Remote Sensing of Surface UXO with Active and Passive Infrared Airborne Line Scanner at Fort Rucker, Alabama

US Army Corps of Engineers
Waterways Experiment Station

8 February 1997

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1. Introduction

1.1 Background Information

The environmental problem being addressed is that of unexploded ordnance (UXO) contamination on Department of Defense sites and formerly used defense sites. There are millions of acres of UXO contamination on these sites. The accurate assessment of these sites is needed so that the resources used in the remediation of the sites are utilized efficiently. Also, the need for dual-use or multi-use technology is becoming greater with the budget reductions taking place in the Department of Defense. One multi-use application is the use of a helicopter-mounted remote sensing and processing system, which was originally designed for airborne minefield detection, as a tool for detecting surface UXO. This detection is based on the remote identification of surface anomalies which indicate the presence of explosive ordnance contamination.

1.2 Official DoD Requirement Statement

A.1.1.d [1.]

> "PROBLEM STATEMENT: The Army has contaminated millions of acres of lands with UXO's. This has made the land unusable and is a major source for potential groundwater contamination. Current technology does not exist to accurately locate and identify UXO's to clear ranges, impact areas and open burning and open detonation sites."

EQSP Thrust: 1.A [2.]

> "USER PROBLEM: Current methods used to detect UXO are unreliable, time consuming and expensive. In addition, UXO detection methods are largely manual effort, and are dangerous for personnel involved."

"TECHNOLOGY OBJECTIVE: Develop, test and evaluate new sensors, platforms, and computer processing techniques for the reliable and accurate characterization of UXO."
"REQUIREMENT SUMMARY: Methods for the accurate, reliable, rapid, and safe characterization of UXO sites are urgently required."
"PROBLEM SCOPE AND MAGNITUDE: Millions of acres across the country are contaminated with unexploded ordnance (UXO). There is a critical need to accurately, reliably, and safely assess the extent of UXO contamination and to possibly remediate these sites."

The REmote MInefield Detection System (REMIDS) will be used to address the surface UXO identification aspect of the UXO detection problem. The U.S. Army Engineer Waterways Experiment Station (WES) developed REMIDS for standoff minefield detection. The REMIDS was successfully integrated in a U.S. Army Aviation Technical Test Center (ATTC) UH-60A helicopter and demonstrated at the U.S. Army Standoff Minefield Detection System (STAMIDS) Advanced Technology Transition Demonstration (ATTD), Phases I and II, at Fort Hunter-Liggett, California, and Fort Drum, New York, respectively. The system performed extremely well in the detection of surface mines; therefore, this technology shows promise for use in surface UXO detection. This project will address the requirement for the accurate, reliable, rapid, and safe characterization of UXO sites with respect to surface UXO.

1.3 Objectives of the Demonstration
The main purpose of the project is to evaluate the surface UXO detection and classification capabilities of the system.

The objectives for this demonstration are to assess the hardware performance, evaluate the software performance, evaluate the demonstration, evaluate the Global Positioning System (GPS) data RMS error, collect additional background data, to determine costs for the system, and to validate the ported parallel processor code.

The additional background data are collected from sites at Fort Rucker. The collection of background data is performed at the end of each test flight.

The Fort Rucker data is used to validate the cuing software that has been ported from the massively parallel processor to the UNIX, NT, and Win95 workstations.

Further details describing the metrics and goals of these objectives are given in the section 4.1.

1.4 Regulatory Issues
N/A

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2. Technology Description

2.1 Background and Applications

The system is flown in a UH-60A Blackhawk helicopter, and consists of an active/passive line scanner, real-time processing and display equipment, and navigational equipment. The scanner collects three channels of optically aligned image data consisting of two active laser channels and a passive thermal infrared channel. The concept of the active laser channels consists of transmitting a beam of linearly polarized laser energy and sensing the reflected electromagnetic components parallel, the P channel, and perpendicular, the C channel, to the transmitted polarization. The relative magnitudes of these two channels are dependent upon the depolarization and directional reflectance properties of the surface. The polarized and reflectance channels are calculated from the spectral channels, P and C, recorded during the test flight. The detailed calculations for the polarized and reflectance channels are given in section 4.4. The common optics for the system are shown in Figure 2.1.a. A top view and side view of the system scanning format is given in Figure 2.1.b. The specifications of the system [3.] are given in Table 2.1.

