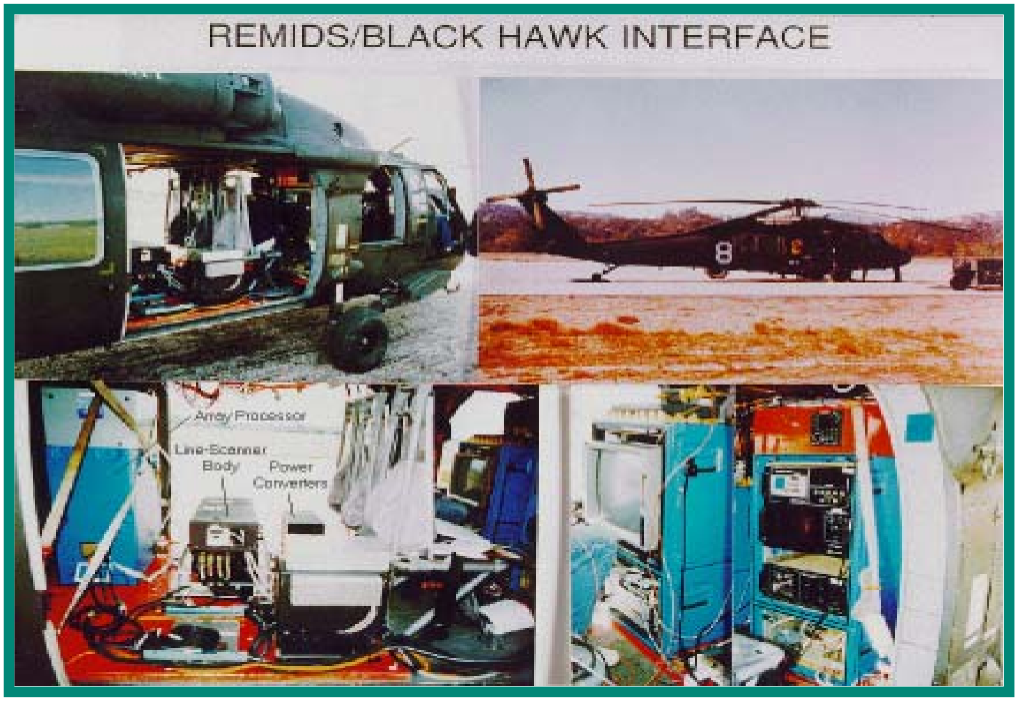
ESTCP
Cost and Performance Report

(UX-9523)



Assessment of the Remote Minefield Detection System (REMIDS)

September 1999

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

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LIST OF ACRONYMS

ESTCP	Environmental Security Technology Certification Program
FAR	False Alarm Rate
REMIDS	Remote Minefield Detection System
UXO	Unexploded Ordnance

ACKNOWLEDGMENTS

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Technical material contained in this report has been approved for public release.

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1.0 EXECUTIVE SUMMARY

1.1 THE REMOTE MINEFIELD DETECTION SYSTEM

Millions of acres of government land are contaminated with unexploded ordnance (UXO), a result of years of testing and training in the armed forces. As part of the effort to prepare some of this land for use other than as test ranges, programs are underway to develop methods to safely and reliably detect UXO so that the contaminated sites may be cleaned prior to realignment.

This report describes the REMIDS developed by the U.S. Army Engineer Waterways Experiment Station to detect surface UXO, and reviews the performance of REMIDS in tests at the Yuma Proving Ground (Arizona) and at Ft. Rucker (Alabama).

The principle behind REMIDS is to enhance the discrimination of surface UXO by relying on multiple signatures: surface UXO may exhibit a unique combination of reflectance, polarization, temperature, and footprint (shape), as compared to natural objects in the UXO's surroundings. Discrimination based on four signatures is in principle greater than that based on fewer signatures.

The REMIDS hardware consists of an airborne line scanner with sensors that measure the reflectance, polarization, and thermal response in 710 round "spots", each of which subtends 1.25 mrad. (The former 2 sensors are active and utilize a Nd:YAG laser; the latter sensor is passive.) The 710 spots partially overlap and are arranged in a line such that the total field-of-view of one scan line is 1.25 mrad by 40o. The scan rate of the device is 350 lines per second. Thus, when the REMIDS is flown in a helicopter at an altitude of 130 ft and a speed of 32 knots, each of the 3 sensors will digitize its own map of the ground level with a pixel size of 1.9" by 1.9".

Analysis of the REMIDS digitized data is performed in three stages. In the first stage, a computer is used to classify each pixel as being from a UXO candidate or from background. (At some sites, the spectral return of the background is sufficiently distinct from all UXO that this stage is the only step required to achieve satisfactory performance.) In the second stage, a requirement on the size of objects (i.e. on the number of contiguous pixels) is imposed. In the last stage, an operator views all potential candidates and determines if they are UXO or background. The operator may also classify the type of UXO.

