Airborne remote spectrometry support to rescue personnel at "Ground Zero" after the World Trade Center attack on September 11, 2001

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ABSTRACT

In order to assist Rescue and Recovery personnel after 11 September 2001, Night Vision and Electronic Sensors Directorate was requested to collect a variety of airborne electro-optic data of the WTC site. The immediate objective was to provide FDNY with geo-rectified high-resolution and solar reflective hyperspectral data to help map the debris-field. Later data collections included calibrated MWIR data. This thermal data provided accurate temperature profiles, which could be warped to the high-resolution data. This paper will describe the assets and software used to help provide the FDNY data products, which were incorporated into their GIS database.

Keywords: Infrared Imaging, Airborne Remote Sensing, Remote Spectrometry, Remote Chemical Sensing, Remote Temperature Estimation

1. INTRODUCTION

The New York City Office of Emergency Management (OEM) contracted with the MITRE corporation to provide high resolution GIS maps of the debris field so visible surface features could be overlaid onto maps of the buried infrastructure, (tunnels, power lines, sewer/water supply etc.).

MITRE suggested to OEM that they request help from the USA CECOM RDEC Night Vision and Electronic Sensors Directorate's (NVESD) Night Vision Imaging Spectrometer (NVIS) sensor suite, which includes a high resolution imager. By coincidence, NVIS was installed in an aircraft and ready for flight tests.

On September 19th, a request for assistance came from the New York City OEM through MITRE's contacts at US Army CECOM to the NVESD to fly the sensor suite and geo-rectify the High Resolution Imagery into GIS maps. Two hours later, the Twin Otter was airborne, heading to New York with the following five sensors on-board: HRI 6000 element line-scanner; NVIS HSI 0.4-2.4 microns, 384 bands; MWIR Calibrated Thermocam; Color Video Camera; CMIGITS GPS/INS unit attached to the sensor frame. A Fourier transform infrared spectrometer (FTIR) spectrometer was included in the airborne sensor suite in order to detect off-gassing. This instrument had some success detecting chemicals, but was not optimized for flight.

2. DATA COLLECTION

The aircraft flew over NYC at altitudes of 1500 to 6000 ft in1500 ft increments. GIS map products were predominantly produced from the 1500ft aircraft data.

As the aircraft and crew flew patterns over the "Ground Zero" New York disaster site collecting data, the NVESD Rapid Prototyping and Field Support Division put together and tested processing software to calibrate and geo-rectify the NVIS sensor suite data. A key piece of software was an ENVI-based geo-rectification tool developed by the Spectral Information Technology Application Center (SITAC) to allow simultaneous geo-rectification and warping of the NVIS hyperspectral data and the high-resolution imagery.

MITRE created a Rapid Mapping Cell in the NYC Emergency Operations Center at Pier 92 in Manhattan. Calibrated data products from the NVIS sensor suite were handed off to the MITRE Corporation, who assembled all the data into useful map based products for the New York City OEM, Fire Department and Health Department.

3. NVIS SENSOR SUITE

Figure 1 shows the NVIS sensor suite as it was integrated into the Twin Otter and deployed to the WTC disaster site September 19th 2001. For detailed information on the NVIS sensor suite and associated processing algorithms see references 1-3.

3.1 NVIS Spectrometer

The Night Vision Imaging Spectrometer (NVIS) is the second improved copy of the TRWIS III hyperspectral system developed by TRW of One Space Park, Redondo Beach California. It was designed for operation in an airborne platform in a nadir push-broom mode. The system produces 384 simultaneous spectral bands with 256 cross-track pixels. It consists of two separate co-aligned imaging spectrometers, which together cover the 0.4-2.35um spectral region. The system's frame rate can be adjusted to accommodate a variety of aircraft velocities.

3.2 High Resolution Line Scanner

High resolution panchromatic imagery is provided by a Dalsa 6000 element line scanner. It can be configured with different lenses depending on ground sample distance and area coverage needed. During WTC flights it was operated in the push broom mode along the track of the airplane.

3.3 MWIR Calibrated Thermocam

Broad-band 3 – 5 um Calibrated 12-bit radiometric data used in the creation of surface temperature maps was provided by a FLIR Systems Thermocam.