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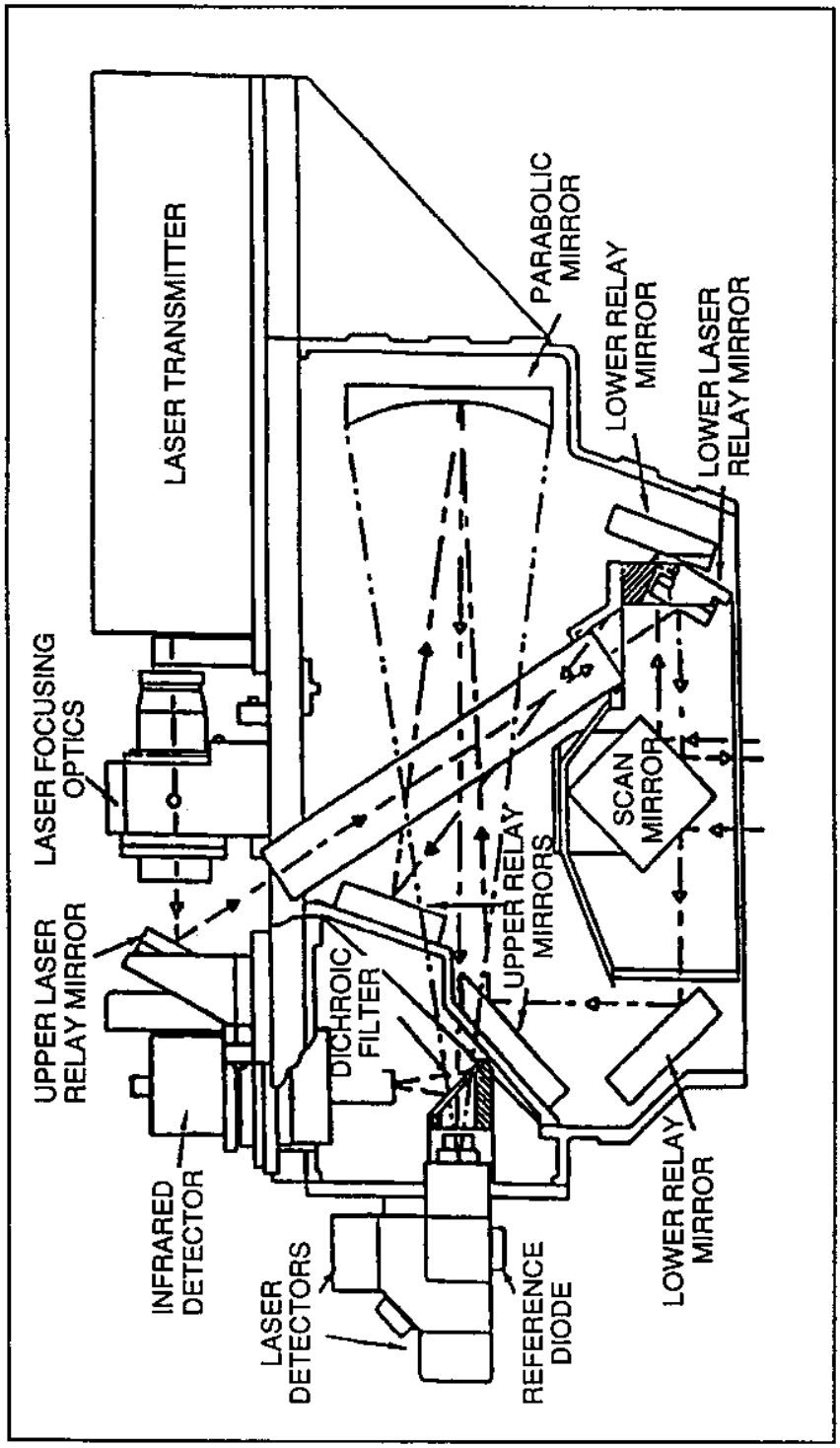