1.2 SYSTEM PERFORMANCE

The REMIDS system was tested at a 2400 m^2 test site at Ft. Rucker, Alabama, and at a 0.5 km^2 test site at Yuma Proving Ground in Arizona. The performance of this system is site-dependent. Some sites contain backgrounds which compromise discrimination based solely on the raw data from the three spectral sensors. If the background is grassy, it is quite likely that a detection probability for surface ordnance of at least 90% is achievable with very low false alarm rates using only the spectral information, as is shown in the Ft. Rucker performance curve below (Figure 1). On the other hand, at sites such as Yuma, such performance is not possible with just the spectral information. However, fair-to-good performance can be expected once a minimum size requirement is established for potential UXO candidates and a knowledgeable operator is used to filter through the images. The probability of detection as a function of radius surrounding the target at Yuma is shown in Figure ES-2, where only ordnance items greater than a four-pixel size were included in the target baseline. Also shown in Figure ES-2 is the fraction of the detected ordnance that was correctly identified.

Fig. ES-1: ROC curve for Ft. Rucker: All Targets

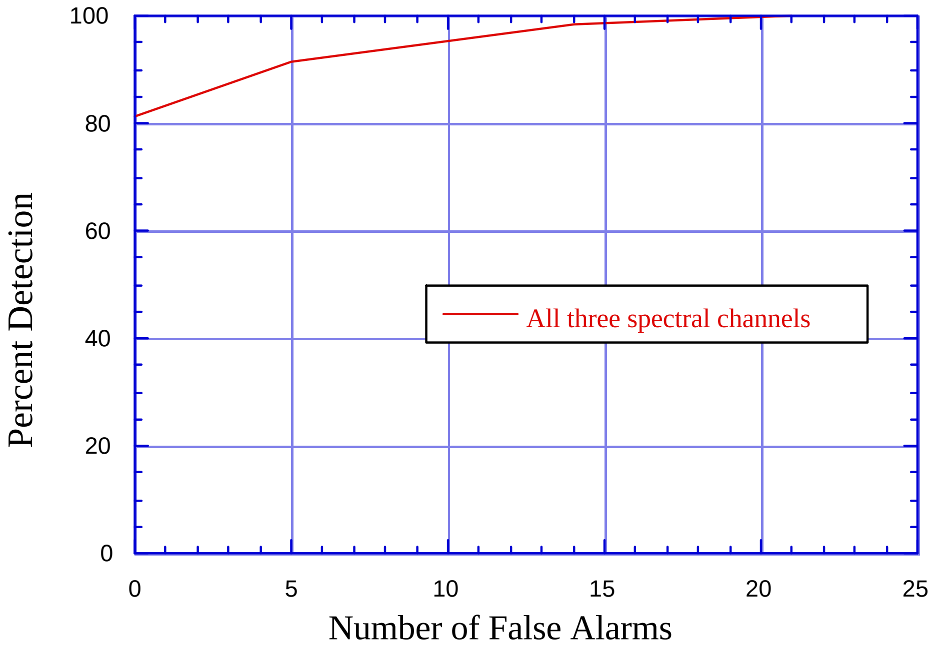
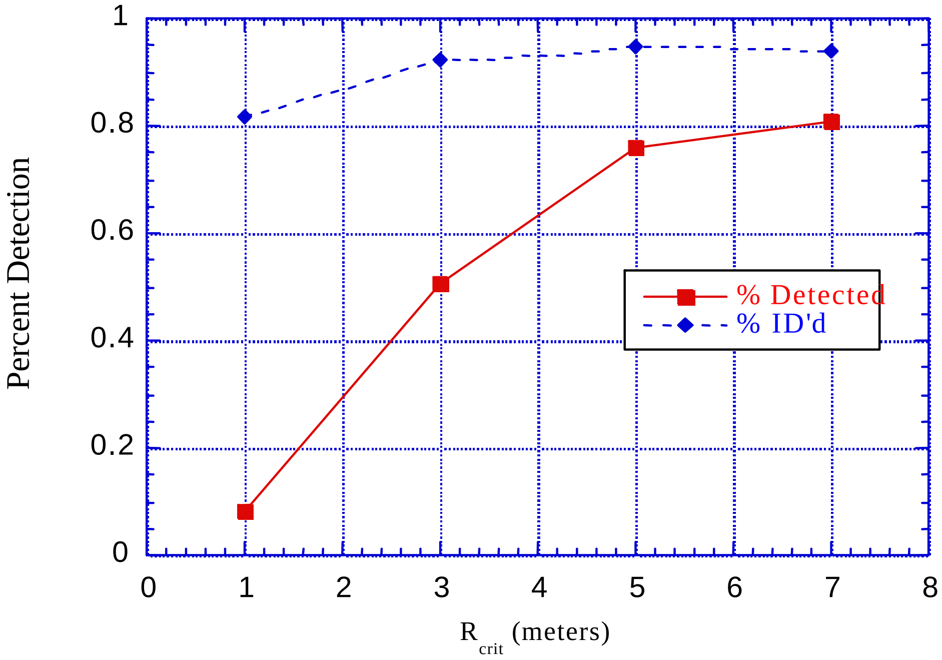


Fig. ES-2: REMIDS Performance at Yuma



The position accuracy of the REMIDS system at Yuma was determined to be 1.55 meters in the easting direction and 2.18 meters in the northing direction, and a false alarm rate of about 33 per km^2 was achieved. The target recognition capabilities of the operator played a crucial role in the performance of this system at Yuma, and it is not known how much the detection probability will vary with operator experience and training.

