NONDESTRUCTIVE EVALUATION APPLIED TO LANDMINE DETECTION

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BACKGROUND

The readers of the popular press need little introduction to the worldwide scourge presented by landmines. These insidious devices have been characterized as one of the largest pollution problems created by mankind. The number of mines scattered over regions in most continents and their overall destructive threat make the detection and elimination of land mines of critical importance to humanity.

Nondestructive evaluation technologies offer useful assistance in the location of landmines. When compared to most NDE applications, however, their use in mine detection has many major differences. These are primarily related to the approach that is used in traditional NDE applications. For example, most NDE work is done with a clear understanding or characterization of the type of flaws or defects to be studied. This includes an understanding of the size, shape, type, location, orientation, etc. of the sought-after flaw or defect, as well as a good characterization of the surrounding matrix in which the flaw may be located.

This is definitely not the case when searching for landmines. Land mines may be:

- a wide variety of shapes and sizes
- made of various containment materials including metal, plastic, and wood
- located anywhere from the surface to 10's of centimeters below
- located in a soil matrix that may be very inhomogeneous over small distances and contain features that look like mines

Finding and destroying mines is a very difficult and hazardous business. The problem addressed in this report is finding landmines with a high probability of detection (POD) and a low false alarm rate (FAR) without the requirement of having landmine detection personnel in the immediate area.

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Typically the detection parameters go together; efforts in increasing the POD often also increase the FAR. Reduction in the FAR is often accompanied by a reduction in the POD. By using the advanced system approach described in this report, the POD can be significantly increased, while, at the same time, the FAR is greatly reduced.

This report focuses only on large anti-tank landmines, both metallic and those containing minimal metal. This limitation is acknowledged, although much of the technical approach and methodology could be used for other types of landmines and for unexploded ordnance.

PROGRAM GOALS

The overall program goal is to provide an integrated system of complimentary sensors on a tele-operated vehicular platform, mathematical data analysis algorithms, and location marking apparatus to provide real-time autonomous detection of landmines.

Specific program goal details include:

- Mine detection is performed while the vehicle is in a forward motion at a minimum detection speed of 3.6 km/hour (on road) and 2 km/hour (off road)
- Detection of anti-tank mines of various shapes, sizes, and compositions (both metallic and those of minimum metal) at burial depths up to 15 cm from the surface within a 3 meter wide inspection swath as the vehicle moves forward
- The probability of detection shall be 95% or greater and the false alarm rate shall be 0.04 or less per meter of forward progress (on road) and 0.15 or less per meter (off road)

A SYSTEMS APPROACH

A concept drawing of the integrated system is shown in Figure 1. This approach was chosen because it uses a remotely operated autonomous vehicle, which significantly reduces the potential personnel hazards involved in mine detection. The tele-operated vehicle is controlled from a remote command vehicle located at a safe distance away from the area where mines could be found. Navigation commands are sent from the command vehicle and sensor data is sent from the tele-operated vehicle to the command vehicle.

A variety of mine investigation technologies for detection *and* confirmation are integrated onto this platform. The system operates in one of two fundamental modes: scanning (while the vehicle is in motion) and confirmation (performed while the vehicle is stopped). As described below, the use of the confirmation sensor is essential in FAR reduction.

The non-intrusive detection methods used in the system are:

1. A 3-meter wide pulsed induction metal detector (MMD)

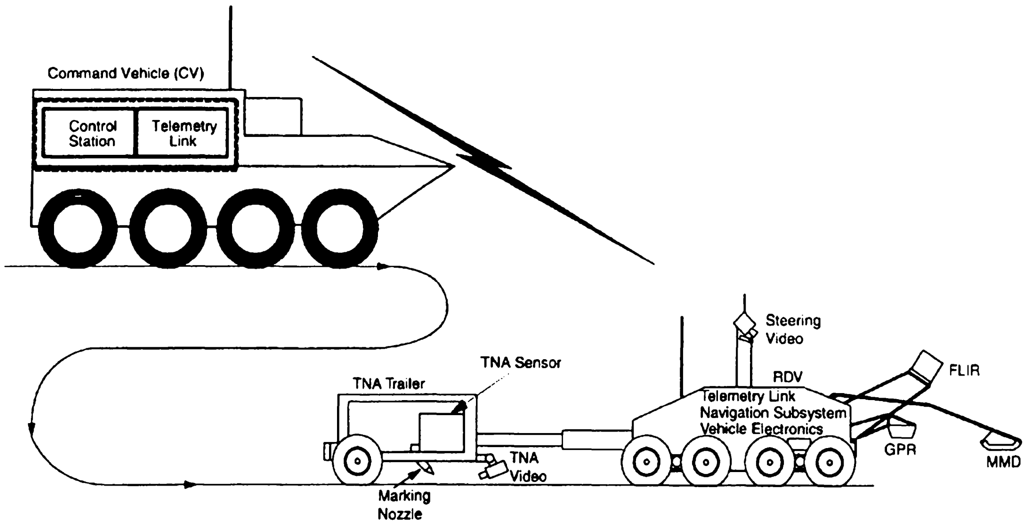

Figure 1 System concept.