Figure 2.1.a. Scanner physical and optical layout

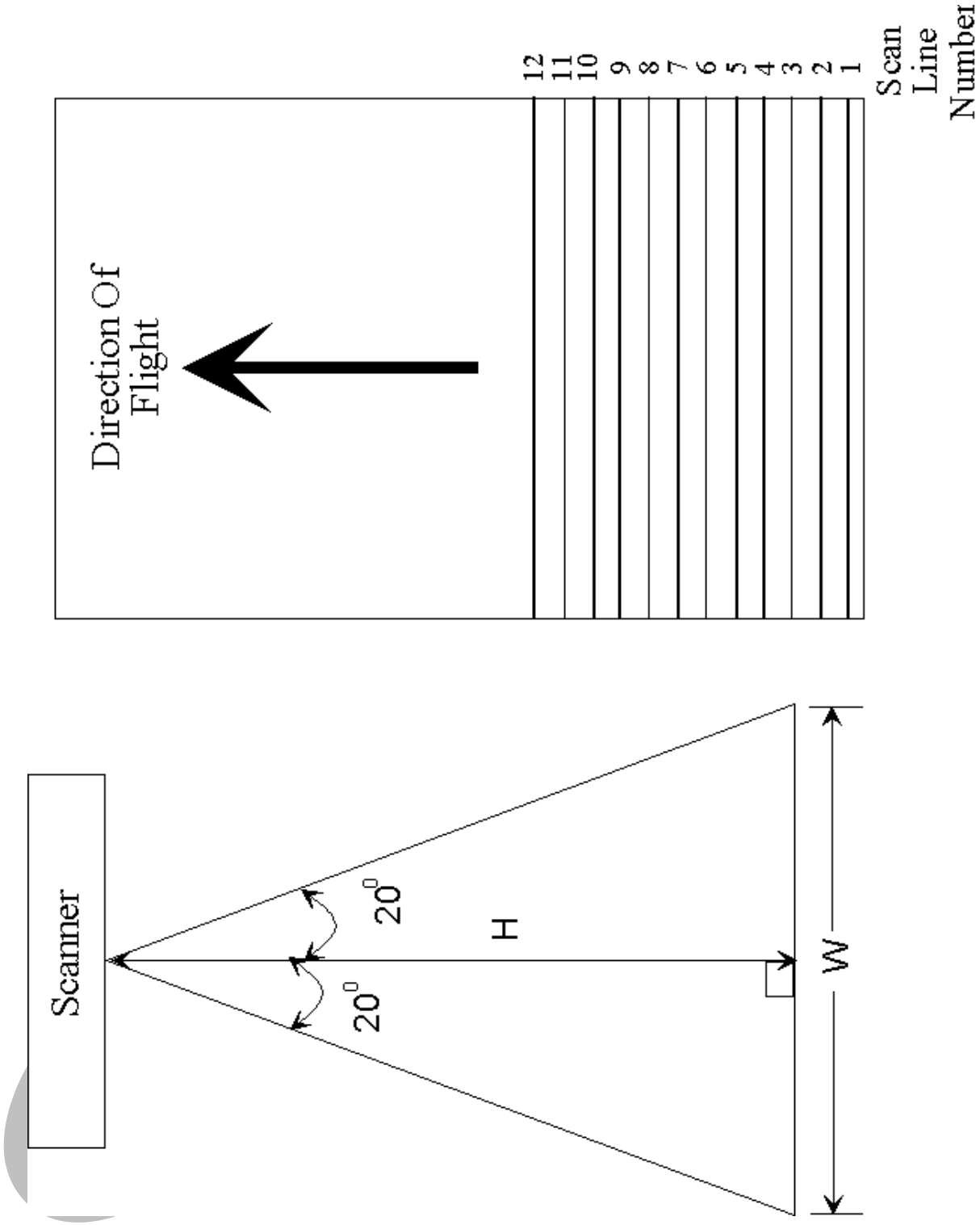

Figure 2.1.b. Top view (top) and side view (bottom) of scanning format

Table 2.1.
REMIDS Operational Specifications

Digitized Field of View	40 deg
Instantaneous Field of View (IFOV)	1.25 mrad
Scan Rate	350 lines/sec
Scan Width	29 meters
	(W=95ft. for H=130ft. in Figure 2.1.b.)
Digitized Samples per Scan Line	710 per channel
Roll Correction	+/- 15 deg
Laser Frequency	1064 nm
Laser Type	Nd:YAG
Spectral Channels	
P Channel	1.064 micron
C Channel	1.064 micron
Thermal Channel	8 - 12 micron

If the system is flown at an altitude of 130 ft., the above IFOV will produce a 1.9 x 1.9 in. viewing area for the active and passive sensors. The laser is adjusted to fill this area. As shown in Figure 2.1.b. the top view, the image is built by the forward flight of the helicopter. A forward speed of 32 knots is used to maintain the aspect of the image being built as the data is collected.

The real-time processing and display system makes use of a massively parallel processor. The system also incorporates onboard recording and a GPS. The GPS data is correlated to the collected data via time stamps. The time offset between the GPS system and the REMIDS system is determined by aligning known points from two passes of a test flight that have a 180 deg difference in the flight heading. The GPS data will allow the location of contaminated areas to be added into a Geographical Information System (GIS) so this information can be overlaid on the base maps of the facility. Test flights will be flown at Yuma Proving Ground, Arizona during 1996. The flights will be over UXO test sites. The data collected from the test flights will be used to determine the level of UXO classification that can be obtained from the system.