3.4 Geo-rectification of NVIS Sensor Suite Data

The NVIS hyperspectral spectrometer and high resolution line scanner data has integrated INS/GPS data attached. This data is generated from a C-MIGITS II integrated INS/GPS system produced by Boeing, Inc. Data communication to the system is through an RS-232 serial port. Message frequencies range from 1 Hz to 100 Hz.

C-MIGITS navigational information is embedded into NVIS data as the 388 spectral band of the hyperspectral data cube. The same navigational information is appended at the end of each line of the high resolution line scanner data. The C-MIGITS data contains the following information: 100 Hz time, aircraft attitude, aircraft velocity; 10 Hz time, latitude, longitude, and altitude; 1 Hz time earth centered fixed (ECF) position, velocity, and acceleration.

SITAC developed an Interactive Data Language based algorithm to roll correct and geo-rectify, using roll, pitch, and yaw information from the INS/GPS system un-stabilized NVIS airborne hyperspectral sensor and high resolution line scanner data.

Roll is consistently the biggest contributor to spatial distortion. In order to preserve the spectral integrity of the data aircraft roll correction is performed without spectral re-sampling. The algorithm automatically generates ENVI compatible Ground Control Points (GCP) file for the roll corrected data. It takes advantage of existing ENVI registration functionality to perform geo-rectification to any desired datum. All NVIS sensor suit produced map products provided to NYC OEM, Fire and Health Departments were prepared using the SITAC algorithm (for details on the operation of the algorithm consult reference number 4).

4. DATA ANALYSIS

4.1 Temperature Estimation Methodologies

The 3 – 5um thermal camera data was calibrated using a black body radiation source. Temperatures and associated radiance values bracketing those imaged at the WTC disaster site were used to calibrate the thermal camera. A full range of temperature / radiance values were used to create a calibration curve for the thermal camera radiance values and were linearly interpreted between calibration points. The resulting calibration curve was then incorporated in the camera software where temperature was then solved for using the Plank equation for an assumed average material emissivity of 0.9 and directly output by the camera. The same model 3 – 5um calibrated thermal camera was used by the NVESD field support team to measure debris temperatures from the ground. The ground based thermal camera temperature measurements were considerably higher than the airborne thermal camera measurements. This was due to the physical pixel size difference between the ground based and airborne images. Airborne temperature measurements were lower due to averaging of material temperatures in the larger pixels.

Areas of the debris field at the base of the WTC towers were hot enough to have significant shortwave infrared (SWIR) blackbody emission. This offered an opportunity to estimate ground temperatures based on the shape of the NVIS SWIR data alone, using the hyperspectral imager as a thermal detector for very hot objects. In order to determine temperatures in this manner, the NVIS data in the SWIR region (i.e. 1.0 -2.4 microns) must be fitted to the SWIR portion of the Plank function describing a black body radiator. Since the region being used for the fit to a black body radiator is so small, the fit must be extremely good to get an accurate temperature estimate. The following paragraphs describe the procedure used.

Initial calibration was accomplished with an integration sphere and tungsten lamp. It was found that the calibration coefficients were a little off at the longer SWIR wavelengths. It is believed this error was due to the varying column density of water vapor resulting from the multiple path lengths inside the integrating sphere as the relative humidity changed. Use of a large area blackbody to flood-illuminate the entrance aperture corrected this longer SWIR wavelength error sensitivity to relative humidity by elimination of the multiple path length accentuation of water vapor column density facilitating consistent SWIR calibration coefficients. Figures 2a & b show theoretical and empirical blackbody response to a 197 C blackbody flood illuminating the entrance aperture. The left curve used calibration coefficients derived using the lamp and integrating sphere alone. The right curve is a result of updating the SWIR calibration coefficients (i.e. wavelengths > 1.0um) with blackbody measurements. Using the NVIS SWIR channels, blackbody temperature estimates were made at several locations by fitting the shape of the blackbody curve to the measured data. These calculated temperatures ranged from 300 to 500 degrees Centigrade. The resulting temperatures calculated from the airborne NVIS SWIR spectrometer data corresponded closely to those taken with the 3 – 5um thermal camera temperature measurements taken from the ground. This was due to a much smaller ground sample distance associated with the NVIS spectrometer compared to the airborne 3 – 5um thermal camera. Figure 3 shows the NVIS HSI 0.4-2.4 microns, 384 bands spectrum of a single hot spot from September 27th and again on October 2nd. There is a significant reduction at SWIR wavelengths compared to the near infrared bands less than 1 micron. This is indicative of significant cooling of the hot spot. This is one area where the NYC Fire Department was dumping a lot of foam for fire suppression. They were very concerned that these fires would spread to critical underground storage infrastructure areas associated with the World Trade Center Tower Complex. This temperature data was able to confirm for the NYC Fire Department that it's efforts were effective.

