Mine Detection Sensors

By Jim Smith

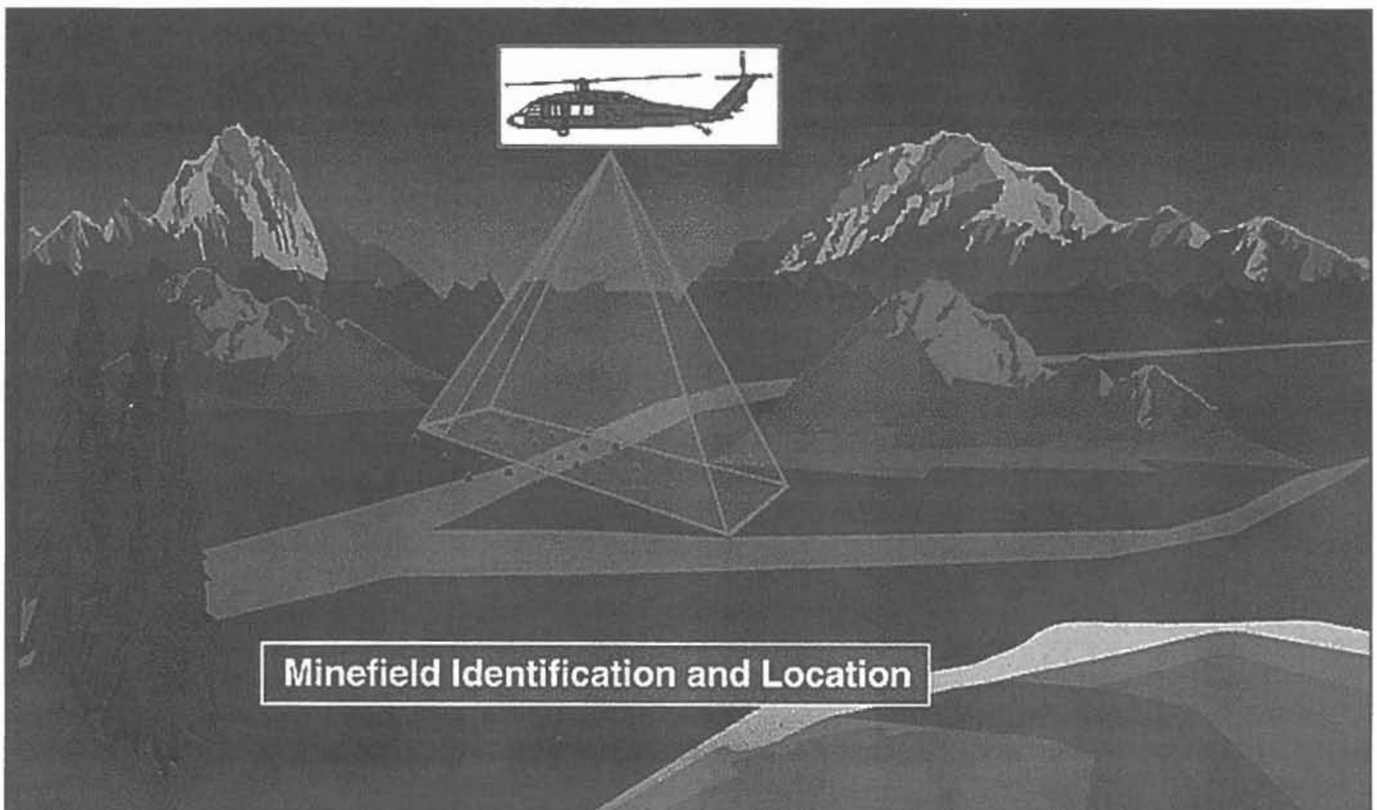
Over the past century, land mines became an inexpensive, effective means to stop enemy movements and demoralize personnel. Deployed and stockpiled, they number in the hundreds of millions. They will continue to pose a threat to soldiers and civilians alike for generations. To combat their threat, countermine efforts have pursued numerous mine-detection approaches. One result is the fielded handheld AN/PSS-12 metal mine detector. The "silver bullet" solution to mine detection has eluded our efforts.