Yuma Proving Ground is being used for demonstrations for the Western Governors Association. The demonstrations at this proving ground are for the evaluation of advanced technologies and systems used for the characterization and remediation of unexploded ordnance.

2.2 Advantages and Limitations of the Technology

The use of remote sensing minimizes the risk to personnel during the UXO detection and location operations. The airborne system also expedites these operations. This, in turn, will allow for future remediation processes to be implemented promptly. The clean up of military ranges, formerly used defense sites, ammunition disposal sites, and other UXO contaminated areas will help avoid the loss of human life due to UXO accidents.

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Vegetation can limit the effectiveness of the system. The system needs a line of sight to the item on the surface before the system will detect it. A site manager can use the following test to determine the effectiveness of the system. If the noon day sun light can reach the items of interest, through the vegetation of the site, then the system will have a chance in detecting the items. Grasses will let the noon day sun light through, while broad leaf vegetation will not.

The presence of dust will deteriorate the systems performance. A simple test for a site manager for the effect of dust is to look at the items of interest at the site to see if the color of the items are distinguishable. If the color of an item can be determined by the human eye, then the system should be able to detect the item. However, the classification of the item may become more difficult.

False positives due to other metal objects in the range will be difficult to overcome. Small deposits of standing water could also cause false positives; however, these false positives could be eliminated using the thermal channel. Water causes the false positive because the it can create a very high polarization return and a very low reflectance return. This water effect has been seen on earlier flights of REMIDS for minefield detection; however, the water effect was not documented during the minefield studies.

3. Site/Facility Description

3.1 Background

Fort Rucker was selected as the site for the initial testing of the surface UXO detection system. The main reason for the selection of Fort Rucker is that it is where ATTC operations are based. This minimized the cost of the helicopter usage and support. The Highfalls staging and practice area was used to setup the calibration site and the test site. This area has facilities in which the ground based processing equipment was setup in. This allowed for quick analysis of the flight data at the test site so that modifications could be quickly made to the system as needed. The calibration site is based on earlier REMIDS calibration sites. The materials used and their function are described in section 3.2. The test site is a newly in placed site that consists of UXO material from Jefferson Proving Ground and Yuma Proving Ground. The description, layout, and map of the test site are also given in section 3.2. Fort Rucker vegetation and soil characteristics have minimal variation. The surrounding land is farm land. The soil classification for the area is a silty sand. Extra backgrounds were collected around the test site for additional system evaluations. The background sites consist of calibration and test site area, newly plowed field, and a field with new vegetation.

3.2 Site/Facility Characteristics

The layout of the calibration site is shown in Figure 3.2.a. The calibration site consists of the water containers, roofing material, UXO material, reflectance standards, resolution targets, and

black and white panels. The roofing material, reflectance standards, and resolution targets are used to calibrate the active laser sensors. The water containers, and black and white panels are used to calibrate the passive infrared sensor. The UXO material is used to define the classification of the UXO material in the test site. Temperatures of the water containers, black and white panels, and UXO materials are collected during the day of the test flights. The weather conditions of temperature, relative humidity, wind direction, and precipitation are also collected throughout the test flight day. The background of the calibration site will be the same as that of test site.

The layout of the test site is shown in Figure 3.2.b. The size of test site is 120 meters by 20 meters. The test site contains UXO material and man-made material. The UXO material consist of whole and fragments of 155mm, 152mm, 106mm, and 105mm projectiles; 81mm and 60mm mortars; and 40mm grenades. The man-made materials consist of aluminum cans, electrical cable, a 55 gal drum, plastic containers, and expended small arm casings. These man-made materials are placed in the test site as representatives of items that may cause false positives. False positives being the classification of an item as an ordnance when it is not an ordnance.

Both sites were surveyed with differential GPS. The calibration site and test site were removed from the Highfalls Test Area at the end of the demonstration test. A video log was made of each of the sites. The locations of the Fort Rucker and Highfalls are given in Figure 3.2.c.

The calibration, test, and the other background sites are characterized according to vegetation coverage, soil type, soil moisture, and geological classification. Samples were collected during the morning on each day that test flights are conducted.

