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13. ABSTRACT (Maximum 200 words)

The objective of this project was to assess empirically the feasibility of detecting the locations of buried landmine through examination of the land surface with normal human vision. Representative samples of landmines were buried at Ft. Leonard Wood, MO, in one area with a bare soil surface and in another naturally vegetated. Photographs of the surface collected over a four-week period were analyzed. Results showed that visible features identify where landmine burial disturbed the ground surface over this period. Analyses of the surface signatures in the bare soil area that employed subject matter experts demonstrated the value of skilled perception to identify (a) features that characterize disturbed soil and (b) their changes over time and with exposure in the natural environment. Results support the conclusion that visual detection of landmines is viable and provide information useful for training visual detection skills. Temporal and environmental limitations that apply to this conclusion merit further study. A photographic system has been designed and configured to investigate the generality of current findings and to extend their depth and breadth. Dissemination of findings has identified potential applications of this work's approach to additional US Army missions: detection of Improvised Explosive Devices and tactical tracking training.

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Enclosure 1

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Introduction

This report is submitted as partial fulfillment of obligations specified in Army Research Office Contract W911NF0610273 for the research project entitiled "Visual Terrestrial Cues for Landmine Detection." It summarizes the activities carried out by the contractor/PI working in collaboration with personnel of the Army Research Laboratory Human Research and Engineering Directorate Field Element at the US Army's Maneuver Support Center at Fort Leonard Wood, MO. and the progress made toward supporting development of training of landmine detection based on visual information over the period 1 July 2006 – 31 March 2007.

Project objectives and background material are first reviewed, followed by a description of project activities, accomplishments, challenges, and implications for supporting U.S. Army missions.

Objectives

The project objective was to systematically generate foundational knowledge about the feasibility of detecting landmines via visual examination of the ground surface where such ordnance has been buried. The products of this effort were sought explicitly for their potential utility to support the design, testing, and development of training for visual detection. Such training, when used to augment current training of operators of handheld landmine detection equipment, holds potential to enhance the US Army's countermine capability and possibly counter-IED capability as well.

A secondary project objective, based on the hypothesis that the data acquired would indicate that detection of landmines via visual information on the ground surface is viable, was to characterize the visual information produced by the burial of landmines that could be used to identify their locations. A related objective was to characterize changes to this information over time and with exposure to naturally changing environmental conditions. Such knowledge would dictate content requirements for visual landmine detection training and so inform its design.

A third objective was to identify verbal descriptors of visual information produced by landmine burial. Such information is directly relevant to support the training of soldiers' visual detection skills. That is because the instructional component of such training should include communicating clearly to trainees the visual cues and patterns of cues that need to be perceived in the natural environment to successfully and safely locate threat mines. Verbal descriptions of these cues and patterns represent the vehicles for communicating to soldier/trainees the information to which attention must be directed.

Background

Informal observations at sites where landmines have been emplaced for purposes of testing landmine detection equipment and training operators of such equipment show that the burial of subsurface mines and mine-like targets (simulated mines) often change the ground surface in visually perceptible ways. Such information may hold potential to improve mine detection capability, a critical task in mine clearance operations, especially if visual detection skills are used as a complement to the methods, equipment, and training procedures currently employed by the US military.

Historical records from WWII (Engineer Agency for Resource Inventories, 1972; Liddel Hart, 1953; Schmidt, 1951; U.S. Army Center for Military History, 1986) and the Vietnam conflict (Birdwell & Nolan, 1997; Fasulo 2003; Magner, 1968; Mine Warfare Center, 1969; Schneck, 1992) confirm the utility of visual information for detecting buried landmines. More contemporary reports from Operations Desert Storm (Schneck, 1992), Restore Hope (Schneck, 1994), and Joint Endeavor (Schneck & Green, 1996) confirm the utility of visual information for landmine detection, as do reports on countermine operations in Operation Enduring Freedom (Engineer Center for Lessons Learned, 2003) and Colombia (deJesus, 2003). Moreover, historical records indicate that German military personnel trained to detect landmines by visual means alone achieved a degree of skill that permitted successful use of this approach for countermine operations in a tactical environment (U.S. Army Center for Military History, 1986). Unfortunately, this literature contains no specification of the information used to locate buried mines successfully, beyond vague references such as "surface anomalies" and "changes in the environment." Nor is there any information about the content information or procedures used for training.

Thus, a prerequisite for evaluating the efficacy of visual detection involves generating a variety of essential resources. Working backward from this goal, such an evaluation first requires training personnel to use this approach, however no training program exists and thus one needs to be designed. Among the prerequisites for design and delivery of sound and effective training is a clear, objective understanding of the environmental information available that can signify the location of buried mines to a human observer. The main purpose of this effort was to obtain such information -- information about the visible effects of landmine burial.

Approach

The novelty of the proposed work dictates an exploratory approach because no substantive body of directly applicable knowledge, scientific or otherwise, is available for guidance. As a result, novel methods were required.

The approach selected has two main components. The first involves capturing and documenting the phenomena of interest: visible signs on the ground surface where landmines had been buried, otherwise referred to as landmine signatures. The observations collected take the form of high-resolution photographs of the ground surface where landmines were buried. Examination of the photographs serves to address the viability and limitations of the training concept, provides material suitable for use as training content, and supports studies aimed at identifying training requirements and content.

The approach taken to generating training requirements and content follows that used by Staszewski and Davison on previous successful efforts to develop landmine detection training programs: Cognitive engineering based on expert skill (Staszewski, 2004; Staszewski & Davison, 2000; 2002). This approach analyzes and codifies the knowledge that supports expert skill in a domain of interest and then uses the results as a template for designing training for novices. In this project, the archive of signature photographs was used to identify the information that especially skilled observers perceived to distinguish the locations of buried landmines from their adjacent undisturbed areas.

Acquisition and Archival of Landmine Signature Photographs

To generate a description of the visual cues that are hypothesized to define buried landmine signatures, the initial and focal effort involved acquiring and archiving for later analysis a systematic body of appropriate photographic evidence relevant to the hypothesis in question. Simply stated, the hypothesis is that disturbances of the ground surface related to the burial of a landmine produce visible signs. The information captured photographically provides material to test this hypothesis.

A related hypothesis is based on the reasoning that both the pro and con views about the viability of visual mine detection may be right, but they fail to specify when and under what conditions cues that may be initially observable disappear due to natural environmental changes. A longitudinal design which permits collection of signature photographs for extended periods was adopted to test the validity of this idea.

The longitudinal corpus of photographs is also expected to provide material for exploring expected changes to signatures as a function of exposure in the natural environment.

<u>Method & Design</u> The key variables manipulated in this study were landmine size and type (values specified in Table 1 below), ground surface (bare soil or vegetated), and the presence/absence of a mine target (in a designated location). Environmental conditions varied in an uncontrolled manner dictated by the natural conditions that occurred at the test site over the observation period.

