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Distinguishing Purposefully Disturbed Soil from Other Anthropogenically and Naturally Modified Soils

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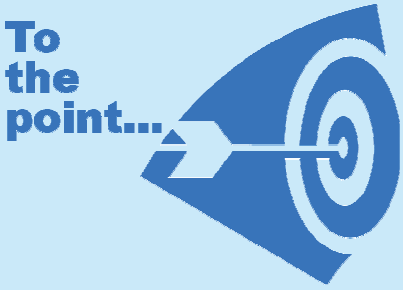
BACKGROUND: In the context of countering distributed munitions, remote-sensing technologies are being advanced to detect "disturbed soil." However, the term "disturbed soil" has been used by various groups of warfighters and researchers to mean soil modified by many types of human and natural activity. In published literature, soil near international points of entry has been called "disturbed" because human foot traffic has changed its original surface characteristics, especially reflectance. The term "disturbed soil" has been used to describe soil-surface characteristics modified by tire-tread marks, game trails, garden plots, and grading of low-volume roads.



In the context of force protection, we recommend limiting use of the term "disturbed soil" to soil that has been disturbed purposefully during current or very recent human activity (few days) with clandestine or malicious intent. This note introduces alternative terms for soil that has been changed by other anthropogenic or natural activities, and lists properties to distinguish among types of disturbed and modified soil. Understanding active and historic processes of change within the soil profile contribute to the overall mission of improving sensor performance.

To address the need to detect "disturbed soil," it is important that stakeholders, researchers, and field operatives have a shared and consistent understanding of what constitutes "disturbed soil." The dominant use of the term has been to designate soil that has been recently and purposefully disturbed for military purposes or unfriendly clandestine activities. Use of the term "disturbed" to denote soil with a myriad of unintentional or engineered changes creates inconsistency and leads to misunderstanding about use of detection technologies.

Inconsistency in use of the term "disturbed soil" prompted us to characterize and define multiple categories of disturbed or modified soil, and to assign unique terms to each category. Each source of soil modification has the potential to create a unique or at least characteristic set of properties and define a "material" that can be distinguished from other materials by a sensor. The following paragraphs explain a consensus classification of four types of disturbed and modified soil.

DISTURBED SOIL: The term "disturbed soil" is hereafter reserved for soil that has been recently and intentionally disturbed by human activity. This first category represents purposeful

disturbance of a very limited extent (centimeter to meter scale) and usually less than 50 cm deep. Further, the soil has been disturbed during current or very recent activity (past few days) with clandestine or malicious intent. The total volume of soil involved in the disturbance is small (usually < 1 m^3).

Boundaries of the disturbed material usually are sharp, but because of the shallow depth of disturbance, properties of the disturbed material may not differ markedly from those of undisturbed soil (minimal co-mingling of different material types). Disturbed soil can be visible at the surface; however, it is so limited in extent and readily disguised that it is often visually obscured from surface observation. With time, weather changes, or as a result of purposeful attempts to mask the disturbance, the detectable properties or characteristics of disturbed soil (such as temperature, reflectance, or moisture content) may revert to those of the original state of the soil. This type of soil disturbance is of intense interest in military operations, especially for countering distributed munitions threats.

UNINTENTIONALLY MODIFIED (UM) SOIL: The second category is unintentionally modified (UM) soil. It is called "modified" to reserve the term "disturbed" for soil as described above. UM soil can be generated by either human or natural activities. Examples of human-caused unintentional modification are tracks left by walking or moving vehicles on the soil surface. Examples of natural unintentional modification include animal footprints, trackways, and burrows, among others.

UM soil commonly is visible at the surface, and often is revealed in images generated from data gathered by light detection and ranging (LiDAR) and other surface-sensor technologies. A volume of UM soil usually is < 25 cm deep (although animal burrows can be meters deep and only centimeters in lateral extent). Soil type, weather, and rainfall also influence the depth of unintentional disturbances. Deeper disturbances occur in wet weather or muddy soils (soils with abundant clay-size particles). Areas of UM soil can be uniform in extent or highly linear (a few meters to kilometers in linear or lateral extent), but usually are limited to surface layers of soil.

UM soils typically result from repeated activity of a certain type, such as daily human or animal foot traffic. These activities are recent or current. Where the disturbance is repetitive, the characteristics of UM soil are continuously renewed, rather than being destroyed by wind or water.

ENGINEERING-MODIFIED (EM) SOIL: Engineering-modified (EM) soil, the third category, can represent historic or recent human activity. It is soil disturbed for human engineering purposes, such as road building, waste burial, foundation modification, or construction. It differs from UM soil not just in origin but also in its depth of disturbance, total volume of soil disturbed, and co-mingling with previously distinguishable soil material types in the subsurface.