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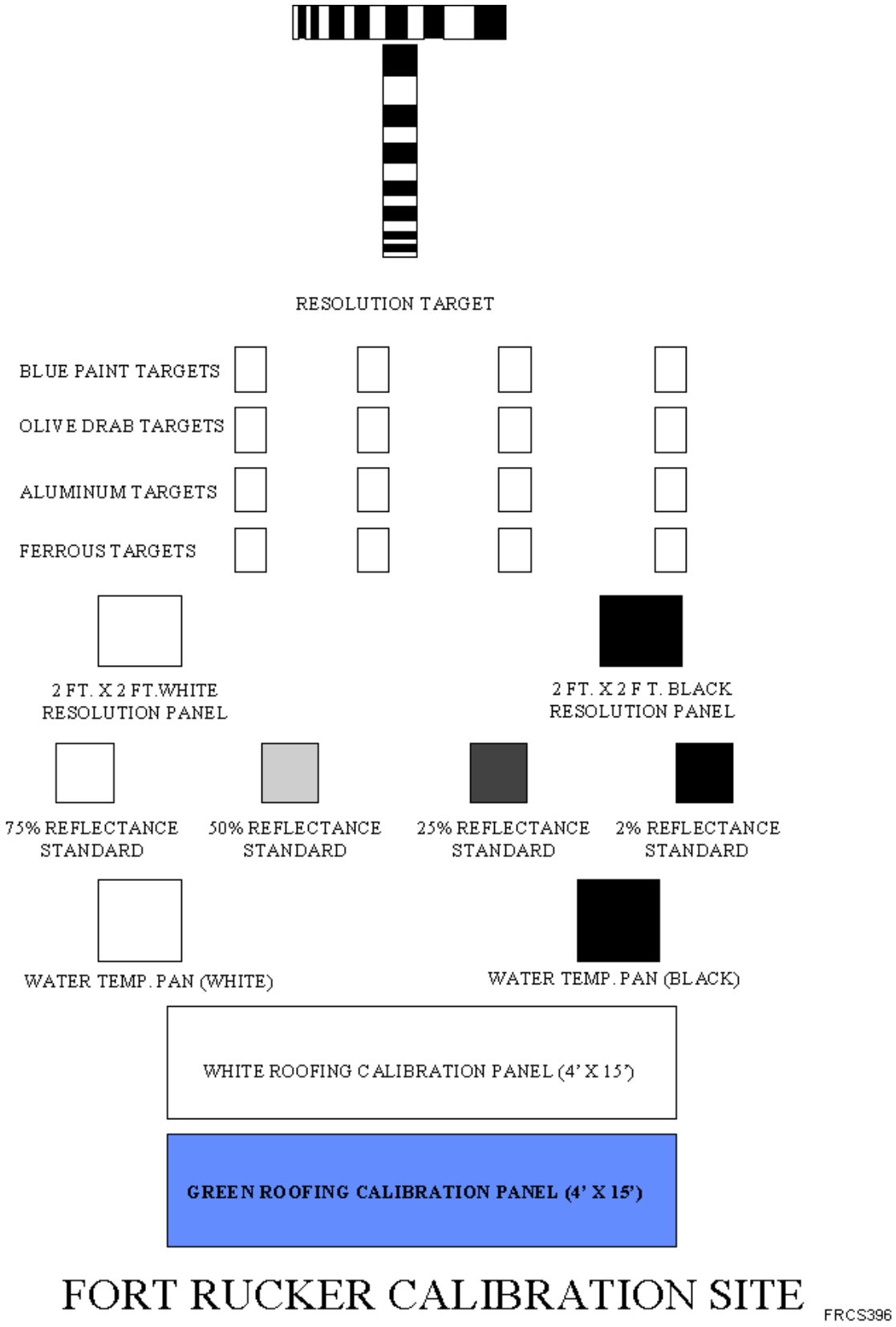

