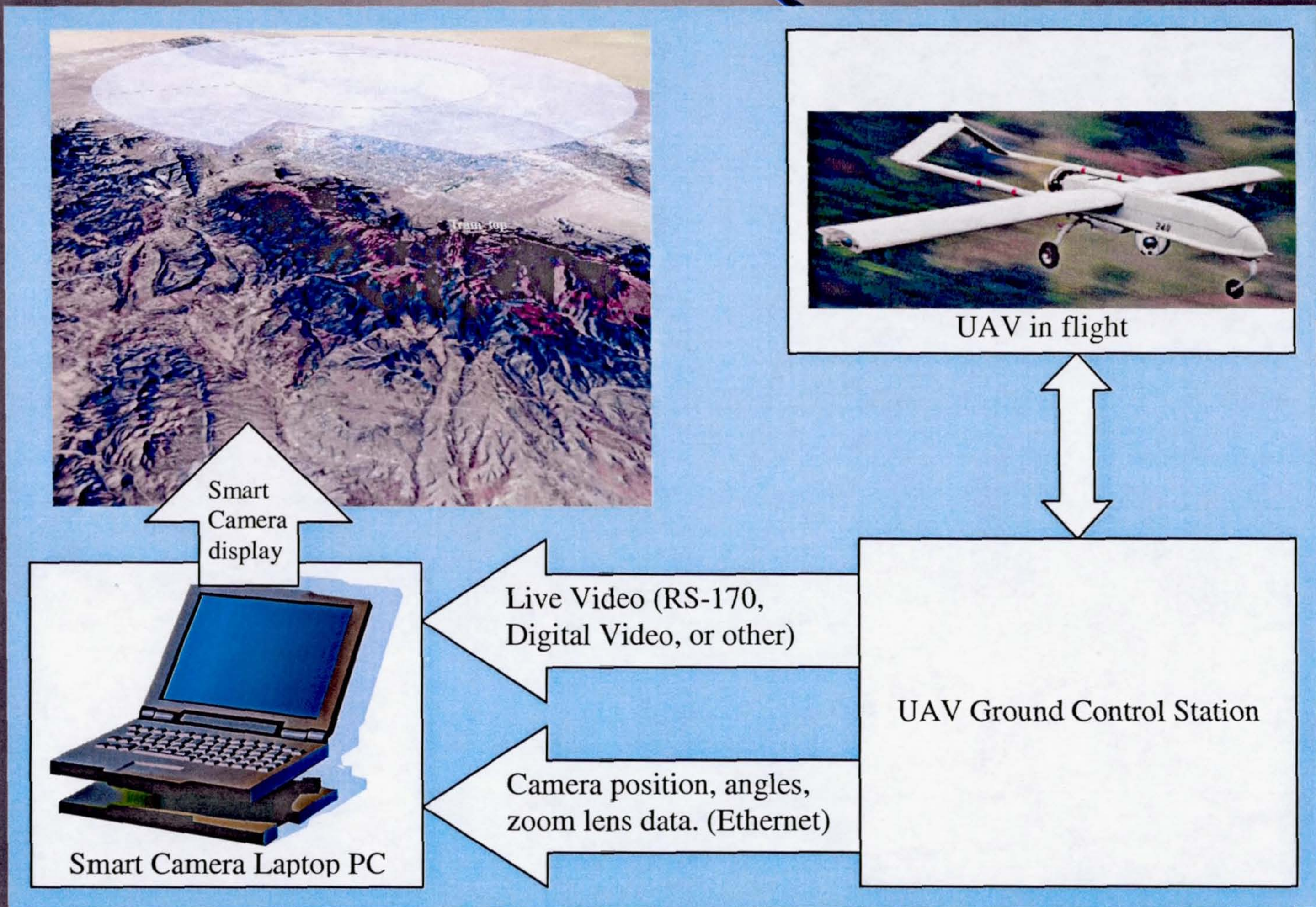


- Intel Pentium computer
  - Windows 2000
  - Ethernet interface (MUSE TCP/IP)
  - Video digitizer
- SmartCam3D Software
- SmartCam3D Global Databases (4GB+)
- User-supplied Databases