Table 1

Type	Mine	Size (LxWxH in mm)	Burial Depth (cm)
AP	PMA-2	66 dia x 30	subsurface
AP	VS-50	90 dia x 45	2.54
AP	PMA-1A	140x68x31	2.54
AT	VS-2.2	240 dia x 117.6	7.00
AT	TMM-1	326 dia x 90	7.00
AT	TMA-5	312x275x113	7.00

Effects of burial were investigated in the context of two ground surfaces: one vegetated with the surface growth present at the site selected for this work; the other a bare soil surface, produced by removing the surface vegetation. A study of mine vapor emissions conducted earlier at the same test site (Jenkins, et al., 2000) characterized its soil as Plato silt loam (fine, mixed, mesic Aquic Fragiudalfs).

Photographic records were obtained for locations where mines were buried and adjacent designated locations where no mines were buried. Two levels or conditions of the latter 'no mine" condition were employed for control purposes. One involved leaving an area equivalent to the size of the area whose surface was disturbed by mine emplacement intact. The other involved digging a hole equivalent to that necessary to bury a mine, but then refilling the hole with the spoil produced (and replacing surface vegetation, in the vegetated condition).

Materials Demilitarized blast mines, generously provided by the US Army's Night Vision and Electronic Sensor Directorate (NVESD), were employed. These are intact landmines containing explosives that have their firing chains interrupted to functionally disarm them. The purpose of using demilitarized ordnance, as opposed to physically similar landmine simulants, was to assess the potential effects of escaping vapors (Jenkins, et al. 2000) on surface vegetation and its growth. The sizes of the mines were representative of the range of ordnance found in the contemporary operational environment (see Figure 1) to maximize the generality of findings. Types and sizes of each mine are listed in Table 1. Two mines of each type were used, one buried in each of the bare soil and vegetated areas of the test site.

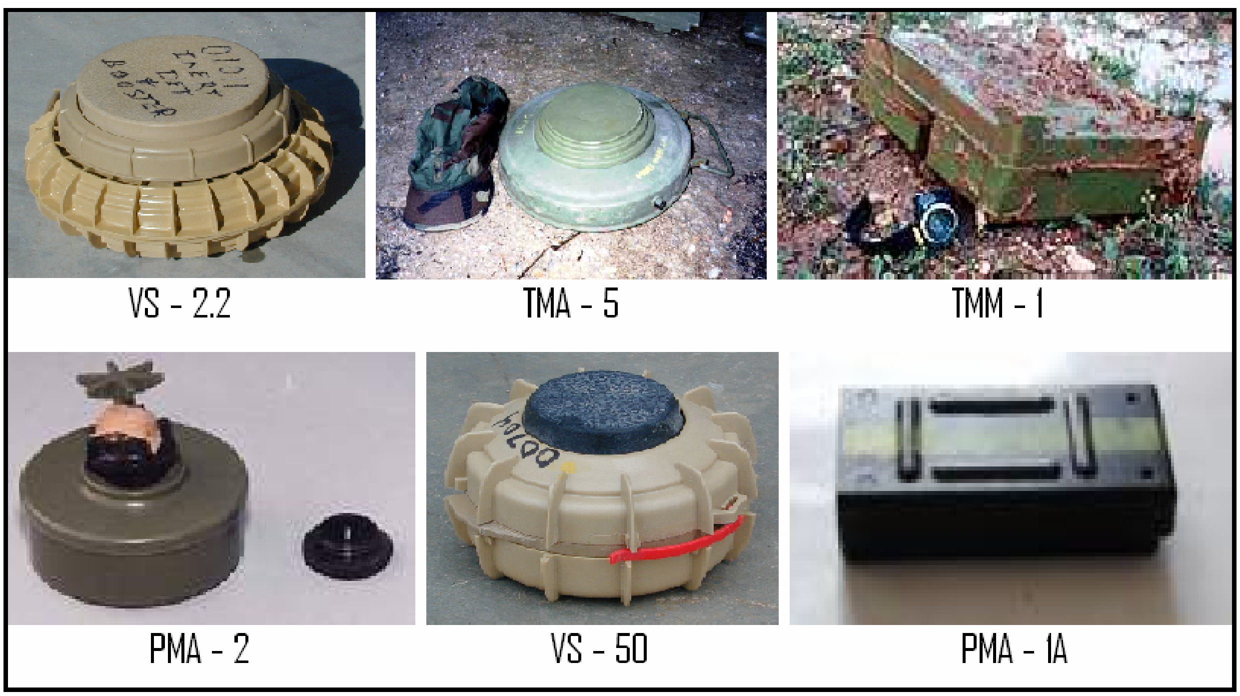


Figure 1. Examples of the different mines used.

Field Test Site The test site is located on a range managed and overseen by NVESD, meeting requirements for burial of demilitarized landmines. After receiving clearance from NVESD for use of this area, a test site of the dimensions shown in Figure 2 was prepared. Preparations included removal of surface vegetation to create a bare soil surface and placement of a centrally-located support column capped with a frame on which the cameras of the system described below attached.

Apparatus Equipment designed for time-lapse photography was employed and adapted to current requirements. The camera system design permitted continuous, remotely controlled capture of high-resolution (7.2 megapixel) digital photographic records of the ground surface of the test area. A commercial vendor provided equipment and services to collect and archive images of the ground surface where mines were buried. The vendor furnished four cameras specially hardened for long term exterior use and packaged this equipment with capabilities for remote control adjustments and services for download, transmission, indexing, and archival of photographic images.

Sampling was set at a rate of one photograph every five minutes from each camera. This high sampling rate was selected specifically to capture visually perceptible effects of short-term transient phenomena that have been observed to identify the locations of mines. (Baertline [2003] has explored such local thermal transients suspected to be related to these observations as means to detect landmine via thermal sensing.) Photos were archived on a computer at the field test site. They were also transmitted via satellite line at the site for review and archival at a remote location.