Figure 3.2.a. Fort Rucker Calibration Site Layout

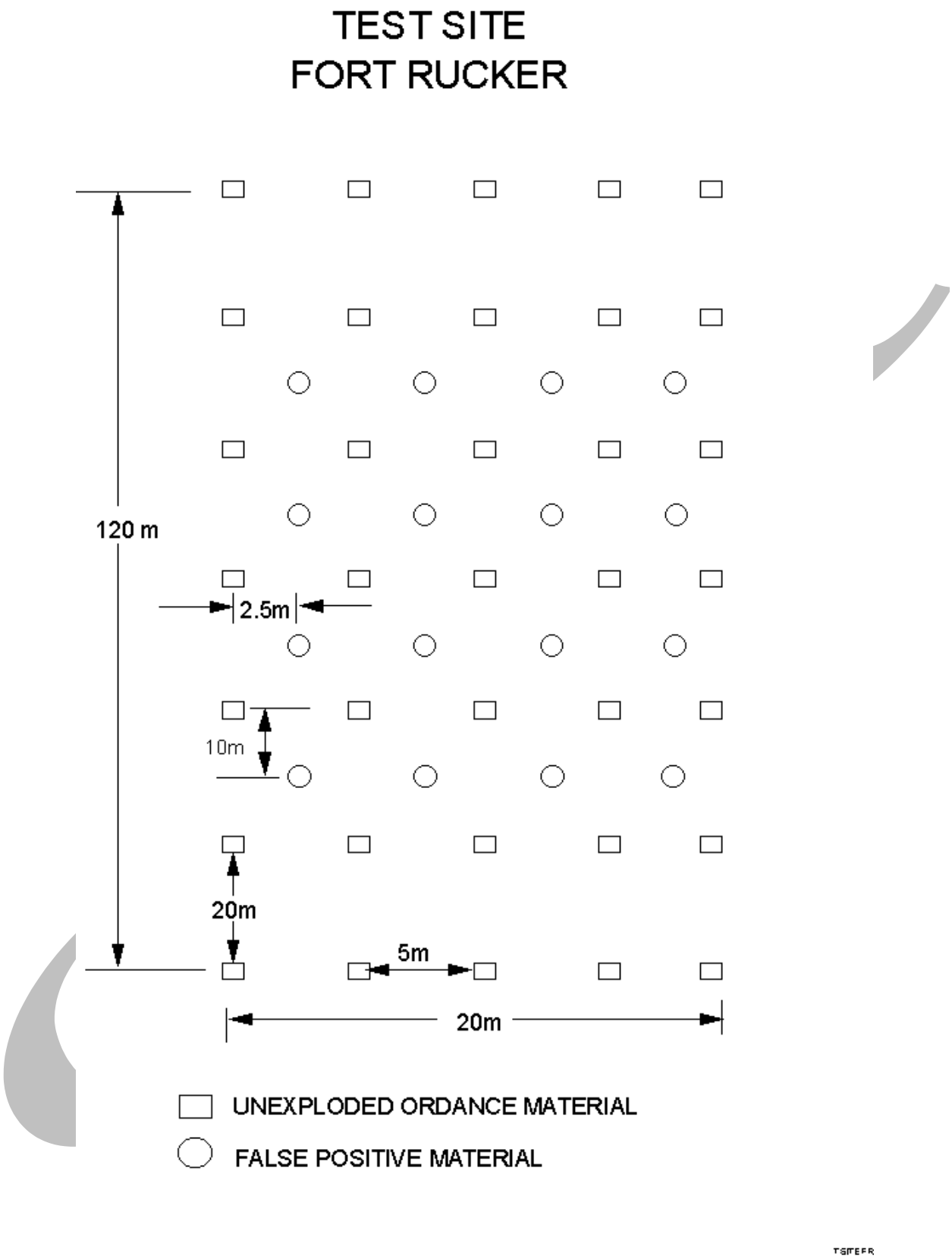

Figure 3.2.b. Fort Rucker Test Site Layout

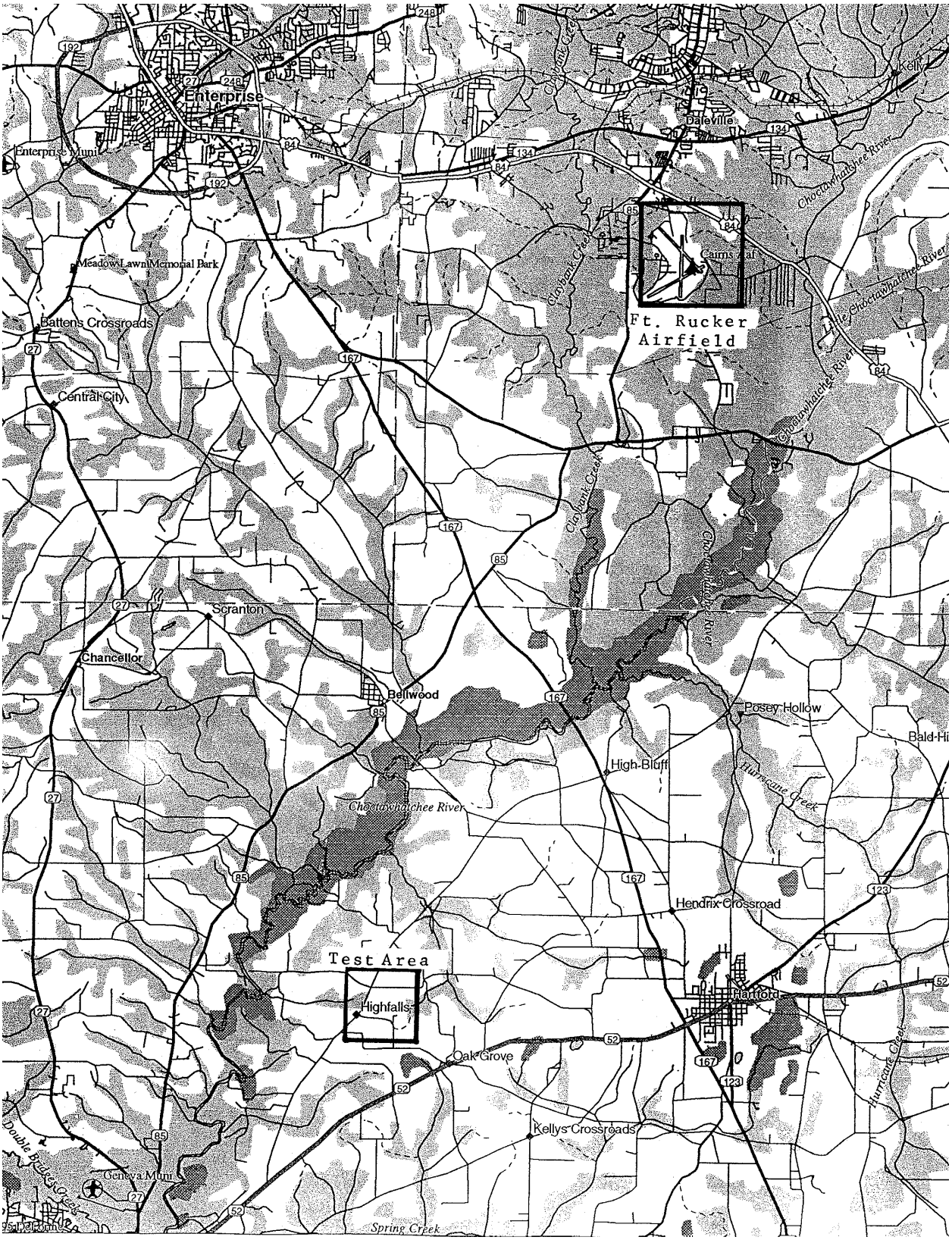

Figure 3.2.c. Map of Fort Rucker and Highfalls Locations

4. Demonstration Approach

4.1 Performance Objectives

The objectives for this demonstration are to assess the hardware performance, evaluate the software performance, evaluate the demonstration, evaluate the GPS data RMS error, collect additional background data, to determine costs for the system, and to validate the ported parallel processor code.

The assessment of the hardware performance is based on the accurate recording of the flight data and the image quality. The image quality assessment evaluates the alignment of the system and the power level quality of the laser.

The software evaluation will determine if the software is correctly cuing the targets, the transfer and integration of the GPS data, and the correct format of the flight data on the flight recorder.

The evaluation of the demonstration is based on the following information. The ordnance detection ratio and the false alarm rate are the metrics used in the evaluation. They are defined in section 4.4. The ordnance detection ratio and false alarm rate of the data collected at the test site are calculated. The grading will be done on the "fused" channels, the polarization channel, the reflectance channel, and the thermal channel. Through post processing at WES, a receiver operating characteristic (ROC) curve will be generated for the individual and combined channels. The usefulness of the items placed in the calibration site for setting the detection thresholds for the demonstration is also evaluated.

Fragments and tail fins of ordnance are considered to be target detections for this system. This is because the system cannot detect beneath the ground surface. The detection of any ordnance material could represent a partially uncovered ordnance rather than a fragment of an ordnance.

The GPS data of the system is evaluated by generating the RMS error of the locations returned from the system with the surveyed locations.

The additional background data are collected from sites at Fort Rucker. The collection of background data is performed at the end of each test flight.

The cost determination of the system is obtained. This is monitored and recorded through flight logs and time logs for the demonstration. Also, time logs are used to determine the preparation cost of the system for this demonstration. This will help verify the information in section 6.

The Fort Rucker data is used to validate the cuing software that has been ported from the massively parallel processor to the UNIX, NT, and Win95 workstations.

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4.2 Physical Setup and Operation

Here is the schedule of test flights flown at Fort Rucker.