SmartCam uses flight data to simulate the camera's view

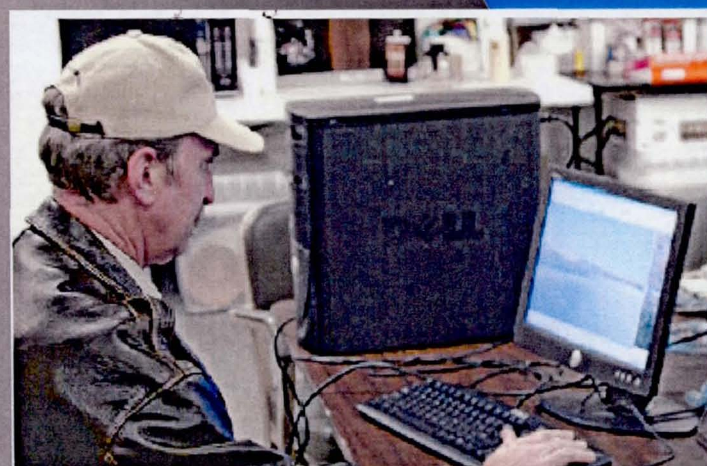


Typical SmartCam Configuration



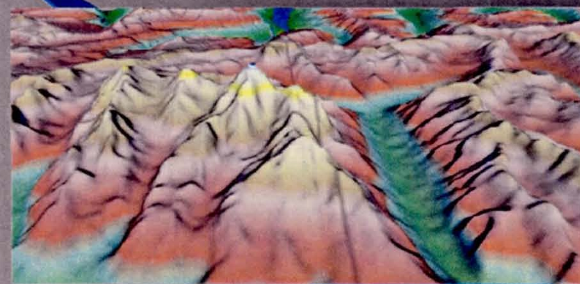
SmartCam is different from other vision systems

- Goal: high information density not photo realistic rendering
- Supports global <u>non-proprietary</u> database formats
- Full earth curvature terrain model
- Targeted users are flight crews not simulation professionals
- Easy to use



SmartCam utilizes global databases

SRTM (also DTED, DEM)	Topography
DAFIF	Runways, Airspace
FAA	Airspace, Part 77 Approach surfaces
USGS DOQQ, GEOTIFF, TFW,…	Terrain Imagery
NIMA CIB, CADRG,…	… various …