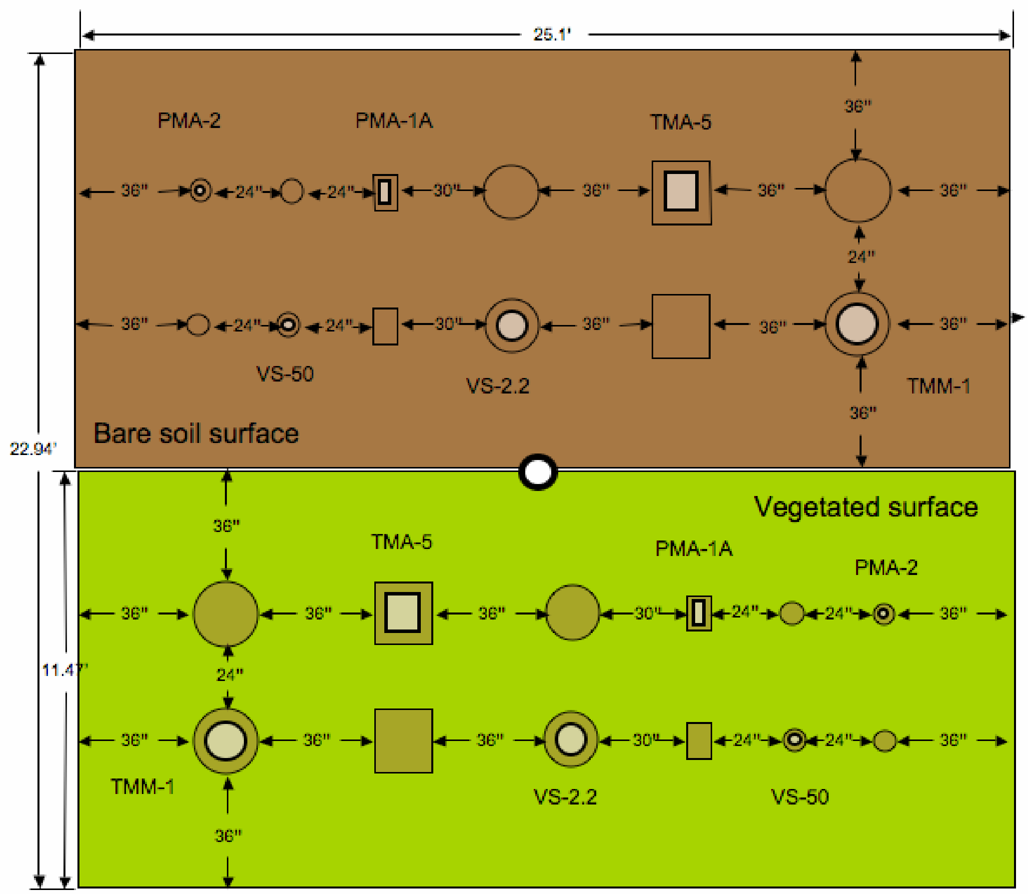


Figure 2. Layout of test area showing locations of mines and 'control' holes.

Procedures After unanticipated delays in receiving the camera system, it was installed in the field in late February 2006. A test period of nearly two months followed, during which multiple problems arose with the system. Solutions required changing various components of the system and subsequent testing to achieve acceptably reliable operation. These shakedown efforts delayed emplacement of mines and the start of data collection until mid-April of 2005.

A NVESD employee and a member of the onsite Army Research Laboratory team emplaced the mines according to US Army doctrine. Burial depths, measured to the top surface of each target, are shown in Table 1. Emplacement began on the afternoon of 13 April and was completed the next day.

Meteorological records for the region of the test site were obtained from the National Oceanic and Atmospheric Administration for the period over which photographic records were collected.

Analyses Analyses proceeded along two paths. The first involved exploratory qualitative examination of the mine signature photos to assess the hypotheses stated above. This included describing both the visual information captured in the photographs and the manner in which this information changed over time.

The second path involved collecting descriptions of the above information from expert observers by presenting a sample of signature photos. Their training and experience were expected to enable them to generate descriptions of the characteristics of the captured signatures that were more definitive and thorough than those generated by naïve observers.

Photographic Archive of Landmine Signatures

Period of Observation and Archive Limitations Plans were to collect photographic data continuously for a period of four months starting in the fall of 2005. However, numerous and chronic problems occurred with the instrumentation provided by the vendor contracted to configure and implement the photo acquisition and archival system. These problems delayed the start of data collection until mid-April 2006. Mine emplacement took place April 13-14, 2006, approximately two and one-half weeks after the start of the growing season in the region (St. Louis Weather Forecast, 2006).

Photo collection continued for four weeks and was only partially successful due to major instrumentation problems. Unreliability in the operation of the photo collection system increased over this period, plagued principally by intermittent camera malfunctions. Their increasing frequency coupled with the inability as well as the unwillingness of the contractor/system designer to diagnose and solve the problems led to the decision to cease operations in mid-May. Shortly afterward the services of the vendor were terminated as well. Consideration was given to litigating for breach of contract. However, upon further reflection, the PI and collaborator, Dr. Alan Davison, decided that such action would be counterproductive in as much as it would expend further time and resources that would be more productively applied to achieving the goals of the project.

These events resulted in a much smaller set of photographic records than planned, and a relatively short longitudinal sample. The sample was further limited by intermittent camera malfunctions during the period of data collection This produced an incomplete and fragmented archive of usable photos. Of the large archive (approximately 42 GB) produced, the overall proportion of usable photos was but 0.19 of those expected, the expectations based on available daylight hours and the sampling rate. Individual cameras performed with extreme variability. The best camera, that which photographed the bare soil area where anti-tank mines were buried, produced 0.40 of the expected photos. The camera photographing the vegetated area where anti-personnel mines were buried produced the lowest proportion of expected photos, 0.01.

The limited sampling posed several problems for analysis. First, culling good quality photos from photos with deficiencies required a large and unexpected expenditure of time and labor. Second, the temporally limited, fragmented, and unbalanced photographic sample negated plans to investigate the perceptibility of landmine signatures experimentally. The “holes” in the sample made it unfeasible to apply experimental paradigms that address the issues of detection and discrimination due to the confounds they created.

Despite these limitations imposed by the attenuated and fragmented sample, the archive contains a sufficient set of acceptable quality photographs to address the basic questions motivating this work, as discussed below.

VS-2.2 TMA-5 TMM-1

Figure 3. AT signatures on bare soil surface. Above photos taken shortly after burial on 14 April, 12:01 PM. Lower photos taken 3 May, 11:59 AM.