Engineering activities may add non-local soil types to the soil profile, such as gravel added to roadways or clay caps for waste-burial pits. Historic EM soil can be obscured from surface observation (buried many meters), but may be revealed by sensors that penetrate the subsurface. The depth of disturbance often depends upon engineering properties of the soil, such as bearing capacity and water infiltration rate, which control the depth of modification required for a

successful engineering project. A volume of EM soil usually has sharp boundaries with surrounding material types both laterally and vertically.

AGRICULTURE-MODIFIED (AM) SOIL: The fourth category is agriculture-modified (AM) soil. AM soil can represent historic, recent, or current human activity and is usually comprised of multiple types of local undisturbed soil materials that have been co-mingled by plowing, often to depths of several meters or more. The depth of co-mingled soil, its lateral extent (areas from garden plots to farm fields), its large total volume, and the characteristic shape of agricultural fields distinguish AM soils from other types of modification or disturbance.

Particularly in areas of the world with multi-century agricultural civilizations, the depth of AM soil can be several to tens of meters. Past agricultural practices in these areas allowed rivers to flood fields annually, replenishing the soil with new sediment. Thus, new material was added to the fields for centuries, and co-mingled with older sediments by plowing. The resulting AM soil can be a single material type present at or near the surface and extending to a multi-meter depth.

EXAMPLES OF MODIFIED SOILS IN IMAGERY: Table 1 lists the categories and characteristics of the four types of disturbed and modified soils described in the previous paragraphs. Figure 1 shows an example of an image generated by LiDAR that reveals marks left by a few vehicle passes, creating UM soil. Photographic imagery may reveal the outlines of historic agricultural fields (AM), as well as EM and UM soils, as shown in Figure 2.

Table 1. Distinguishing characteristics of four categories of disturbed and modified soils.

Category	Age of Modification	Depth	Shape	Lateral Extent	Loss of Stratigraphy at Depth	Visible at Surface
Disturbed	Very recent (hours to few days)	50 cm or less	Close to equi-dimensional	Very limited, usually < 1m	Only surface layers affected	Yes/no: depends on success of attempts to obscure
Unintentionally modified (UM)	Recent (days to months)	Commonly < 20 cm	Equi-dimensional to linear	Can be tens of meters to multi-km if linear	Only surface layers affected	Yes
Engineering-modified (EM)	Historic to recent	Up to multi-meters but usually < 1 m	Equi-dimensional to linear	Multi-meters	Yes; full depth of engineering modification usually well defined	Yes, if recent; often no if historic
Agriculture-modified (AM)	Historic to recent	Usually multiple meters	Farm fields	Tens of meters (historic) to km (recent)	Yes; soil units co-mingled to full depth of historic plowing	Yes, unless farming ceased centuries ago or area obscured by recent cultural clutter

SIGNIFICANCE OF TYPES OF SOIL DISTURBANCE AND MODIFICATION: The processes that formed any volume of disturbed or modified soil control its depth and lateral extent, as well as the sharpness of its boundaries with other material types. Understanding processes and presence of disturbed and modified soils is critical to interpreting sensor data. Two or more types of disturbance and modification can be superimposed, as was true in the sampling area shown in Figure 2. LiDAR of part of the study area revealed shallow vehicle tracks (UM soil) superimposed on both EM and AM soils.