Why is it so difficult to find an object buried just inches underground? One reason is that Mother Nature provides an endless number of roadblocks in the way of environmental factors that change hourly. Also, mine manufacturers produce an almost infinite variety of mine features such as size, shape, and composition. Their only commonality is the intent to thwart effective mine detection. Technological approaches often fail to meet all of the combat developer's requirements. Often, the solutions are too big, too heavy, or too slow to meet requirements. Finally, countermine program funding is usually too low and fluctuates with demands for other military equipment.

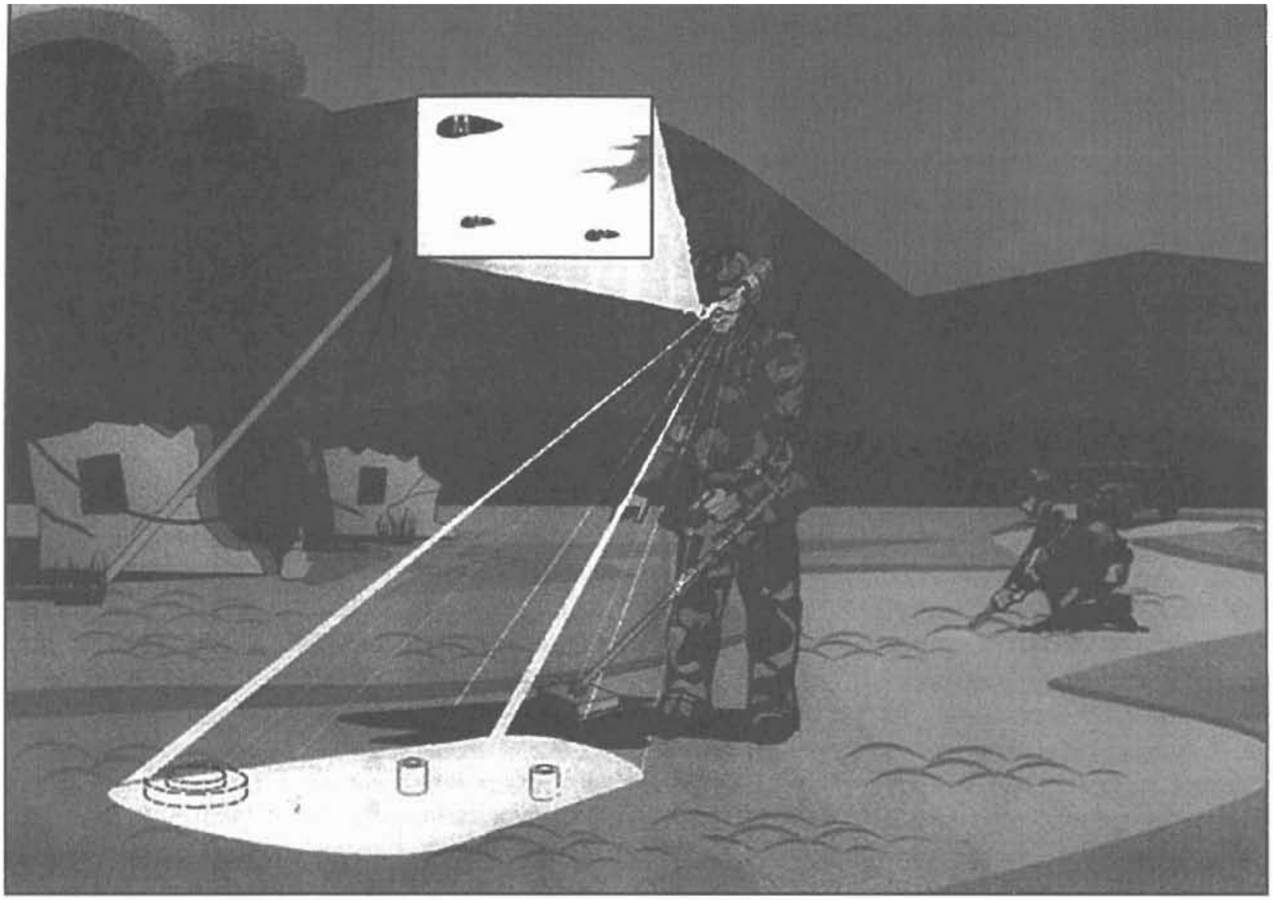
The Defense Science Board of 1987 suggested three technologies with potential to meet the mine detection challenge:

- Metallic detector sensors.
- Ground-penetrating radar (GPR).
- Infrared (IR) sensors.