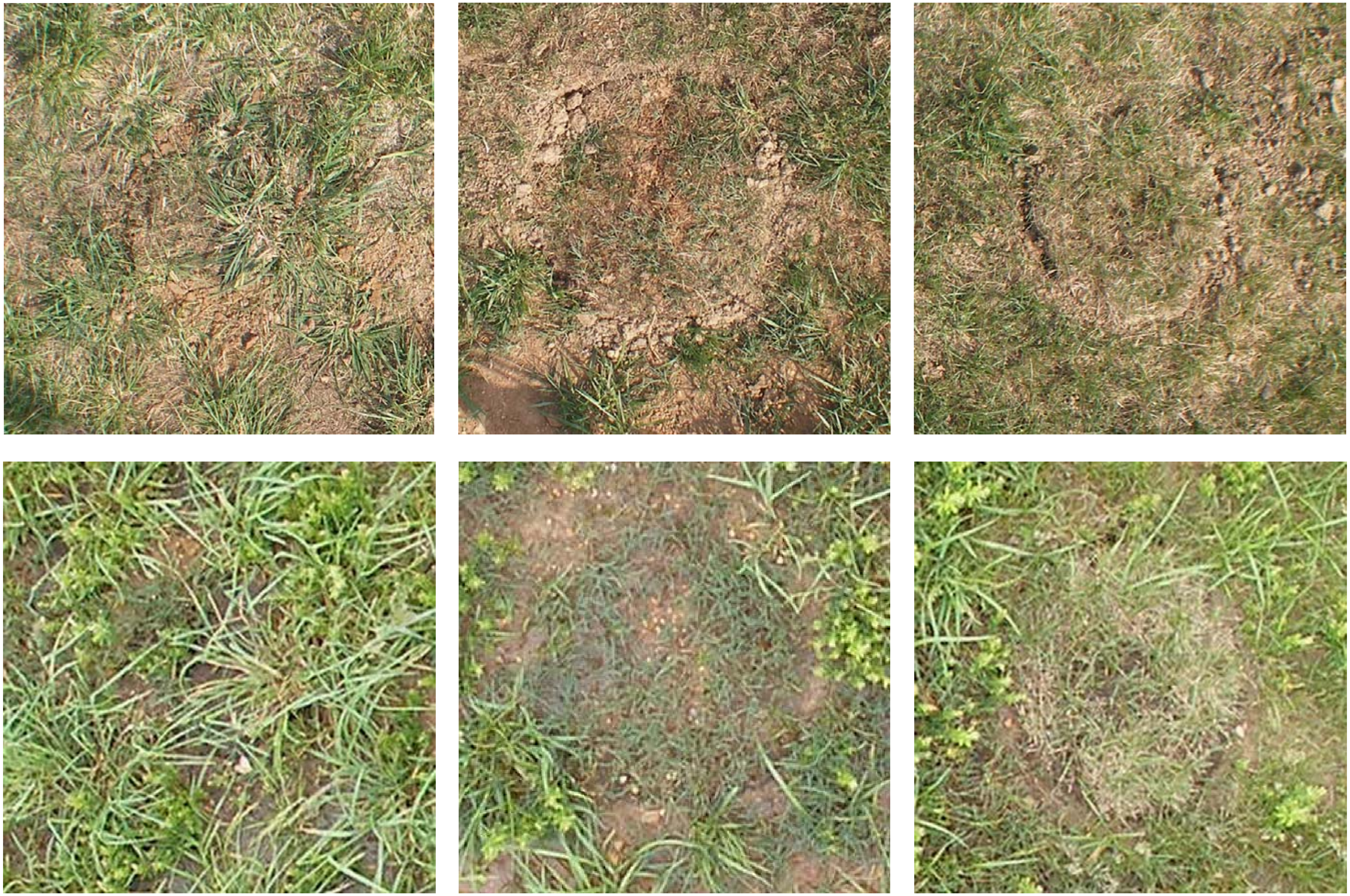
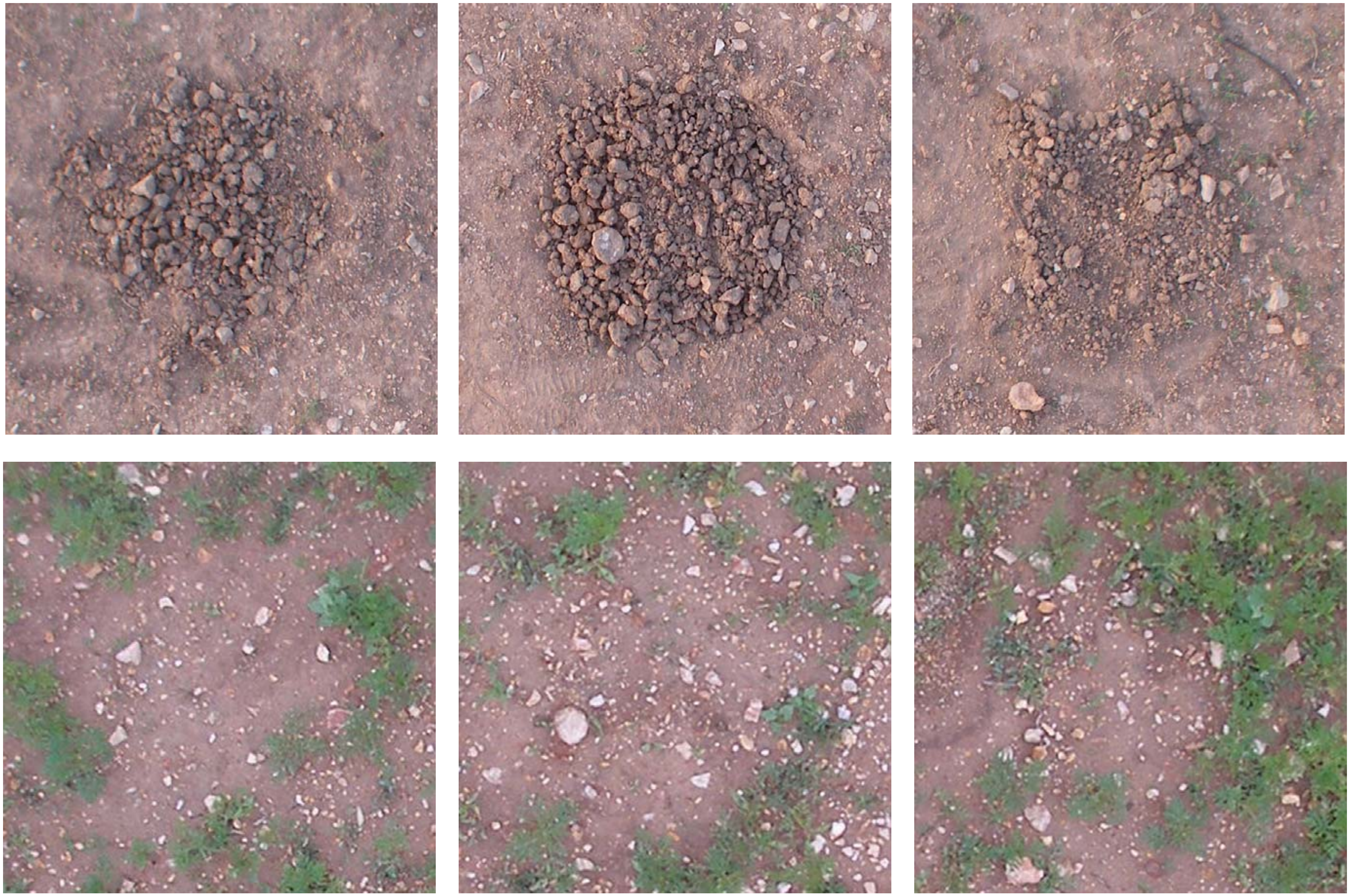


Figure 4. AT signatures on grass surface. Above photos taken shortly after burial, 14 April, 9:31 AM. Lower photos taken 11 May, 5:00 PM.



PMA-2 VS-50 PMA-1A

Figure 5. AP signatures on bare soil surface. Above photos taken shortly after burial, 14 April, 6:24 AM. Lower photos taken 11 May, 7:23 PM.

PMA-2 VS-50 PMA-1A

Figure 6. AP signatures on grass surface. Above photos taken shortly after burial, 14 April, 6:49 PM. Lower photos taken 5 May, 4:25 PM.

Proof of Visual Landmine Detection Concept

The photo archive is sufficient to permit informal comparison and contrast of the signatures produced by landmine burial with surrounding undisturbed regions. Although a more rigorous and systematic analysis is desirable and was planned, one that permits holding constant key variables (e.g., time of day) and a balanced sampling of others (mine types and surfaces) to reduce obvious confounds, the inconsistencies in the photo archive due to unreliable performance of the photo collection system prevent doing so. All findings reported here should therefore be regarded as tentative and subject to verification when a more complete body of photos collected from a second wave of data collection is available.