4.2 Fourier Transform Spectrometer Analysis

The Fourier transform spectrometer was not an integral part of the NVIS sensor suite. It was available on September 19th and was therefore included in the hopes that it could provide additional information on gaseous emissions coming from the debris field. Unfortunately this instrument was not suitable for airborne operation. The airborne environment is very stressing on the performance of a Fourier Transform Spectrometer FTS. Many laboratory advantages of a FTS such as high signal to noise ratios obtained by long integration times are not obtainable in an airborne platform. Furthermore, dynamics associated with airborne imaging such as platform vibration and motion in the field of view during the formation of the interferogram will introduce false signal into the interferogram and the resulting transform spectra (see reference 5). For information and operation of a FTS optimized for remote airborne chemical detection, see reference 6.

5. MAP PRODUCTS PROVIDED TO NYC OEM, FIRE and HEALTH DEPARTMENTS

Since the NVIS sensor and high resolution line scanner data was tagged with integrated INS/GPS data form a C-MIGITS II system, preparation of useful map products and incorporation of those products into the NYC OEM GIS data base was straight forward. There were basically three high-resolution map products provided by the NVIS sensor suite that proved to be the most useful to recovery operations.

The high resolution 6000 element line scanner imagery was collected in a push-broom mode of operation. Swaths were corrected for pitch, yaw and roll and geo-rectified using the SITAC provided software. At an altitude of 1500 ft the high-resolution line scanner provided 0.1 meter ground sample distance panchromatic data. This basic map product, geo-rectified panchromatic surface imagery with a Latitude and Longitude grid was what OEM was looking for to overlay with their GIS based infrastructure maps (see figure 4.)

The NYC OEM and Fire Department were very concerned with obtaining information on the location and intensity of the subsurface fires burning under the rubble at the base of both WTC towers. To provide this information and track progress in controlling these fires, calibrated 3 – 5um broad band thermal camera data was merged with the high resolution line scanner imagery (see figure 5.) Merging the calibrated 3 – 5um thermal image to the High Resolution Imager allowed geo-location of the thermal imagery, which was not tagged C-MIGITS GPS/INS data. To increase the Geo-rectification accuracy of this map product, fiducial marks were used to merge the thermal image onto the high-resolution line scanner imagery. Ground truth was provided by the city at surveyed points throughout the area in order to improve position accuracy. The overall position accuracy of the map data was approximately 3-4 meters.

The NYC health dept. was looking for ways to identify and create maps of materials in the entire debris field. To help provide this information, hyperspectral imagery data of the debris field was collected with the NVIS sensor. End members were identified in this NVIS data set using TRA's N-FINDR algorithm (see reference 3 for algorithm details.) A geo-rectified false color image was created using three of these end members showing materials that were similar in composition at different locations throughout the area (see figure 6.) Unfortunately, the complete pulverization of materials in the rubble made it unfeasible to attempt to unmix and identify specific materials using a spectral signature library of construction materials. These like-material maps were provided to the NYC health department to show how similar types of materials were distributed. The NYC health department conducted specific debris material identification by gathering samples on the ground. The like-material maps were able to help guide the health department to areas of similar materials facilitating more efficient ground sample collection and concentration of their safety efforts.

6. CONCLUSIONS

Near real-time exploitation was essential in order for the map products produced from the NVIS sensor suite, or any other remote sensing platforms to be of maximum value to rescue and recovery operations. Because of the scope and dynamics of the constantly changing disaster site environment, map products produced from remote sensing platforms needed to be near real-time and rapidly updated to be an effective tool in the operations decision process of rescue and recovery personnel.