All three technologies are useful in mine detection, but they have latent limitations that impact the mission. One common point is that none of them is



ASTAMIDS consists of sensors (IR or IR and laser) mounted on either fixed or rotary-wing aircraft and helicopters. Data processing (minefield detection) will occur onboard a helicopter or in a ground control station.



HSTAMIDS is a multisensor handheld mine detector that will replace the AN/PSS-12. The "standoff" sensor is a FLIR. A metal detector and GPR sensors are mounted on a wand similar to the AN/PSS-12.

specifically a mine detector. They are anomaly detectors, because they look for metal, ground density, or thermal anomalies. By judicious use of equipment coupled with visual cues, an experienced mine sweeper can find many (if not most) mines under varying soil, weather, vegetation, and topographic conditions. Of course, there is no perfection in this world, so some mines may be missed. The challenge is to know when and how to use the various sensors for the best results.

Other technologies are emerging from industry, universities, and the government. These will be evaluated for technical potential as well as operational utility, and we will need lessons learned about them. We can assume that each will have some strengths and some weaknesses. Many are so new that it will take years to prove their capabilities.

Our mine-detection capability will improve when the Army fields three emerging Standoff Minefield Detection Systems (STAMIDS). They are—

- Airborne STAMIDS (unmanned aerial vehicle (UAV) or helicopter-mounted) is scheduled for fielding in FY02.
- Handheld STAMIDS (the replacement for the AN/PSS-12) is scheduled for fielding in FY03.
- Ground STAMIDS (vehicle-mounted) is scheduled for fielding in FY06.

A brief description of the sensor technologies used in these systems and how they are fuzed together follows.

Metallic Detector Sensors

The theory is simple. Although there are different metal-detection technologies (such as balanced bridge and metallic induction), the basic concept remains the same: As the detector head moves over a metallic mass, the detector senses a change in the magnetic field under it. This initiates an audible signal (and often a visual signal for reduced noise operations), which alerts the operator. By moving the detector head forward/back and left/right, the location can be narrowed to within a few inches. Mine and "coin" detectors share many characteristics, but the capabilities of coin detectors pale by comparison. Today's advanced mine detectors find minuscule metal traces, are hardened for rough field use, and some can be used underwater.

To some extent, metallic detectors are our most dependable workhorses. They are not subject to error from soil moisture and other weather-induced variables. If all mines possessed enough metallic content, metal detectors would be adequate as stand-alone sensors. Unfortunately, mine construction is veering from large, metallic bodies to small, nonmetallic mines. Lightening and reducing mine size decreases the cost, weight, and manpower needed to transport and employ the mines. Gluing metal onto nonmetallic mines is one answer, but it is expensive and labor intensive. In addition, there is no way to control the mine producers and users to ensure that all mines receive the metal tab. We foresee more nonmetallic mines in the future, because they defeat metallic sensors.

The AN/PSS-12 evolved out of an effort to find low metallic content mines. In use by many NATO and U.N. forces, it proved itself in Operation Desert Storm, Somalia, Haiti, and in Bosnia. Along with its improved maintainability, cheap operation, and interoperability among friendly forces, the AN/PSS-12 detects minuscule metal amounts. However, it has two major shortfalls that are common with all handheld mine detectors:

- It is "look down" only (it must be within inches of mines to detect them).
- It cannot find totally nonmetallic mines.

Finding mines from outside their lethality distance is a critical detection survivability objective.

Ground-Penetrating Radar

The GPR sensor is typical of all radars. It includes two antennae: one to broadcast an active signal through the ground and another to receive the reflected signal that bounces off whatever is in the ground. These bounced-back echoes are plotted to trace the surface texture of the target. Homogeneous soil sends back a flat image, but add a mine and the picture changes. The mine body, buried in the same homogeneous soil, disrupts the soil density. It reflects an active signal which, in certain radar designs, can actually trace the mine surface much like a topographic map.

One radar developed by the Lawrence-Livermore Laboratory may penetrate the mine housing, search for component planar arrays, and possibly identify the mine by its characteristic planar structure—essentially its fingerprint. This is the high end of advanced radars. To date, it is unproven and requires a detailed mine-construction database.