For a challenging site like Yuma, the resultant cost range for using REMIDS is $75-225 per acre depending on the site geometry and chosen flight trajectory. Costs would be reduced to $70-210 per acre for an easier site like Ft. Rucker. If a lower resolution could provide acceptable target discrimination results, costs could be further reduced to around $14-15 per acre.

1.3 ADVANTAGES AND LIMITATIONS

The REMIDS technology possesses both advantages and limitations in locating UXO. As an airborne system based on current technology, it promises several advantages:

- It will be of minimal risk to the personnel performing the measurements.
- The method may be able to cover large tracts of land in a relatively short time.
- The assessments may possibly be done at a reasonable cost.
- It could be used to locate "potential hot regions" for buried UXO in cases when surface debris is correlated with buried UXO.

The technology has important limitations, however:

- REMIDS relies on direct line of sight for all three sensors. It would be risky to rely on this technology in areas with broad-leaf vegetation or trees. Further, any buried UXO will not be detected by REMIDS. Even a thick layer of dust could compromise a sensor's reading, leading to a lower detection probability of the UXO.

- A priori knowledge of the ordnance type is important to calibrate REMIDS, as different types of UXO will have different reflectance, polarization, and thermal signatures. Thus REMIDS may be unreliable at detecting unexpected or uncharacterized ordnance.

- REMIDS may not be reliable at detecting small ordnance when the background around the UXO has similar characteristics to the UXO.

- Currently, REMIDS relies heavily on an operator to discriminate UXO from background in challenging environments. This raises questions concerning operator training and operator-to-operator variability.

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2.0 TECHNICAL DESCRIPTION

2.1 INTRODUCTION

Millions of acres of government land are contaminated with UXO, a result of years of testing and training in the armed forces. As part of the effort to prepare some of this land for use other than as test ranges, programs are underway to develop methods to safely and reliably detect UXO so that the contaminated sites may be cleaned prior to realignment.

This report describes the REMIDS developed by the U.S. Army Engineer Waterways Experiment Station to detect surface UXO, and reviews the performance of REMIDS in tests at the Yuma Proving Ground (Arizona) and at Ft. Rucker (Alabama). The principle behind REMIDS is to enhance the discrimination of surface UXO by relying on multiple signatures: surface UXO may exhibit a unique combination of reflectance, polarization, temperature, and footprint (shape), as compared to natural objects in the UXO's surroundings. Discrimination based on four signatures is in principle greater than that based on fewer signatures. Analysis of the REMIDS digitized data is performed in three stages. In the first stage, a computer is used to classify each pixel as being from a UXO candidate or from background. In the second stage, a requirement on the size of objects (i.e. on the number of contiguous pixels) is imposed. In the last stage, an operator views all potential candidates and determines if they are UXO or background. The operator may also classify the type of UXO.

2.2 HARDWARE

The REMIDS system consists of an active/passive line scanner, real-time processing and display equipment, and navigational equipment[1]. The scanner collects three channels of optically aligned image data consisting of two active Nd:YAG laser channels, which measure reflectance and polarization, and a passive thermal infrared channel. One line in the scanner consists of 710 pixels, each of which subtends a cone angle of 1.25 mrad. The 710 pixels partially overlap such that the total field-of-view of one scan line is 1.25 mrad by 40o. The scan rate of the device is 350 lines per second. Thus, when the REMIDS is flown in a helicopter at an altitude of 130 ft and a speed of 32 knots, each of the 3 sensors will digitize its own map of the ground level with a pixel size of 1.9" by 1.9".[2] Specifications of the system are given in Table 1. Information is presented in the table for three spectral channels. The "P channel" senses the reflected light that is polarized parallel to the transmitted light, while the "C channel" senses the reflected light that is polarized perpendicular to the transmitted light. The reflectance is essentially the sum of the two channels, while the polarization is the normalized difference.

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[1] J. H. Ballard, R. M. Castellane, B. H. Miles, and K. G. Wesolowicz, *The Remote Minefield Detection System (REMIDS) II Major Components and Operation*, Technical Report EL-92-30, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 1992.

[2] The distance between pixel centers is 1.6" for these conditions.

Table 1. REMIDS Operational Specifications

Digitized Field of View	40 degrees
Digitized Field of View	1.25 mrad
Instantaneous Field of View	350 lines/sec
Scan Rate	29 meters
Scan Width (at an altitude of 130 ft)	710 per channel
Digitized Samples per Scan Line	+/- 15 degrees
Roll Correction	Nd:YAG
Laser Type	1.064 µm
Laser Frequency	1.064 µm
Spectral Channels	
P Channel	1.064 µm
C Channel	1.064 µm
Thermal Channel	µm

2.3 PROCESSING REMIDS DATA

The REMIDS surface mine/UXO detection algorithm comprises three sequential steps. In the first step, the reflectance, polarization, and thermal returns are used to assign a classification to each pixel. Such a classification provides information on material type, and allows for some reduction in the total number of pixels that must be investigated. In the second step, pixels of like classification are joined together to form objects. Each object is characterized by its total area, boundary, and distance between its two furthest pixels. At the end of the second step, a table is generated that groups the objects together according to location and gives both the spectral and size/shape information of each object. In the third step, the operator decides which objects are targets, using the table provided in the second step to guide his decisions. In the following, each of these three stages is discussed in some detail, and a quantitative estimate is provided of the role of each step in reducing the false alarms.