Rapid and accurate location of the information gleaned from the spectral data was essential to its integration into the NYC OEM, Fire and Health Department's recovery operation. INS / GPS information integrated into the NVIS sensor suite data was essential for the rapid automated production of useful map products from the remotely sensed spectral data. The ability for this information to be overlaid onto NYC's GIS infrastructure maps (i.e. tunnels, power lines, sewer/water supply etc.) was essential to their operations.

The geo-rectified map products described in this paper proved to be an important tool in concentrating NYC Fire Department efforts to contain and extinguish the fires in the debris field as well as the NYC Health Departments efforts to minimize risk to rescue recovery personnel and the public. This map based information provided a useful focal point for helping the NYC OEM coordinate the overall efforts.

7. REFERENCES

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PARAMETER	SYSTEM VALUE	UNITS
Sensor Type	Michelson	N.A.
Spectral Range	7 to 13.5	μm
Spectral Resolution	(2 opt), 4, 8, 16	cm^{-1}
Optical Path Diff. (Max)	(0.5 opt), 0.25	cm
Scan Format	Single Sided	N.A.
Field-of-View	0.5 x 0.5	Degrees
Scan Rate @ $4cm^{-1}$	5 to 40	Spectra/sec
Retardation Rate	1.25 to 10	cm/sec
Mono Frequency	20 to 160	kHz (nominal)
Sampling Freq. @ 1x	20 to 160	kHz (nominal)
Signal Frequency (Max)	~ 14.3	kHz @ 7μm and 10 cm/sec
Aperture Size	7.8	cm
NESR (13μm)* per scan	$< 5 \times 10^{-9}$	watts/(cm^2cm^{-1}Sr)
NESR (11μm)* per scan	$< 3.1 \times 10^{-9}$	watts/(cm^2cm^{-1}Sr)
NESR (8μm)* per scan	$< 5 \times 10^{-9}$	watts/(cm^2cm^{-1}Sr)
Interferometer Drive	Linear	N.A.
Velocity Error	1% rms	N.A.
Laser Reference	0.63 μm HeNe Laser	N.A.
White Light	Yes	N.A.
Signal Detector	HgCdTe	N.A.
Detector D* (@λpk)	$> 4 \times 10^{10}$	cm $Hz^{1/2}$/watt
Detector Size	0.5	mm x mm
Detector Cooling	LN_2 (opt.),Closed Cycle Stirling (std)	N.A.
Cooler Power	< 3.5	Watts
System Power	< 25	Watts
System Voltage Input	28, (+4,-7)	VDC
Physical Size (LxWxH) w/o Tscope.	9 x 6 x 6.25	Inches
System Weight	~ 12	Pounds
Mounting	Hard Mounted	N.A.
Mounting Orientation	Any Orientation	N.A.
Operating Temperature	0 to 50	deg. C
Output Signal	16 Bit Digital	N.A.

Table 1(Fourier Transform Spectrometer Specifications)