GPRs are limited by distance from the ground surface and do not work well in conditions of high soil moisture. They work best with aspect angles of "near nadir" (+/- 5 degrees from the vertical); performance drops off as the angle off

GSTAMIDS is a multisensor vehicle-mounted mine detector. It is in concept exploration with development scheduled to begin in FY98. This concept drawing shows GSTAMIDS mounted on a teleoperated HMMWV. The actual system will be different.

the vertical increases. As such, almost all GPRs can be characterized as "look-down" detectors. This requires the sensor to pass over the mine to detect it. Look-down sensors may accidentally trip the mines, thereby detecting the mine by losing the sensor. Also they are slow because every inch of the mined area must be "viewed." A few emerging "look ahead" GPRs promise increased standoff and detector/crew survivability.

Infrared Sensor

Military forward looking infrared (FLIR) sensors search for thermal anomalies. A FLIR can find an active heat source quite easily. A main battle tank silhouetted against vegetation or clear sky is easily detected, but it is more difficult to differentiate between passive thermal targets. Passive targets are those that receive heat from another source (typically solar loading for mine detection). The ability of an object to radiate its heat is impacted by many factors, including size, construction material, and soil moisture. A metal mine radiates heat at a different rate than a plastic mine beside it, as does the soil on which it rests and vegetation and water nearby. This enables a FLIR to "photograph" a scene from its passive, radiated electromagnetic energy.

On the surface, it appears that a FLIR may make an admirable mine-detection sensor, especially since IR is a true "look ahead" sensor. A camera enables the user to take photos from a distance; this is the same concept—just a different slice of the electromagnetic spectrum. Visible light is 0.4-0.7 millimicrons, short-wave IR is 0.7-1.2 millimicrons, medium-wave IR is 3-5 millimicrons; and long-wave IR is 8-12 millimicrons. Most mine-detection sensors are in the medium- and long-wave IR portions of the spectrum. The 3-5 range works in most areas and reduces the number of false alarms because of its narrower sensitivity. The 8-12 range is more sensitive, but it has a higher false-alarm rate.

IR has technical limitations. It requires solar loading to develop passive heat signature. As the sun moves throughout the day, shadows from trees, buildings, and other solid objects move. This changes the amount of solar loading available to a mined area. Cloudy days lower or eliminate solar loading. Precipitation reduces the dielectric at the soil/mine interface. Any object (such as a rock, beer can, or lost wheel cap) buried in a given soil type has its own thermal signature. Additionally, IR sensors can't "see" through solid objects (such as foliage); they require optical access to mines or at least to the soil over mines.

As the sun rises, mines and their environment soak up solar heat at different rates. During the morning, cold mines show well against the warmer soil. During the evening, warm mines show well against rapidly cooling soil. At full night and around noon, mines and their background environments are at roughly the same temperatures; hence, no thermal signatures.

The FLIR is essentially blind at certain hours, but has excellent vision at other times. Having the flexibility to use the sensors only when they work well makes IR an excellent tool. Unfortunately, soldiers must conduct operations throughout the day and under all weather conditions. The trick is to use IR when it is most effective and plan mine-detection operations around its best target of utility.

Sensor Fusion

There is one important option in using the three sensors discussed in this article: We can take each sensor's output, combine the best features of each, and process them using a mature algorithm. By processing data from each sensor into an integrated whole, we keep their strengths and filter out their weaknesses. At times, the processor must ignore one sensor and use the remaining two. This sounds easy, but developing complex processors and efficient algorithms is as difficult as developing complex sensor technologies. A few commercial companies entered the market during the early 1990s, and today we have high-speed processors that can handle the huge data influx from the sensors. Companies with in-depth countermine experience are working diligently to improve their sensor fusion algorithms. Algorithm development remains the long pole in the tent for mine detection.

Conclusion

Mine detection is a complex, difficult task we are working to solve. The challenge to materiel developers is tremendous. Combat developers (in this case the Engineer School) often establish stringent operational requirements. Our intent is to provide a family of robust mine detectors that will safeguard the force. Combat and materiel developers are working together to achieve this goal.

Jim Smith is a countermine combat developments materiel analyst at the Engineer School. He has 32 years of military/retired service with nine years of countermine experience. Mr. Smith holds a bachelor's degree in earth science.