Despite this important caveat and with the intent to exploit to a reasonable extent the information relevant to project objectives, qualitative photographic evidence relevant to the objectives of this study will be described.

Figures 3, 4, 5, and 6 display the signatures of each of the mines shortly after emplacement and when the last useable photo of each signature was taken. Informal inspection of the photos by observers without specialized training or knowledge reveals several regularities that characterize the mine signatures captured in the collected set. These are best prefaced by descriptions of the features observed to distinguish the signatures in their surrounding locations.

Immediately after burial, mines buried in the bare soil areas as per doctrinal procedures produced salient surface signatures as shown in the top row of photos in Figures 3 and 5. The regions of disturbed soil are characterized by homogeneous areas that have rougher surface textures and darker colorations than observed in the surrounding undisturbed areas. The contrast between the signatures and their surrounds on these dimensions varies somewhat among the signatures and thus does the clarity of signature contours, but a regularity in the midst of this variation is the roughly circular shape defining where the surfaces have been disturbed.[1]

The six top row photos in Figures 4 and 6 show the vegetated surface of the test area where AT mines were emplaced within an hour or two after their burial. Five out of the six photos show relatively salient signatures. In each of these cases, darkened outlines show continuous boundaries of the circular sod "plugs" removed. In the case of the TMA-5, some clumps of bare soil can be seen along the edges of the sod plug. The signature for the VS-2.2, however, can be seen upon close inspection, but its boundaries are considerably less salient than for the other five signatures in the grassy area.

Differences between the defining features of the AT signatures and the AP signatures are easily noticeable in Figures 4 and 6. The grass on the surface of each of the AP plugs has become discolored and shows greater contrast with its surrounding vegetation, whereas the grass above the larger AT plugs remains roughly the same color as the vegetation surrounding the signatures.

The bottom rows of Figures 3-6 show the last clear and focused photos of the signatures covered by their respective cameras. In the cases of Figures 3 and 6, a period of approximately three weeks had elapsed since mine emplacement. The photos shown in Figures 4 and 5 show the AT and AP signatures roughly 4 weeks after mine emplacement. During the period April 13 -May 5 seven rainfalls in amounts in excess of .25 inches occurred. Two additional rainfalls occurred between this period and May 11.

The signatures for the mines in the bare soil area remain salient and are still defined by color differences between the signature and the surrounding area. The colors that contrast the signatures from their surrounding areas are different, however, from those observed shortly after burial. Now, new vegetation growth outlines the circular areas of relatively bare soil. In addition, light colored stones also appear over and around the signatures.

Visible signs persist in the vegetated area for all of the mines, although those of the VS-2.2 and the PMA-2 require close inspection. Fairly dark soil contrasts with the surrounding grass for all, however this sign must be seen through the grass in the case of the VS-2.2 and the cue for the PMA-2 covers a

[1] Different techniques for landmine emplacement in vegetated areas can produce different patterns. In this case, removal of a circular section of sod held together by the vegetation's roots was removed and later replaced produced the observed patterns. Techniques that cut sections in either a square or a rectangular shape would yield a different pattern. Another technique that cuts an "+" pattern, peals back the four sections of turf created, excavates subsurface soil and places the mine at the intersection of the "+," and then replaces the turf quadrants to their original positions would yield a different pattern shape that would nonetheless be defined by signs of cut turf.

small area. A rainfall of approximately 1.16 inches the previous evening is a plausible contributor to the darkened color of the visible soil. For the TMA-5 and the TMM-1, bare soil marks the edges of the sod plugs and the colors and textures of the grasses on the plugs also contrast with their surrounds.

The visibility of the signs both at the early and later stages of photo collection argues against claims unequivocally dismissing the utility of visual landmine detection. Rather the photographic evidence is consistent with historical claims about the utility of this approach. The claim is not that such utility is unlimited, but, rather, that under conditions observed here visual detection by an appropriately knowledgeable and/or trained observer appears viable. Nor is it claimed that it would be easy for novices to detect the signatures of either the VS-2.2 in the bottom left photo of Figure 4 or the PMA-2 in the bottom left photo of Figure 5. The question of whether personnel trained to scan for such apparently subtle cues could detect these and others like them remains an open question. The information available in these photographs suggests that the question about the viability of visual detection should not be viewed as an either/or question. Instead, the evidence indicates that "When?" is the more appropriate question. Efforts directed at identifying limiting conditions are underway.

Comparison of the signatures photographed immediately after mine emplacement with those in the near-final photographs shows that the features that characterize the signatures change considerably in quality and in salience. Initially, surface cues consist generally of regions exhibiting patterns of distinguishable geometries defined by visible elements differing in color and texture. Changes in the colors and textures occur, but the geometric patterns appear to be preserved over these changes, at least over the relatively short period covered in the corpus of captured photographs. These featural changes for the signatures in the bare soil area are elaborated in the following section that describes preliminary findings from studies employing individuals with task-relevant expertise to describe photos of the ground surfaces where landmines had been buried.

Striking evidence for localized, context-conditioned variability in the features of signatures is apparent. Such variability appears not only for the defining features of the signatures of different mines photographed at the same time, but also with the changes that occur over time. Comparisons of the early and later signatures in Figures 3-6 illustrate considerable change in signature cues over the entire period of observation.

Considerable change was also observed over relatively short temporal intervals. Not surprisingly, these changes appear to be linked to changes in weather conditions. For example, Figure 7 shows how the features that define the signature of the TMA-5 buried in the soil surface area change over the period of 8 hours. This photo sequence illustrates change in the color of the soil surface.

Figure 8 illustrates how spatially localized change in defining features can be. Here, the surface coloration that marks the signature of the TMA-5 shown on the left (the same photo is the last in the sequence shown in Figure 7) contrasts sharply with the surface coloration of the signature of the TMM-1 located roughly 1.5m away and observed at the same point in time. Paradoxically, it is the whitish surface coloration that distinguishes the signature of the TMA-5 from its background, whereas the whitish coloration serves as the background against which the contours of the signature of the TMM-1 are contrasted. This reversal of featural roles in defining adjacent signatures highlights the context-conditioned variability of signature phenomena.

Practically, such variability holds important implications for the design of any visual detection training program. The difficulty, if not the impossibility, of identifying mine signatures by a fixed set of invariant features even within the context of this narrow sampling of signatures, should be apparent. This variability does not mean that visual detection is unfeasible, however. The cues may vary widely from signature to signature from time to time, but these photos show that they define emergent spatial patterns; the important regularity observed in these photos is the presence of visible, if abstract, patterns whose contours emerge on the basis of fairly continuous color differences. These patterns are distinguished by homogeneous regions whose populating features contrast with the features that dominate the surrounding regions. The instructional implications are that any training must be oriented toward facilitating trainees' acquisition of highly abstract spatial patterns, to contend with substantial context-conditioned variability.