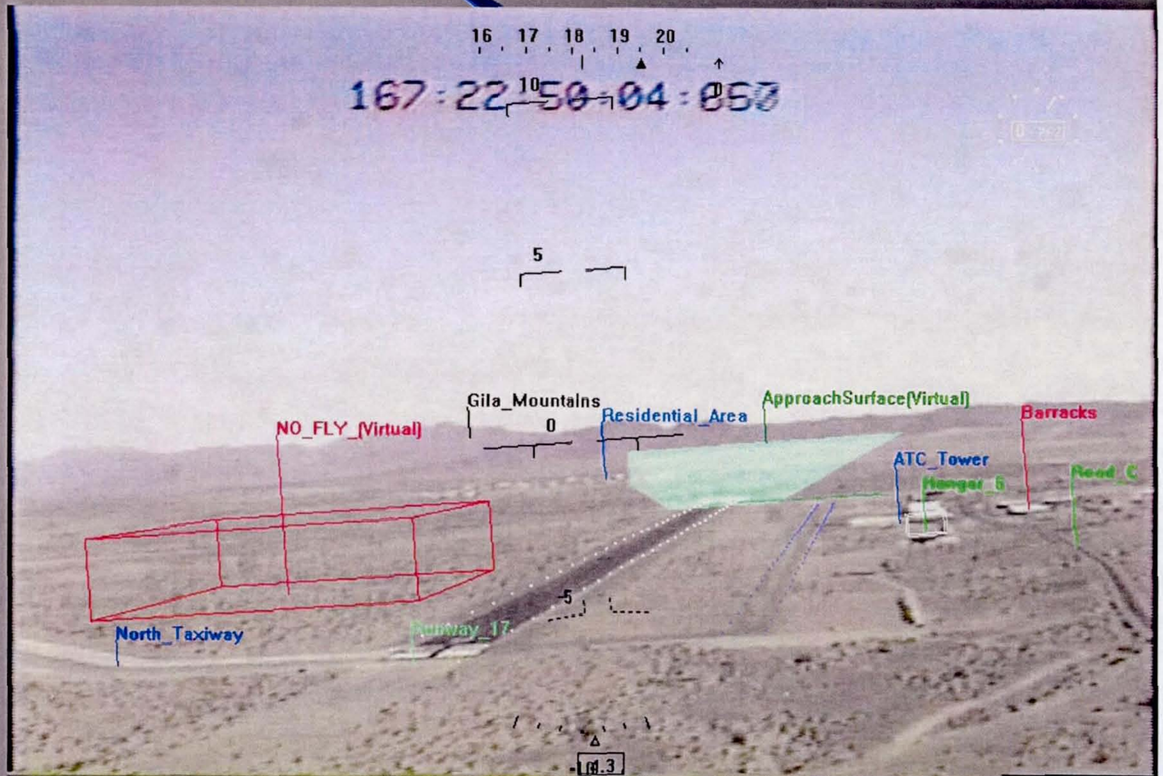


SmartCam Benefits

- Better situation awareness
  - Works at night
  - Under obscuring conditions
  - During loss of video signal
- Better flight / payload operations
  - Information dense display
  - Locate targets by know geographic features
  - Merge instrument and visual flight

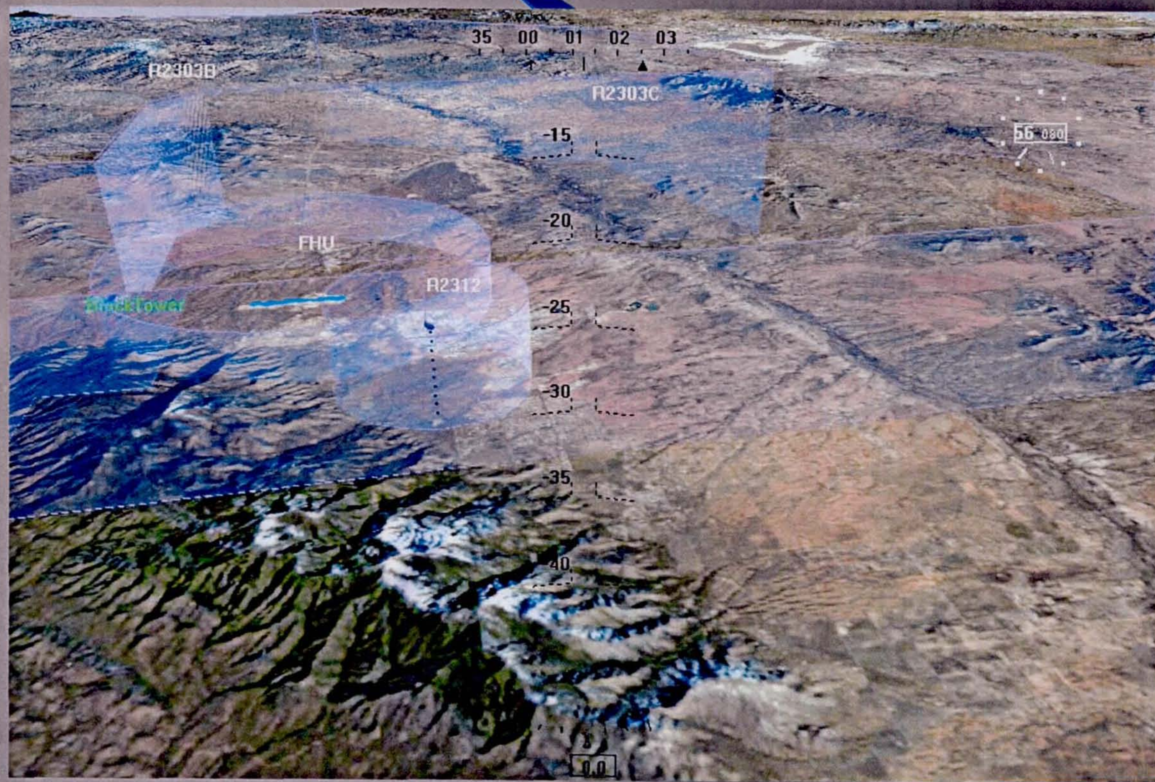
Better Situation Awareness

- Avoid terrain, obstructions, controlled airspace volumes, no-fly zones.
- Provides a video-like display that *works at night, in clouds, dust, smoke, fog, and during video camera failure.*
- Find locations without video.
- Play back flights for post mission analysis on any PC.