Stage 1: Spectral Discrimination

Stage 1 in the algorithm relies on the fact that different materials yield different polarization, reflectance, and thermal responses. Metals will, in general, have a very high reflectance. The polarization of a material is essentially a function of its "smoothness" as measured on the scale of the wavelength of the incident light (which is 1.06 µm for REMIDS). The polarization return of a material cannot be predicted based on how it looks or feels. Rust, for example, which may seem rough to the touch, has been found to yield a significant polarization return at 1.06 μm. The thermal returns of both ordnance and background depend upon their thermal properties, as well as on the time of day and the weather conditions of the survey. The discrimination capabilities of the thermal channel should be best soon after sunrise and sunset, when objects with different thermal diffusivities and surface absorptivities and emissivities heat up and cool down at different rates. Near mid-day, when thermal equilibrium is approached, the thermal discrimination between objects is more difficult.

Completion of Stage 1 of the REMIDS algorithm does not require that the helicopter obtain the calibration data, land, and then obtain the target data. All polarization, reflectance, and thermal data are post-processed. Thus, the REMIDS approach is to fly over the calibration site and then fly directly to the real site. In fact, this is necessary for thermal channel calibration data to have any applicability.

The completion of Stage 1 results in a significant reduction of the total number of pixels that might contain targets of interest. Nonetheless, Stage 1 cannot always be relied upon to provide sufficient discrimination from the background to be a viable surface/UXO mine detection system in and of itself. This is particularly true at sites such as Yuma, where the existence of "desert varnish" (a rock with a glass-like sheen) resulted in many tagged pixels. Other sites may fare better; for example sand is easily distinguishable from the targets. Grass, too, is an "easy" background, as was seen in the results of the Ft. Rucker test, presented in the performance assessment section of this report.

Stage 2: Size/Shape Discrimination

In the Stage 2 of the REMIDS algorithm, pixels of like material classification (as determined by Stage 1) are joined together to form objects. The operator has the option of specifying further requirements on the objects formed. For example, an object with a very large area may be rejected, as may one that is too small, too thin, or irregularly shaped.

The level of discrimination provided by the size/shape filter greatly affects the number of objects that are passed on to the operator: a low level of pre-screening in Stage 2 may result in too many man-hours spent in the final step, but too much pre-screening could result in too many missed targets. The optimal level of discrimination used in Stage 2 is ultimately determined after several iterations through the data. At Yuma, for example, it was decided that a minimum size be set such that any object smaller than four pixels was rejected. This served to greatly reduce the number of false alarms due to desert varnish, at the expense of missing targets smaller than four pixels, such as grenades and Valmeira mines. On the other hand, discrimination based on "irregular shape" was found to be unreliable at Yuma because variability in helicopter air speed caused some targets to appear irregular in shape. Thus, the only discrimination provided by the size/shape filter in Stage 2 for the Yuma data was that of the minimum size requirement.

Stage 3: Operator Discrimination

In Stage 3, the operator chooses a spectral channel (usually the polarization channel) and scrolls through images, using the information from Stages 1 and 2 to help decide where to focus attention. Usually, the man-made ordnance items are easily discernable by eye[3]. Thus, a trained operator is able to identify many of the ordnance items and eliminate many of the false alarms very quickly, without having to study each individual object in great detail. For example, at Yuma, about 95% of the roughly 20,000 false alarms were located in the wash areas, which is where most of the desert varnish was located. After carefully examining a few of these objects, the operator realized that most of the items located in these areas were false alarms. Thus, the operator was able to scroll through about 19,000 objects fairly quickly, without having to focus on any of them in detail.[4] Those candidates that the operator could not identify or eliminate quickly were carefully examined in each of the three spectral channels. The operator not only determined whether a suspicious object was a target, but also identified the target after deciding that it was an ordnance item.

It is clear that the role of the operator is crucial to the success of this system. The operator is involved in each of the three stages. The total time required is dictated by operator efficacy and skill. For the data collected at Yuma, one day was devoted to processing the calibration site data. The analysis of the test site data then took three days, the vast majority of which was due to time spent by the operator. Of those three days, roughly 60% of that time was spent scrolling through images, while the remainder of the time was dedicated to the detailed examination of the roughly one hundred suspicious objects that could not be quickly identified.