Figure 7. TMA-5 signature in soil surface area on 12 May 2006 at 10:00 AM (top left), 2:00 PM (top center), 3:00 PM (top right), 4:01 PM (bottom left), 5:00 PM (bottom center), and 6:01 PM (bottom right).

Figure 8. Adjacent TMA-5 (left) and TMM-1 (right) signatures in soil surface area. 7:01 PM, 12 May 2006.

Expert Perception of Landmine Signatures

The goals of this analysis were to identify in greatest possible detail (1) the visual cues and their organization which result from landmine burial in the surfaces used in this project, (2) the ways in which information defining landmine signatures changes as a function of time in the natural environment, and (3) the language that accurately and succinctly describes the information distinguishing landmine signatures from their surroundings and the manner in which this information changes over time and with exposure to natural elements.

To maximize the sensitivity of the analysis, experts -- individuals with extensive experience in a relevant task domain and whose credentials exhibit high levels of knowledge and skill -- were recruited. Studies of human expertise repeatedly demonstrate that experts exhibit superior sensitivity to the task-relevant information, detecting patterns and cues that novices typically fail to perceive.[28] This effort sought to exploit expertise in task-relevant domains to describe the information that constitutes surface signatures and their changes. Because no experts at visual landmine detection could be identified, experts from the logically related areas of tactical tracking and geological research were recruited to serve as participants. Their task was to compare and contrast areas in photographs where landmines were buried and the adjacent areas where the ground surface was undisturbed, by verbally describing the surface where mines were buried.

Method

Participants Three individuals with expertise in interpreting soil disturbances provided descriptions of photographs of mine signatures. Two were geologists with Ph.Ds whose strong publication records and consistent success in the competitive environment of research funding confirm their expertise. The third expert was a tactical tracker with 40 years experience as a tracker and trainer of trackers. He has authored an authoritative book on the topic, and he has designed and now delivers tactical tracking training to US military personnel.

Design and Materials To obtain expert descriptions of landmine signatures, one set of trials presented photos of individual signatures of three anti-tank mines buried in the bare soil portion of the test area which were paired with control photos. The controls were taken at the same time as the signature photos and showed the undisturbed surface of the test area immediately adjacent to the location of a presented mine signature. The signatures and paired controls sampled the period of observation at four different intervals; the day following landmine burial and one, two, and three weeks afterward. Half of these photos were taken at mid-day. The other half were taken the same day at roughly 45 minutes after sunrise. This design yielded twenty-four “signature-control” displays. Figure 7 shows one of these displays. A second set of trials used a slightly different task to examine feature change. Each trial presented a pair of photos, one showing the signature of each AT mine signature taken just after burial and the second showing the same signature either one, two, or three weeks later.

Figure 7. Sample trial display showing target photograph and control photograph.

Analysis Extraction of qualitative data from the verbal protocols involved three stages of coding carried out by two independent coders. At each stage, after reading through the protocols, preliminary generic coding rules were established and then coders would perform a first coding pass. Results were then compared, and coding rules were tuned or added, and a second coding pass occurred. First, all descriptor words and phrases were identified. The second level of coding categorized each descriptor based on judgment of whether it referred to a signature or undisturbed area. Third, semantic coding categories were established along with rules for category assignment based on semantic content, and coders proceeded to assign each descriptor to the appropriate categories.

Results

To illustrate the qualitative data produced by the experts to which the above analytic procedures were applied, Table 2 shows the verbatim transcriptions of the verbal reports provided by the expert tracker and one of the geologists for the photos shown in Figure 7.

Coding of the verbal protocols proved highly reliable. The two coders’ categorizations agreed 100% in the first stage, and on 97% of the items in the second stage. Reliability in the third stage, aided substantially by reference to a basic textbook on soil and geomorphology (Birkeland, 1999), showed agreement at a level of 99.9%.

First, as expected, experts consistently and explicitly describe features of signatures that a convenience sample of novice observers fails to notice. Significantly, these features become salient to novice observers *after* exposure to the descriptions of experts. In addition, the descriptors are easily communicated to other novices. For example, “sharp, angular stones,” also known in the technical language of geology as “clasts,” are a distinguishing surface feature of disturbed soil - at least in the observed bare soil surface areas shown in Figures 1 and 3. “Washed” clasts are a salient feature of the signature shown in the bottoms rows of photographs in these figures.

Surface topography is the feature most frequently used to characterize the mine signatures. References to this feature occurred on 66.7% of signature presentations. In contrast, generic references to excavated or disturbed soil occurred for 52.2 % of signature presentations. More specific differences between signature surfaces and undisturbed areas related to vegetation, the presence of clasts, structured soil aggregates--also referred to as peds or clods (Birkeland, 1999)--and color differences, occurred 51.1%, 38.9%, 26.1%, and 23.3% of the trials, respectively. Explicit references to shape occurred on 16.7% of the signature presentations.

Table 2

BH – Expert Geologist:

Uhh a target that's been emplaced for some period of time. Some structural elemental elements are still observed at the surface, but most of them are broken down. Surfaces beginning to smooth out again to be more equivalent to what you find in the control. The con, surface of the control is a grey color whereas over the target area, there's ah more reddish coloration associated with sub-surface soil features being brought to the surface. There's micro-topography over the target area itself that has smoothed out or giving comparison to the smooth area. Of the control, appears to be an increase in the number of surface clasts, um over the target area compared to the control. And also a change in the amount of vegetation with the least amount, over the target area.

DSD – Expert Tracker:

Sixteen: Looking at the control picture, ah, seen this picture before from the previous control, uh. Once again constancy of the vegetation, no disturbance, no unnatural pattern of vegetation growth. Uh looking perfectly natural, a darker area to the top of the picture, this looks like water may have gathered there, and the soil may have been moist. That shows a bit of a color change, but it's a natural color change and not an unnatural one. Moving across to the target picture, again what draws the eye is the angular stones that have been excavated out of the hole, which are now on the surface of the ground, which don't appear on the control picture. The color change, the fact that there is more moisture probably in the excavated soil than there is in the surrounding ground showing it up in a different color. I will suggest that, um, this mine hasn't been in the ground really long, but there has been some weather effects in as much that the, uh, sandy grains have been washed back into the ground, but not yet to the state where it, where it appears natural. Um, my guess is probably several days…(*inaudible*)…definitely the rain has fallen on it. Affecting appearance, cause you almost see rain drops and a smoothing effect. But naturally um speaking, there is a color contrast, there's a shadow contrast, and there's a, there's a stone contrast compared to the surrounding ground.

Examination of the signature characteristics generated by the experts as a function of signature age reveals some systematic components of featural variation and sharpens understanding of how signatures change in the natural environment with time and weather exposure. To be specific, the experts consistently noticed how soil structure elements -- not present in the undisturbed 'control' surface photos -- eroded and smoothed out as a function of the passage of time. Table 3 shows the percentages of signature presentations in which statements about the condition of soil structure elements appeared. Note the trend relating decomposition of these to signature age and to the cumulative rainfall amounts reported earlier. A monotonic decrease in references to signs of excavation or soil disturbance is also observed (72.2%, 55.6%, 38.9%, and 22.2%) as signature age and precipitation total increases.