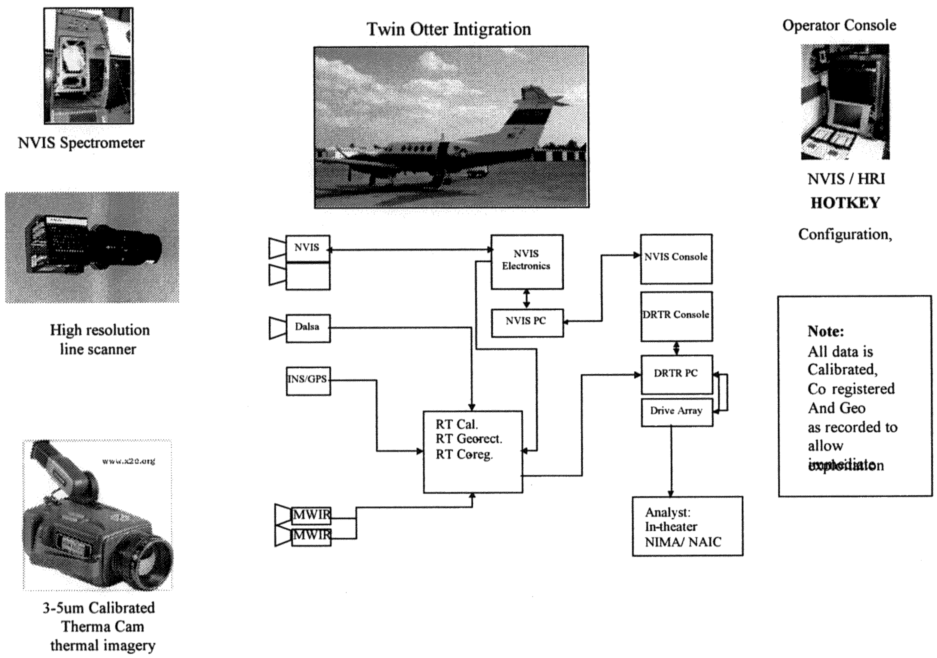

Figure 1. NVIS Sensor Suite
Twin Otter Configuration

Calibrated using Lamp only

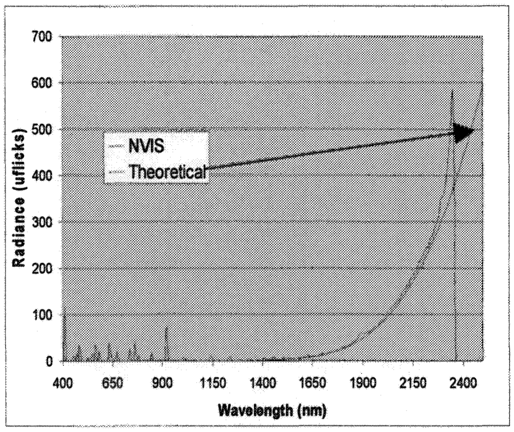

Figure 2a Calibration of NVIS spectrometer data using tungsten lamp and integrating sphere.

Calibrated using Lamp and Blackbody

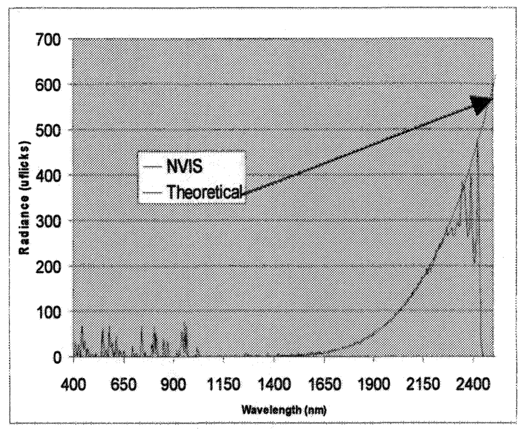

Figure 2b Calibration of NVIS spectrometer data using tungsten lamp and integrating sphere for wavelengths below 1.0um and a large black body source for wavelengths above 1.0um