Given that an area of only 0.5 km^2 entailed three man-days of tedious data analysis, an obvious question to address is whether the role of the operator can be automated. Clearly, it should be possible to reduce the amount of time spent scrolling through images, since that is determined primarily by the level of pre-screening provided by the size/shape filter. At Yuma, this pre-screening was limited to just a minimum size requirement. It is believed by the developers of this system that a robust size/shape filter can be developed that will allow for extensive filtering of the objects before they are passed to the operator, but that has yet to be tested. However, if it is decided to rely heavily on a size/shape filter to screen the objects, then some degradation in performance over that of the current system should be expected, because it is unlikely that any computer can provide the level of discrimination of the human eye. Nevertheless, it seems impractical to rely on the operator to perform the bulk of the discrimination for large areas in future versions of this technology.

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[3] While man-made ordnance is fairly easily distinguished from natural backgrounds, it should be noted that it may not be easily separated from man-made clutter. The test site at Yuma was a fairly "clean" site, with very little man-made clutter.

[4] There were some ordnance items located in the wash area as well. Some of these targets were discernable based on their size, while others could be distinguished by their spectral signature. Furthermore, the rocks often possessed irregular shapes compared with the man-made targets. However, some targets were lost; small items made of iron or covered in olive drab paint would have been particularly difficult to pick out.

3.0 REMIDS PERFORMANCE

In this section, the performance of the REMIDS system at two test sites (Ft. Rucker, AL and Yuma, AZ) is summarized. It will be seen that the performance at Ft. Rucker was superior due to the fact that the background was mainly grass. In essence, Ft. Rucker looked like a "short rough" on which the targets were easily seen, even with just the polarization information. At Yuma, the existence of desert varnish, with its high polarization return, made the targets much more difficult to distinguish, and a 4-pixel minimum object size was required in the analysis. This resulted in a limitation of the size of the objects that could be detected at Yuma (e.g., grenades fell below this size limit).

3.1 FT. RUCKER RESULTS

The detection probability (Pd) vs. number of false alarms is presented. Figure II.1(a) shows the performance of the individual spectral channels with respect to the detection of aluminum items, while Figure II.1(b) shows the performance of the individual spectral channels with respect to ferrous and painted surface items. The performance of the combined spectral channels for the detection of both aluminum and ferrous/painted targets is shown in Figure II.1(c). Figure II.1(a) shows that the polarization channel alone was sufficient to detect the aluminum ordnance items: 100% Pd was achieved with only 15 false alarms in 2400 m^2. In Figure II.1(b), it is seen that the performance of the polarization channel in detecting ferrous or painted objects, while not as remarkable as for aluminum, was still quite good, with a Pd of about 95% at 15 false alarms. It is clear from Figure II.1(c) that the combination of the three spectral channels yielded excellent performance: greater than 80% Pd was achieved with essentially zero false alarms, while 100% Pd was possible with only 20 false alarms. Thus, the spectral filter alone was sufficient at Ft. Rucker; no size/shape filter was required, and the operator's role was minimized.

3.2 YUMA RESULTS

The effectiveness of REMIDS was tested on targets that were larger than the four-pixel threshold, and that are of interest to the UXO community. The targets chosen were: 500 lb bombs, 2.75" rockets, 81 mm mortars, 105-mm projectiles, and 155-mm projectiles. Grenades, Valmeira mines, gator mines, volcano mines, and painted mines were excluded. All but the last of these were too small to be detected with the four-pixel threshold. Dielectric mines, although not of interest to the UXO application, were included because they were a particularly easy target for REMIDS to detect, and thus provided a means of estimating the location accuracy of the system.[5]

Using the position data for the dielectric mines as well as from 500 lb bombs (also an "easy" target), the location accuracy of the REMIDS system was determined to have a standard deviation of 1.55 meters in the easting direction and 2.18 meters in the northing direction. In addition, an offset bias was found in the REMIDS position compared to ground truth, specifically a 1.12m offset in the easting direction and 0.44m offset in the northing direction. These offsets were left in the data

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[5] Dielectric mines were easily detected because their polarization return was well separated from backgrounds and other targets.