The frequency with which clasts are mentioned increases monotonically over the observation period 4.2%, 22.2%, 50%, respectively, leveling off at 50% for the oldest signatures. A monotonic increase related to signature age is also observed in references to contrasts in vegetation on the signature surfaces with the vegetation found on the undisturbed surrounding surfaces (33.3%, 44.4%, 66.7%, 77.8%).

Table 3

	State of Soil Structure			
Age (weeks)	Intact	Lightly Decomposed	Heavily Decomposed	Completely Decomposed
0	51.4	0.0	0.0	0.0
1	25.0	13.9	8.3	0.0
2	5.6	5.6	16.7	5.6
3	2.8	0.0	5.6	11.1

The covariance of descriptors implies linkages among the features, however the linkages are sometimes more overt. Some examples of such linkages can be found in the following excerpts: "lack of vegetation over the disturbed site," "darker reddish brown color in the micro-topographic lows," "no vegetation growing in a circular area," "lack of vegetation on that circle makes it apparent," and "angularity of the clods of soil and the stones that had been excavated from the surface of the ground."

Discussion

Engagement of the expert perceivers worked as predicted yielding a detailed characterization of visible mine signatures, insights into how they change, and language for communicating their features to naïve observers, noting that the knowledge gained is specific to mine burial in an area with a bare soil surface. The approach of using experts as filters to identify critical information in a complex, information-rich environment offers a way of separating and extracting the proverbial "wheat from the chaff."

The identification of a relatively small number of signature attributes and dimensions is important considering the "use-inspired" motivation for executing this study: to construct a foundation of knowledge that can serve as content for training soldiers to detect landmines more effectively by developing their visual detection skill. This apparent reduction in the complexity of mine signatures helps to reduce the impact of instructional time shortages and the information-processing constraints that limit individuals' ability to quickly learn and retain large amounts of new information. Also, the simple labeling of defining features and the apparent ease with which these descriptors can make the visual features to which they refer salient is promising considering the practical application in mind. The experts' protocols yielded simple naming terminology, which is likely to facilitate communication and thus instruction.

The covariation observed among the identified signature features--which must be confirmed before any strong interpretations can be put forth--suggest potential for further reduction of the number of signature cues that can support visual detection. Future studies with a wider temporal sampling can examine stability of these relations more rigorously as well as their predictive value for visual detection, if measures of signature detectability are collected.

General Discussion and Conclusions

The current findings about the nature and longevity of landmine signatures suggest that visual training may be a viable approach and merits further study. The findings and the materials used to produce them in this study provide valuable resources for designing such training, which is one item on the future research agenda. Such work should involve development of a training program and assessment of its effectiveness. Although it is possible that visual detection skills may have value independent of the use of handheld equipment, from the perspective of visual detection offering a supplement to applications of handheld equipment, the incremental improvement that visual detection skills confer (if any) and return on investment in visual detection training should be foci for evaluation.

The findings have implications that go beyond relevance for training applications. Specification of signature properties can inform technologies that pursue optical processing as a means for remote detection by narrowing the pool of visual cues that should be explored as candidate inputs for visual processing algorithms. Such visual information may also hold potential utility for technologies that exploit sensor fusion. Recognition of the complexity of mine detection has led to recommendations for research on technologies whose algorithms exploit inputs from multiple sensors[4]. Conceivably, optical signature information may have higher value in combination with other streams of sensor data than it does alone.

Optical information as it has been treated in this work is restricted to that carried by the limited portion of the electromagnetic spectrum to which human vision is sensitive. Recent research on the utility of hyperspectral information for distinguishing disturbed and undisturbed soils suggests that it may be fruitful to explore how a combination of visible information and hyperspectral optical information might support mine detection (Hibbits, 2007; Koh, Winter, & Schattern, 2006; Maathuis, & van Genderen, 2004). Work that does so is planned.

The generality of the findings reported here is a major issue to be pursued. There is a clear need to extend the period of observation for as long as possible or until signatures disappear. Collection of photographs at a temporally high sampling rate is desirable to address the issue of short term change in signature features observed here. The research agenda should also examine how robust the results are to variation in soil types, vegetation, weather variables, season, climate, etc.

This exploration appears to have scratched the surface of a set of complex, but tractable, phenomena of practical importance. It has led the previously naïve authors into soil science to interpret the phenomena at hand, and plans for future work involve collaboration with soil scientists to exploit the knowledge and understanding of their field to guide upcoming studies. Given the dimensions of generality it seems prudent to investigate, taking a broad multidisciplinary approach that also engages specialists in geophysics, botany, climatology, etc. seems both necessary and likely fruitful.

Dissemination of Findings

Findings of this project have been disseminated via conference presentations by the PI at the 10th Annual Army Landmine Detection Research Review Meeting and a Symposium titled Detection and Remediation Technologies for Mines and Minelike Targets XII. Another presentation is scheduled for the 2007 UXO/Countermine meeting to he held in late August 2007. Finding are published in the proceedings of SPIE--The International Society of Optical Engineering under the title of the above symposium. In addition, COL Robert Nicholson has received copies of the presentations and paper listed above.

Extension and Expansion of Effort

The results produced in this initial effort have proven sufficiently promising and provoking relative to the research questions addressed to motivate a second round of data collection, for which preparations are well under way. This follow-up effort is intended to generate a photo and data archive more complete than this initial problem-plagued effort has produced.

Dissemination of information about project goals and findings has led to an expansion of the number of investigators working on this effort as well as the funding available to exploit the knowledge gained thus far and continue investigation of the phenomena of interest.

Included in this effort is a group of environmental scientists from Lincoln University. This group brings technical expertise to understanding the effects of landmine emplacement and the changes the resulting signatures undergo in vegetated areas. They have also contributed financial support to purchase instrumentation that will enable precise measurement of local subsurface soil variables (moisture content and temperature) and meteorological variables predicted to relate to changes in the visual properties of signatures.

Lessons learned from instrumentation problems described above heavily influenced the selection of a technical team to design and field test a new photo acquisition and archival system locally and to install and service of the system at the Fort Leonard Wood test site. This team consists of an expert in scientific time-lapse photography, a photography expert, and two individuals with expertise in software and computational system integration. System design and purchase of all photographic equipment was completed early in the fall and as of the end date of this contract outdoor testing began. A description of the system, the Networked Time-lapse Photography System, and its main components follows. As of 30 June 2007, the system has proven to be robust.

Use of a new test area adjacent to the original area has been approved by NVESD and site preparations are under way for a July 2007 installation of the system. Following a successful 2-3 week on-site shakedown of the system, mines will be buried and another round of signature acquisition and analysis will begin.

Networked Time-lapse Photography System (NTPS):

C& V Innovations (CVI), Inc. contracted to provide a data collection and display system for the Visual Cues for Landmine Detection project funded by the ARO. Prior attempts at collecting a baseline data set failed due to irresolvable technical setbacks by the previous vendor. CVI performed an in depth analysis of the previous system’s limitations and technical issues and collaborated with Mr. Ted Kinsman, recognized authority in time lapse photography, to design and build the Networked Timelapse Photography System (NTPS).