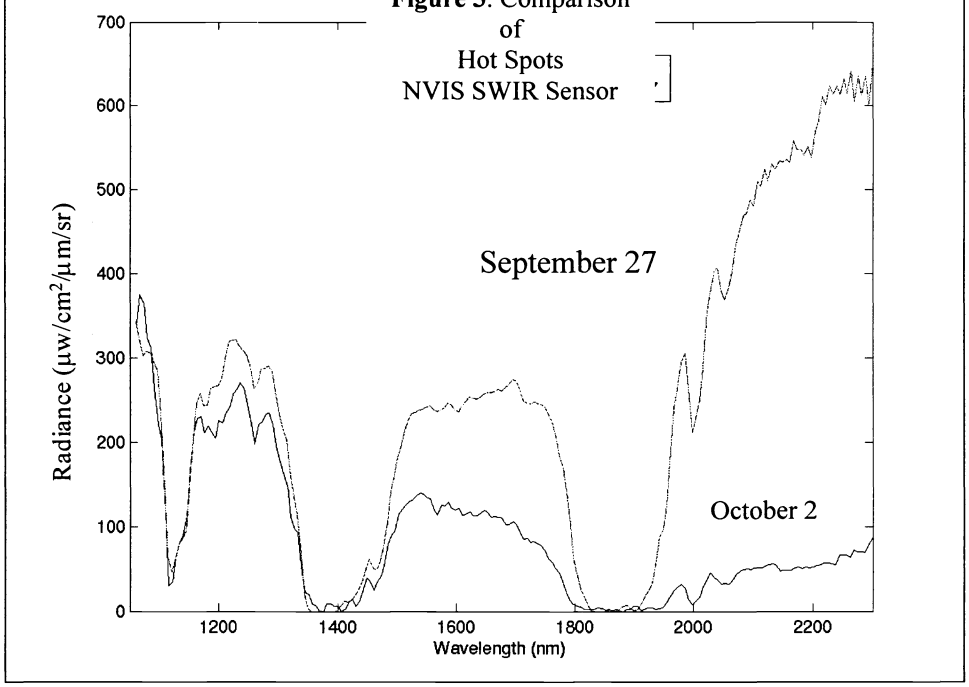

Figure 3. Comparison of Hot Spots NVIS SWIR Sensor

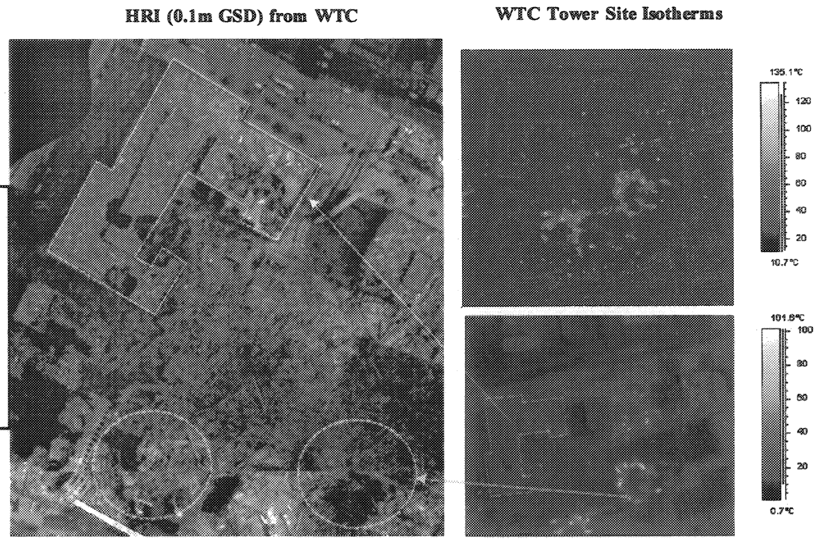

Figure 4. High resolution line scanner imagery on left, Therma Cam 3-5um calibrated temperature data on right. OEM GIS infrastructure overlaid

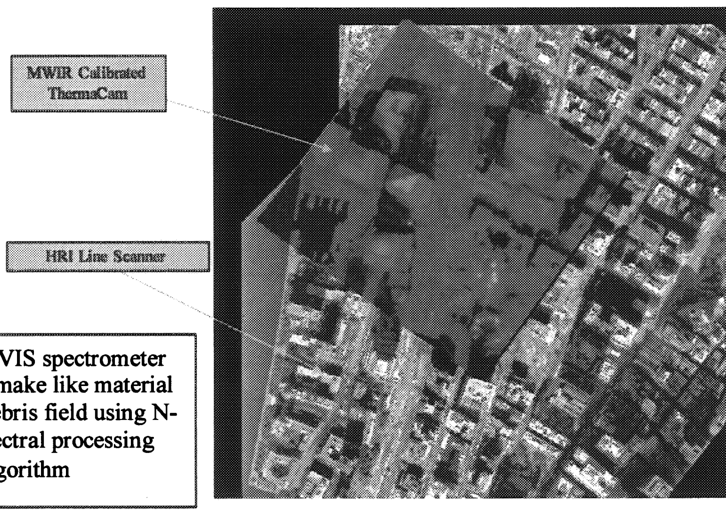

Figure 5. High resolution line scanner and calibrated ThermaCam mosaic

Figure 6. NVIS spectrometer data used to make like material map of the debris field using N-FINDR spectral processing algorithm