Fig. II.1(a): Performance curve for Ft. Rucker: Aluminum Targets

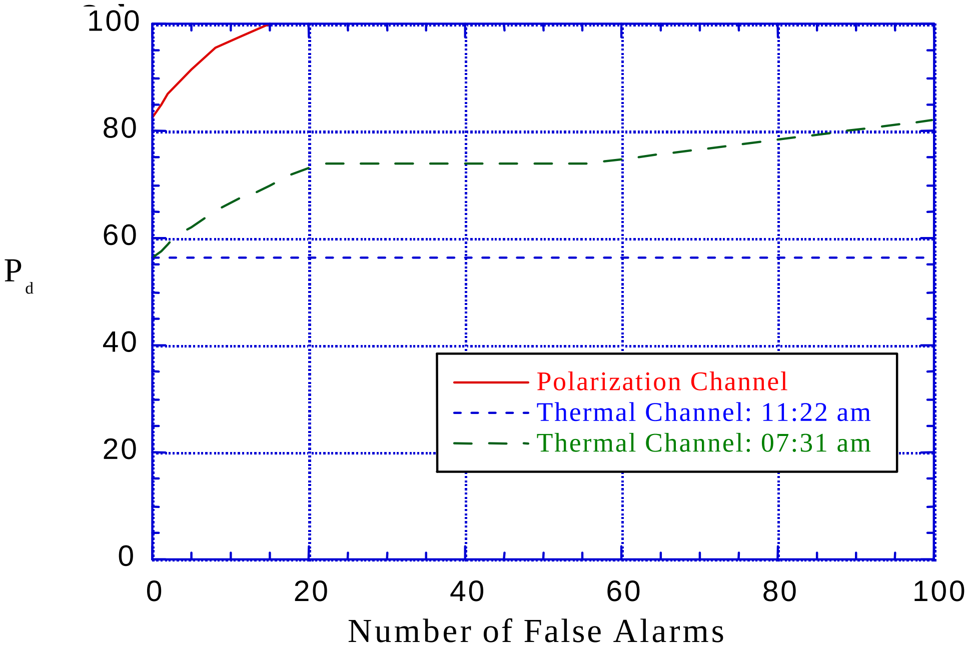


Fig II.1(b): Performance curve for Ft. Rucker: Ferrous and Painted Targets Only

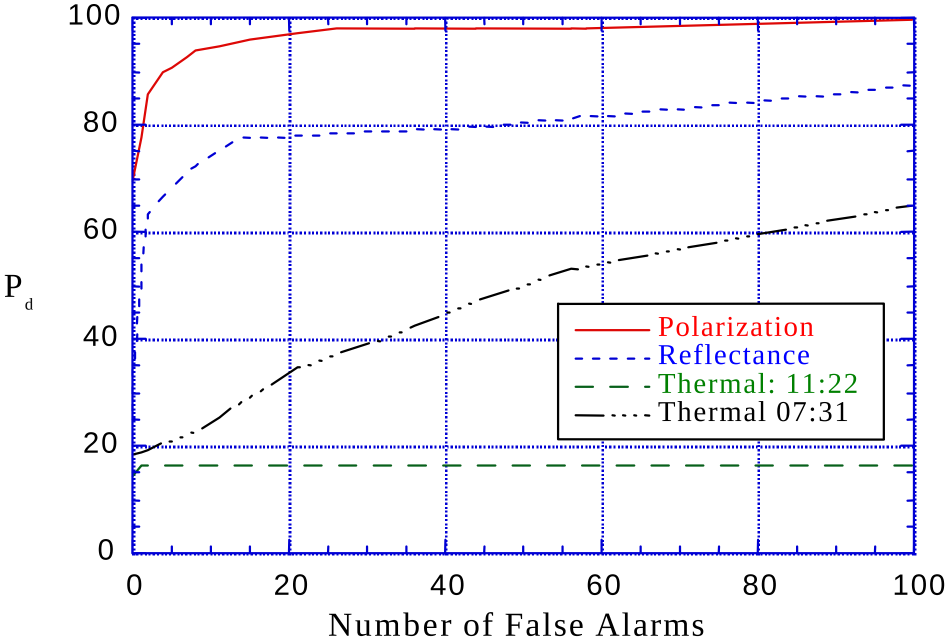
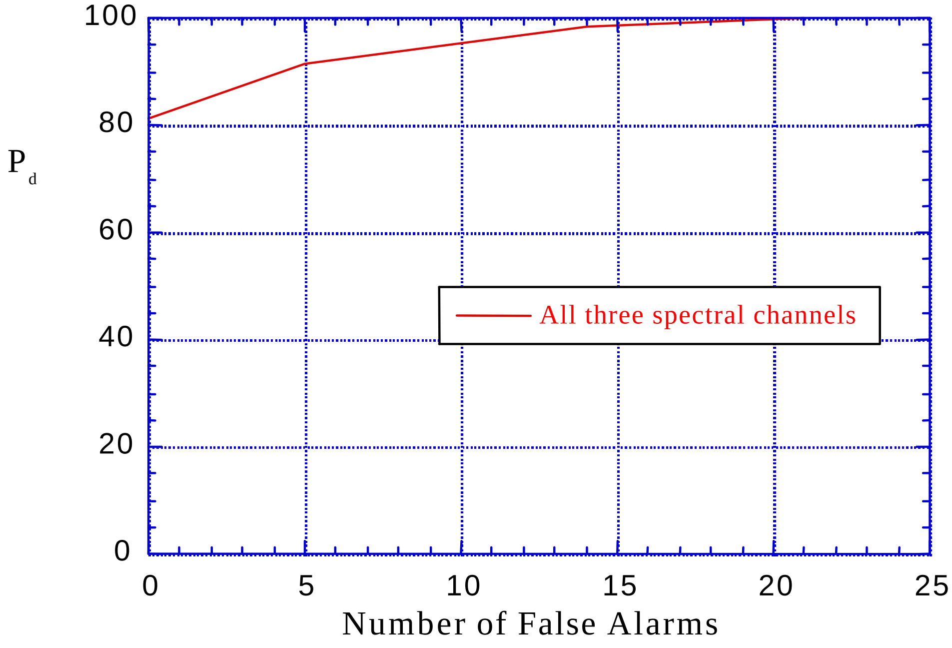


Fig. II.1(c): Performance curve for Ft. Rucker: All targets



during the analysis of the probability of detection outlined below, because this was the data as derived from the test.[6]

The Pd of the REMIDS system as a function of radius, R_{crit}, surrounding the target was then estimated. To perform this calculation, the dielectric mines, which are not relevant to UXO clearance, were excluded. Thus, the set of ground truth target data against which REMIDS was graded consisted of 124 ordnance items (70 81 mm mortars, 24 105 mm shells, 15 155 mm shells, 13 2.75" rockets, and two 500 lb bombs).