The NTPS is a networked, fault tolerant and versatile solution to collect data and present it for analysis. There are three primary layers of the system, the acquisition layer, the transport layer, and the display layer. The system's form and function is similar to many video surveillance systems on the market today. In a standard surveillance system at the acquisition layer, a camera collects video data; then in the transport layer, the data is transferred to a remote server, and is then made ready for review at the display layer. In the acquisition layer of the NTPS, a control server controls the data collection devices and collects data from the cameras, soil moisture sensors, and an on-site weather station. Then the data are transferred via internet to a server housed offsite for storage. At the display layer, the data is prepared for review and analysis. Furthermore, remote access to the system through the onsite network connection provides the capability to monitor the data collection and perform advanced troubleshooting.

The NTPS is designed to require minimal onsite support. Ideally support tasks will be limited to cleaning the enclosures on a bi-weekly basis and visually inspecting the cables and connections for signs of erosion or tampering. The most complicated task foreseen at this stage is restarting all systems due to an extended power failure, which exceeds battery backup capacity.

Acquistion Layer

The acquisition layer components will be housed onsite at a secure field test site at Ft. Leonard Wood, Missouri. The components consist of a custom enclosure containing a control server, network equipment, fault tolerance equipment, high resolution digital cameras also housed in custom enclosures, Decagon moisture sensors, and an ADA Weatherpod.

The custom enclosure is designed to withstand environmental conditions in all seasons. The system enclosure is foam insulated, weather resistant, and outfitted with a custom HVAC system to control the internal climate of the enclosure. Furthermore, the enclosure is outfitted with a lock and can be secured to prevent tampering.

The control server was custom built with a fault tolerant backup drive and can survive a single catastrophic hard-drive failure and still maintain data integrity. The server hardware has been configured to turn on the system as soon as it detects sufficient electrical current in the event of power interruption or extended loss to limit the need for onsite support. The control server uses the Microsoft Window XP Pro operating system and runs various programs that control and collect data from all of the devices. A program developed from the camera manufacturer's software developer's kit controls four high resolution cameras. The software runs as a series of threads, all working together to achieve stable, consistent time-lapse photography. This program is fault tolerant and designed to automatically respond to errors encountered during the beta testing phase of the system development. The program provides a GUI (graphical user interface), which allows a user manually controls the firing of the cameras, setup different time-lapse photography intervals with begin and end times, and troubleshoot system errors. The moisture sensors and Weatherpod are controlled by the software provided by the manufacturers.

The network equipment housed in the enclosure will consist of networking equipment provided by a contracted vendor such as a modem and router configured with static IP addresses to allow direct access to the equipment onsite.

The fault tolerance equipment includes a UPS (Uninterruptable Power Supply) battery backup and a remote power switch. The UPS battery unit at full capacity will be able to support the camera system and control computer for approximately 1-2 hours to ensure continuous functionality of the system through power fluctuation and short power outages. The remote power switch is an essential fault tolerance component. This device allows the control computer to power cycle malfunctioning devices. Furthermore, in the event that the control server freezes and becomes unresponsive, a technician will be able to remotely power cycle the control server and attempt to mediate the issue.

Transport Layer

The transport layer will rely on a reliable network connection at the acquisition site and at the storage site at Carnegie Mellon University (CMU). A FTP (File Transfer Protocol) program running on the control server at the acquisition site will collect the data sets from the cameras, moisture sensors, and Weatherpod from their locations on the hard-drive and transfer them to the offsite server at CMU. File transport will occur throughout the day and during the nighttime maintenance window each day.

Display Layer

The display layer consists of a single piece of equipment, an Event Triggered Camera system manufactured by KBport LLC. The ETC is a highly specialized server created for the collection, integration, display, and analysis of data from multiple data sources using proprietary software. Assuming no issues with the transport layer, the ETC will collect, organize, and can display captured data in real time. The ETC brings all of the collected data from the cameras, moisture sensors, and Weatherpod into one easy to use web based interface. The ETC server interface can be remotely viewed and worked on by multiple users in local and remote locations simultaneously. The ETC is an intelligent database and can track and tag factors according to parameters set to quickly organize datasets for analysis.

Due to the nature of the exploratory analysis anticipated, the GUI and underlying database were designed very simplistically so that both can be customized for different types of analysis. The ETC can essentially morph into any type of interface required for analysis. Each user is assigned their own unique user id and all of the data from different analyses can be stored in one comprehensive dataset which can searched, sorted, and ultimately exported to various analysis packages such as Matlab and SPSS after further development..

The ETC supports the use of multiple interfaces for different types of analysis as well as a video mode for fast playback of large ranges of time.

Dissemination

Findings of this effort have been reported as conference presentations at the 10th Annual Army Landmine Detection Research Review Meeting and the Detection and Remediation Technologies for Mines and Minelike Targets XII symposium. A presentation is scheduled for August 2007 at the 2007 UXO/Countermine Forum. Findings have also been published as Staszewski, Davison, Tischuk, and Dippel (2007).

Results and progress have also been reported to COL Robert Nicholson, TRADOC Capability Manager Assured Mobility, Fort Leonard Wood, who provided critical encouragement and support for the execution of this work.

Implications Beyond Landmine Detection: Broader Army Mission Relevance

This work holds relevance for two US Army missions beyond landmine detection. First, a presentation of preliminary findings to US Army Engineer School senior officers has suggested to them the applicability of this approach to the problem of detecting Improvised Explosive Devices. Plans to apply findings from this work to this related area are ongoing.

Second, recruitment and contact with the Director of the Tactical Tracking Operations Training Program, Mr. David Scott-Donelan, has revealed the dual relevance of the findings and approach of this project for training military personnel in tactical tracking. Due to the possibility that teams engaged in tracking operations may encounter mined areas, developing trackers' ability to detect emplaced landmines by visual means can enhance both the chances of mission success and the physical safety of the personnel involved. Informal investigations of visual landmine detection capability and approaches to develop it have been initiated at Fort Huachuca, a site where tactical training skills are trained.

This project is relevant in another way to tactical tracking training. Both visual detection of buried landmines and tracking operations share important general characteristics. In both, successful performance depends upon effective visual detection and interpretation of disturbances to ground surfaces. As current results have shown, the visual cues related to landmine signatures vary with time and environmental conditions. As taught in tracking training, the visual cues that identify human tracks show similar variability and context specificity. There have been no systematic studies of how tracks change as a function of time and weathering, as has been the case for visual landmine detection. It follows that tracking training programs could benefit from a systematic study and documentation of the visual cues that support effective tracking. For a specific example, detailed photographic records of how human tracks appear and change have acknowledged value as training materials. In addition, discussions with Scott-Donelan auggest potential benefits of applying the cognitive engineering based on expert skills approach employed in this project to tracking as a potential way to enhance training.

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