Date	Tasks
07 Mar 96	1. WES personnel and equipment arrive at ATTC
08 Mar 96	1. Briefing on Test Site
	2. REMIDS equipment is loaded
	3. REMIDS equipment is tested and calibrated
	4. Site setup
09 Mar 96	1. Equipment Test Flight
	2. Mid-Afternoon Test Flight 1 for one hour at ATTC
	3. Late Afternoon Test Flight 2 for one hour at ATTC
	4. Process Data
	5. Check and Modify equipment as needed
10 Mar 96	1. Survey Site
11 Mar 96	1. Early Morning Test Flight 3 for one hour at ATTC
	2. Mid-Morning Test Flight 4 for one hour at ATTC
	3. Mid-Afternoon Test Flight 5 for one hour at ATTC
	4. Late Afternoon Test Flight 6 for one hour at ATTC
	5. Process Data
	6. Check and Modify equipment as needed
12 Mar 96	1. Early Morning Test Flight 7 for one hour at ATTC
	2. Mid-Morning Test Flight 8 for one hour at ATTC
	3. Mid-Afternoon Test Flight 9 for one hour at ATTC
	4. Process Data
13 Mar 96	1. Site removal
	2. REMIDS equipment is unloaded
	3. WES personnel and equipment leave ATTC

The no go criteria for the test flights follows:

Weather:
Winds over 40 knots - Safety of the test flight.

Rain - The thermal return will be degraded.
The standing water will give high polarization returns.

Equipment:
Failure - The equipment is continuously monitored during the test flight. If the equipment fails, then the test flight is stopped and the equipment is evaluated.

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The calibration, test, and background sites are characterized according to vegetation coverage, soil type, soil moisture, and geological classification. Two samples from each site were collected.

The calibration site and test site are surveyed with differential GPS. A video log and still picture log are made of the two sites.

The calibration site and test site are removed from Fort Rucker at the end of the demonstration test.

The effort to set up, log, survey, and remove the calibration site and test site is four man-days. The effort needed to collect and log the UXO material for the calibration site is estimated at two man-days if EOD already has materials collected from the site. If the UXO materials that have been cleared from the site are not available, the cost for collecting the materials from the site will need to be considered. The cost for analyzing the soil samples is one man-day per two samples. A one man-day effort is needed to collect the soil samples. The cost of doing calibration runs is five minutes of helicopter flight time plus the time needed to ferry between the calibration site and back to the site of interest. Facilities are needed to house and support a UH-60A Blackhawk Helicopter with a five man crew. Facilities are also needed for the data collection/processing equipment and the six man support team. Two regular size office areas with typical electrical outlets would meet these requirements.

4.3 Sampling Procedures

The samples collected by the system are three digital channels. The three channels are polarization, reflectance, and thermal. The system will be flown at an altitude of 130 ft. with a forward speed of 32 knots to collect the samples. This allows for the surface scan resolution to be nominally 1.9 x 1.9 in. The resolution is the same for both the active and passive channels. The system has a scan rate of 350 scans per second with 710 data pixels per scan for each channel. Refer to section 2.1, section 2.2, and Figure 2.1.b. for the further description of the data collection.

The samples will be collected at the calibration site, the test site, and the background sites. Sampling of all sites is done with REMIDS. Samples are digital data and the care of the data is outlined in Demonstration Plan for Fort Rucker [4.].

4.4 Analytical Procedures

The calculation of the polarization and reflectance is frozen post-flight. They are based on the following equations:

```
pol = ((pgain*(parallel return - poffset))
        - (cgain*(cross return - coffset)))
        / ((pgain*(parallel return - poffset))
        + (cgain*(cross return - coffset))).
```

ref = ((pgain*(parallel return - poffset))
+ (cgain*(cross return - coffset))).

The parameters are set according to the returns from reflectance standards placed in the calibration site. The fusion of the channels will be done by adjusting the distance thresholds to a point where detection is determined by when the distance of the sum of the three channels does not exceed the distance threshold. This is defined in the following equation:

distance threshold > SQRT(((pol - mean pol)/pol range)**2
+((ref - mean ref)/ref range)**2
+((thm - mean thm)/thm range)**2).

The algorithm's adjustable parameters will be the distance threshold, the mean values, and the range values. They will be based on the returns from the calibration site.

The ordnance detection ratio is calculated as follows:

ODR = total ordnance detected / total ordnance emplaced.

The false alarm rate is calculated as follows:

FAR = false alarms / area.

The receiver operating characteristic curve will be the trade-off between the ODR and the FAR as the distance threshold for the three channels is being adjusted.

A single optical path is used for all data channels, as described in sections 2.1.; therefore, boresight accuracy is not applicable. The analysis of the GPS is done by aligning a known point from the two flights that have 180° difference in the flight heading. The GPS RMS errors are calculated for items in the calibration site and the test site.

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