The results of this analysis are summarized in Table 2 and Fig. II.2. Table 2 gives the breakdown of detection probability versus R_{crit} for each ordnance type. These results are summarized in Fig. II.2, which shows Pd as a function of R_{crit} for the combined set of ordnance items, as well as the fraction of the detected items that were correctly identified vs. R_{crit} . Using Fig. II.2 and taking an example value of R_{crit} = 5m (which is more than a 2 sigma cut according to the estimate of the system's position resolution), REMIDS detected 76% of the target test sample and correctly identified 95% of the ordnance detected.[7]

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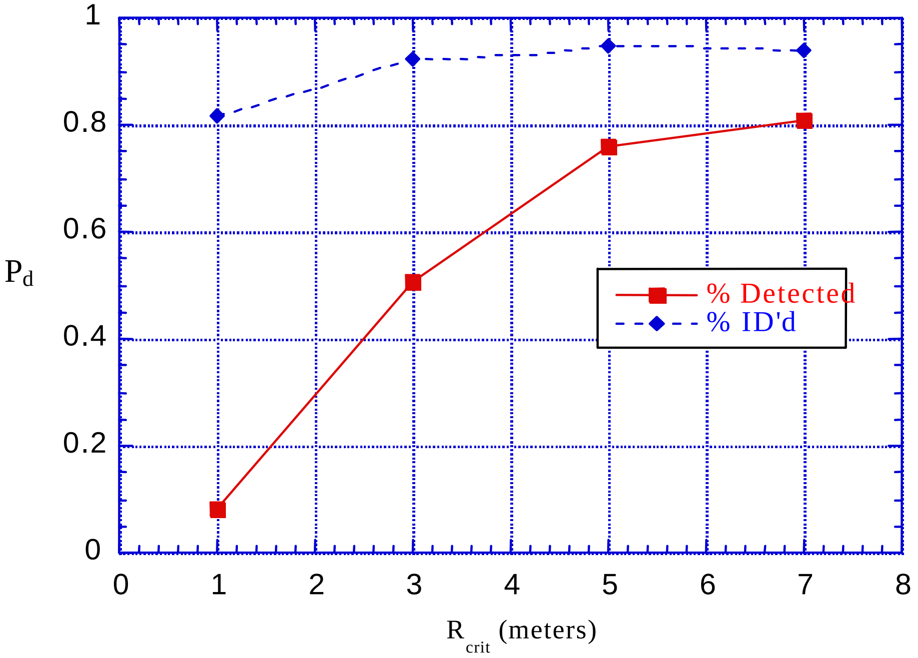
[6] Correcting for these offsets improves the device's detection efficiency discussed below by only a few percent.

[7] The calculation of Pd does not correct for areas that may have inadvertently been missed by the helicopter. It was estimated that the flight coverage was about 96% at Yuma. Hence if the coverage had been 100%, then the Pd may have been improved by a few percent over the measured value of 76%.

Table 2. Probability of Detection by Ordnance Type

Ordnance Type	Pd@R_{crit}=1m	Pd@R_{crit}=3m	Pd@R_{crit}=5m	Pd@R_{crit}=7m
81 mm	14.3%	57.1%	72.9%	78.6%
105 mm	4.1%	45.8%	75.0%	75.0%
155 mm	0.0%	46.7%	86.7%	86.7%
2.75"	0.0%	30.8%	76.9%	92.3%
500lb	0.0%	50.0%	100.0%	100.0%

Fig. II.2: Detection probability vs. R_{crit} at Yuma



To estimate the false alarm rate (FAR), three regions of the site that contained no targets were investigated. The area of the first region was 0.073 km^2, and the REMIDS system declared a total of three targets in that area, identifying all three as gator mines. This translates into a FAR of 41 per km^2. The second region was 0.049 km^2 in area, and the REMIDS system declared two targets, one a gator mine, and the other UXO scrap. This also yields a FAR of 41 per km^2. The third region was a much smaller area of only 0.028 km^2, and in this region, the REMIDS system declared no targets. Based on this subset of the Yuma site, the REMIDS system, with its three-stage analysis, yielded a false alarm rate of about 33 per km^2. It must be emphasized, however, that the false alarm rate would have been much higher if only the first two analysis stages had been employed (spectral and size/shape), because the operator played a crucial role in recognizing and eliminating false alarms.

4.0 CONCLUSIONS

4.1 ADVANTAGES AND LIMITATIONS OF REMIDS

The REMIDS technology has both advantages and limitations in locating UXO. As an airborne system based on current technology, it promises three advantages. First, the use of REMIDS will pose minimal risk to the survey personnel performing the measurements, as the personnel are on an airborne platform and are thus not physically disturbing the UXO site. Second, the method may be able to cover large tracts of land in a relatively short time because of the relatively high speed of the helicopter platform. Last, the surveys may possibly be done at a reasonable cost, again because of the relatively short time needed to perform the survey (see the Section IV for more details regarding cost).