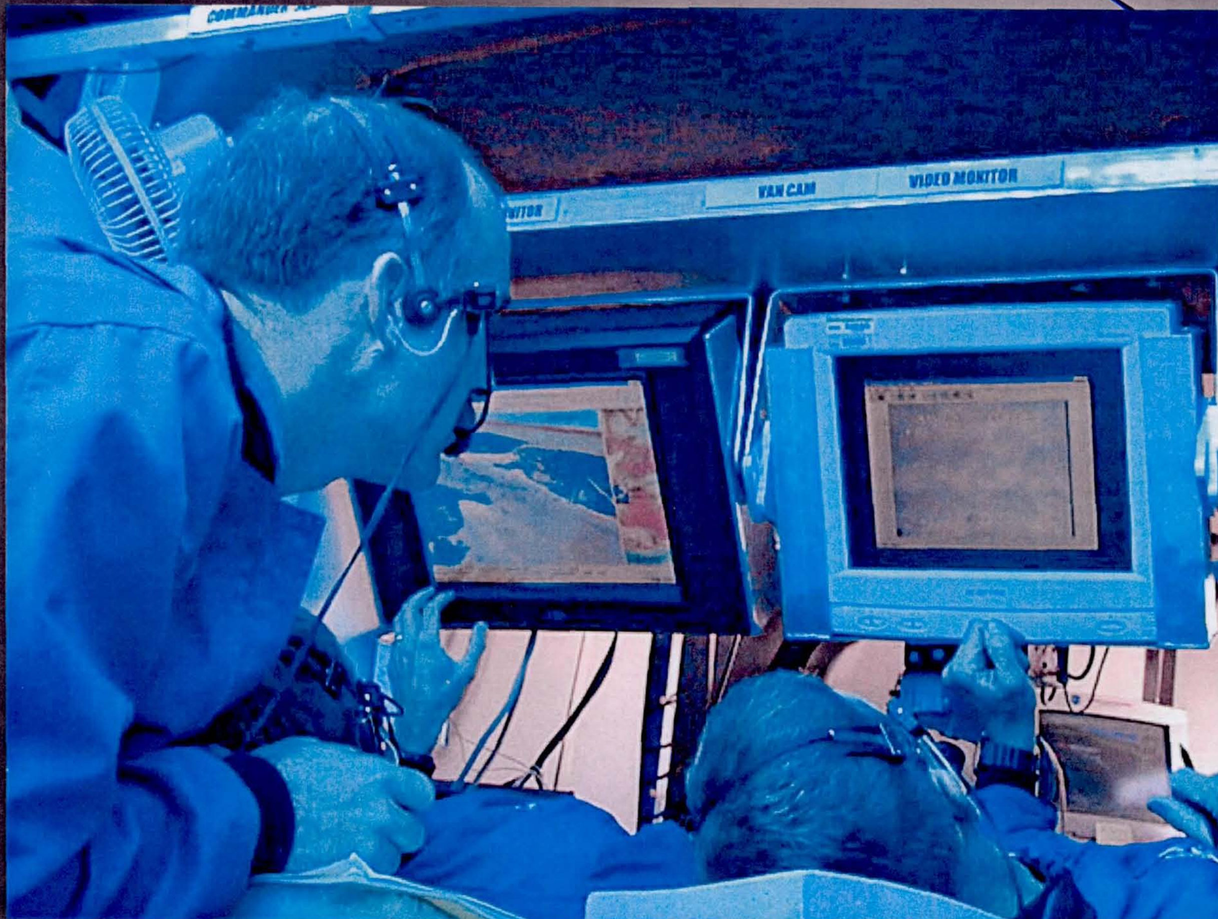


Better Flight / Payload Operations

- See airspace volumes in 3D
- Improves payload scene understanding
- Insert 3D markers into video scene
- Locate targets in terms of known geographic features
- Enhance image analysis