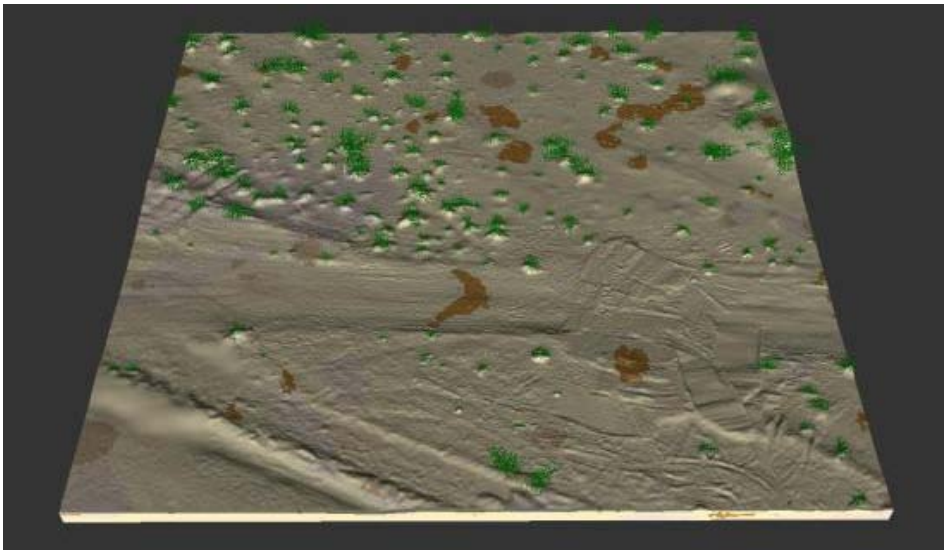


Figure 1. Tire marks (middle to lower right) revealed in LiDAR imagery of UM soil.

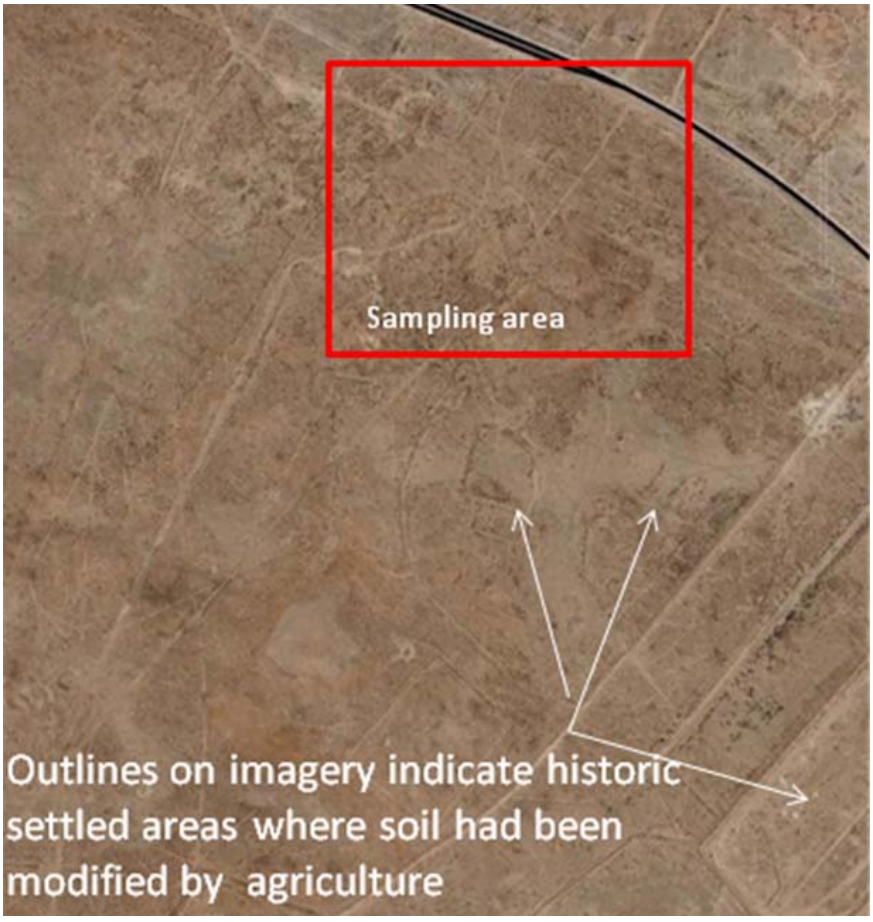


Figure 2. Image from a middle-eastern desert showing historic areas of AM soil (white arrows). EM and UM soils appear within the soil-sampling area indicated in the figure, which includes a paved highway with adjacent soil berms (EM soil), lightly graded low-volume roads (EM), and evidence of other human activity (UM).

Military units are aware that small areas of disturbed soil associated with distributed munitions threats are commonly superimposed on the EM soil of roadways. Almost any combination of disturbed and modified soil is possible, and multiple sources of surface modification have the potential to mask the signature of a small area of disturbed soil relative to a given sensor.

Further complicating the issue in areas of sparse vegetation, geo-environmental factors such as wind or heavy rainstorms may move large quantities of soil rapidly. Within hours, surface features are visually obscured, and soil signatures change relative to sensors.

Modification of soil by human and other natural activities creates unique or at least characteristic sets of soil properties and defines "materials" that can be distinguished from other materials by a sensor. Thus, understanding active, recent, and historic processes of change within the soil profile contributes to the overall mission of improving sensor performance. Consistent terminology to distinguish among types of soil disturbance and modification is intended to improve communication among groups working toward improved detection of distributed threats in areas of military operations.