The technology has important limitations, however. First, the REMIDS laser must have a line of sight to the surface ordnance items. Thus, broad-leaf vegetation, trees, understory, snow, and even dust can all pose a laser penetration problem for surface UXO. Buried UXO cannot be detected by REMIDS. Second, advance knowledge of ordnance type is important to calibrate REMIDS, as different types of UXO will have different reflectance, polarization, and thermal signatures. Thus REMIDS may be unreliable at detecting unexpected or uncharacterized ordnance. Third, the REMIDS system performance is highly site dependent. The grassy background at Ft. Rucker enabled the system to easily pick out the targets based on their spectral information alone; no size/shape filter or human scanning was needed. On the other hand, the desert varnish at Yuma rendered the spectral information insufficient, and thus the size/shape filter and especially the target recognition capabilities of the operator played a critical role in the analysis. Hence in challenging environments, REMIDS may not be reliable at detecting small ordnance items, and its performance will further depend on well-trained operators.[8]

4.2 POTENTIAL USES FOR REMIDS

In areas where there is a direct line-of-sight from the air to the ground, REMIDS may be used in a large-area search mode of operation to identify potential regions containing buried UXO in circumstances when surface debris could be correlated with buried UXO. For example, surface debris at an impact point of a bombing or artillery range may be detected by REMIDS, and this could betray possible buried UXO. In this situation, follow-up detection methods (such as magnetometers, metal detectors, and radar) would have to be employed to determine the existence and location of any buried UXO. This application is especially appropriate for grassy or sandy sites, where the spectral filter and crude size/shape filter would perform a reliable and fast analysis of the survey data. In regions where there are more challenging backgrounds (such as at Yuma, with its desert varnish), either well-trained operators or more sophisticated size/shape analysis filters will be needed for large area searches.

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[8] Though it is not currently part of the data reduction flow, it may be possible to automate the shape discrimination algorithm in future implementations.

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5.0 COST ASSESSMENT

A REMIDS cost estimate based on the collection of 18 hours of flight data at the Yuma Proving Ground, which had a challenging "desert varnish" background, is provided in Table 3.

For a challenging site like Yuma, the resultant cost range for using REMIDS is $75-225 per acre depending on the site geometry and chosen flight trajectory. Costs would be reduced to $70-210 per acre for an easier site like Ft. Rucker. If a lower resolution could provide acceptable target discrimination results, costs could be further reduced to around $14-15 per acre.

Table 3. REMIDS Cost Estimate

Cost Category	Yuma (Regular DGPS) $	Yuma Flight-Aided DGPS $	Easier Site Flight-Aided DGPS $
Equipment Installation and Calibration[1]	$50,000	$95,000	$95,000
Helicopter Support[2]	$120,000	$120,000	$120,000
Ground Equipment Rental, Transportation, and Setup[3]	$18,000	$18,000	$18,000
Data collection[4]	$70,000	$48,000	$48,000
Data analysis on site[5]	$68,000	$68,000	$34,000
Operator Training[6]	$68,000	$68,000	$68,000
TOTAL	**$394,000**	**$417,000**	**$383,000**
Cost per Acre (crosswise)[7]	$219	$232	$212
Cost per Acre (lengthwise)[8]	$73	$77	$71
Cost per Acre (low resolution)[9]	$15	$15	$14

Notes:

[1] The use of regular DGPS rather than the flight-aided DGPS would reduce the installation cost to $50,000. See also Note 4.

[2] Includes ferry hours to transport both the helicopter and its crew.

[3] Includes the cost of transportation of the REMIDS system to and from the site

[4] Includes the cost of flying the helicopter and the crew for 18 hours. The use of regular DGPS rather than the flight-aided DGPS would increase the cost of data collection to $70,000. The lack of flight aided DGPS would limit the ability to cover areas missed on the initial fly-over, and would also necessitate the use of visual markers on the ground for the desired flight lines.

[5] Roughly 3 man-months, including per diem and transportation. Estimated costs for an "easy" grassy site like Ft. Rucker are lower (1.5 man-months) because less operator time would be required for data analysis and target discrimination.

[6] Roughly 3 man-months, including per diem and transportation.

[7] The area that can be covered in 18 flight hours depends upon the profile of the data collection flights (i.e., altitude and forward speed), as well as the chosen flight path. The 0.5 km by 1 km site at Yuma was traversed crosswise (i.e., using 500 m passes), and during one flight hour, only about 15 minutes was dedicated to actual data collection. The rest of the time was spent making turns and lining up for the next pass. In this case, with a pixel resolution of 1.9" by 1.9", one flight hour yielded about 100 acres of coverage.

[8] If a site were traversed lengthwise, the coverage would be much greater; estimates provided by the REMIDS team are of order 300 acres per flight hour.

APPENDIX A

Points of Contact

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[9] Decreasing the pixel resolution to 4.5"x 4.5" from a resolution of 1.9" by 1.9", would increase coverage per flight hour by about a factor of five.

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