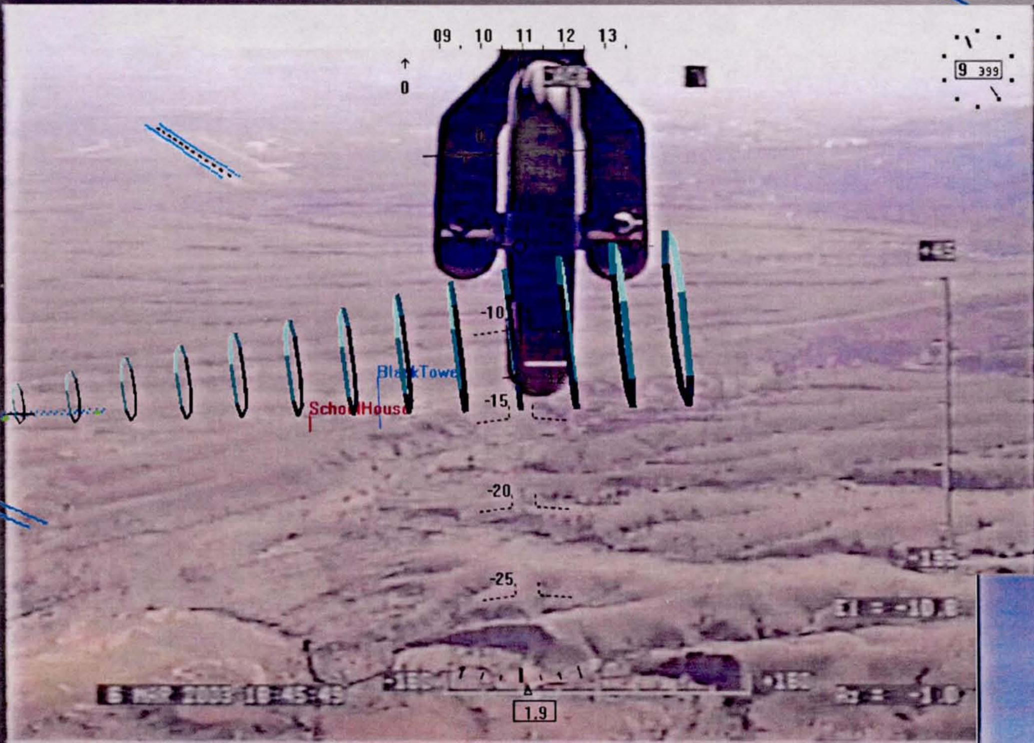


Flight Test Results

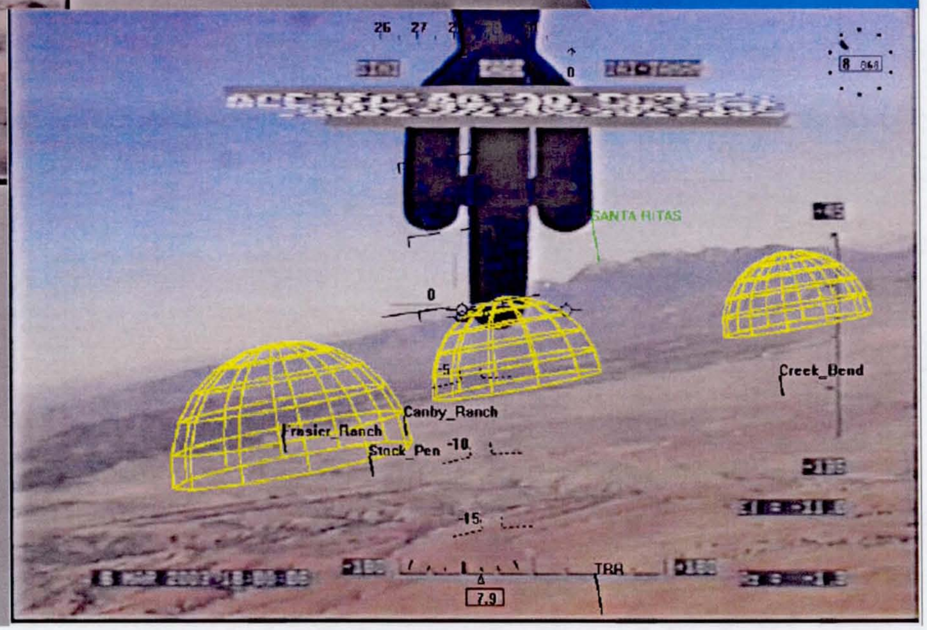


"Best seat in the house"- X-38 Remote Cockpit Vehicle pilot

SmartCam UAV Flight Test



- Successful integration with ground control station
- Enhanced situation awareness



Vehicle: US Army UAV

SmartCam X-38 Flight Test