2. A 3-meter wide ground penetrating radar (GPR)
3. Forward looking infrared and visible optical sensors (FLIR)
4. Thermal neutron analysis (TNA)

The system also contains a device used to physically mark the surface location where a mine may be located (observable day and night) as well as differential GPS (DGPS) for electronic marking.

INFORMATION GAINED AND DATA ANALYSIS

Each type of sensor provides data on the presence _or absence_ of physical properties that accompany the presence _or absence_ of landmines. The sensor suite is capable of detecting:

- metal components of the mine (MMD)
- materials (including metal, plastic, wood, etc.) that have dielectric properties different than the soil matrix where the mine is located (GPR)
- disturbances in the thermal properties of the soil matrix (FLIR)
- presence _or absence_ of relatively large amounts of nitrogen found in the high explosives in the landmine (TNA)

Data from all of the sensors are used with advanced analysis algorithms to achieve the desired high POD and low FAR.

In addition to the physical property data, the integrated system provides information for navigation and marking of locations considered having a high probability of containing a mine.

Figure 2 illustrates how the multi-sensor data are used in identifying these high probability locations. It shows a stylized view of

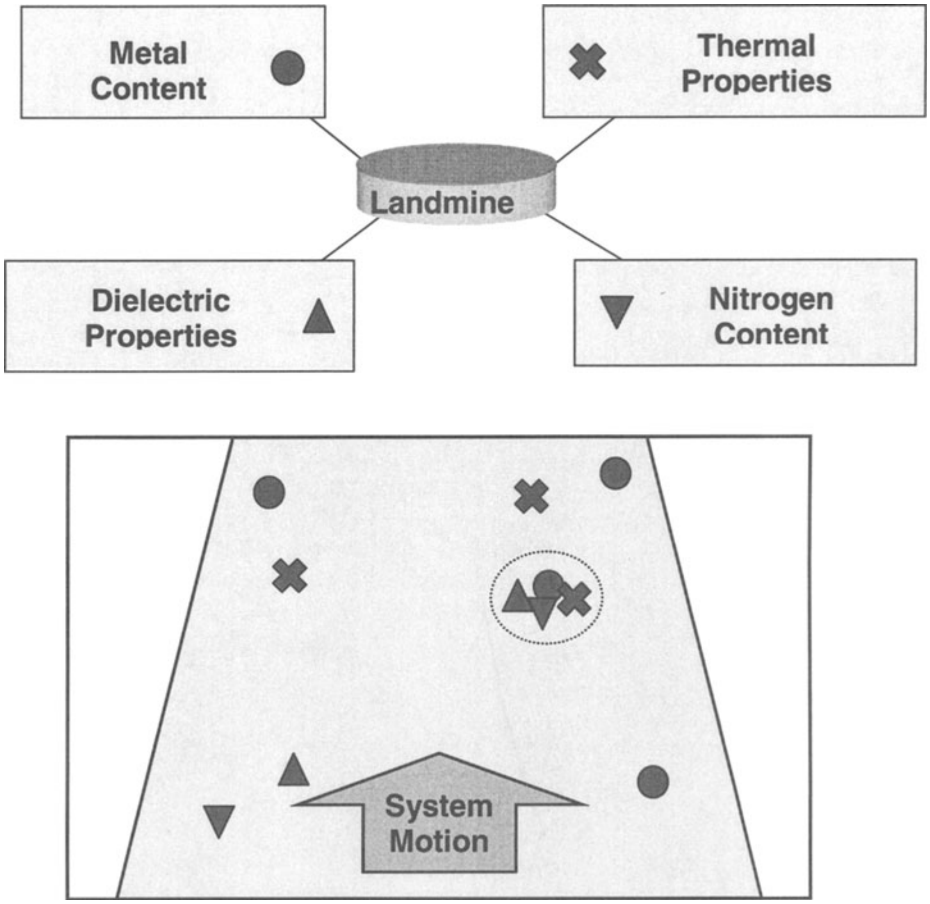

Figure 2 Multi-sensor data fusion.

what a system operator would see. As the autonomous vehicle moves in a forward direction, each sensor "measures" a different, complimentary characteristic. In some locations only one of the characteristic sensor signatures are detected. These are likely the result of interfering "clutter". When all of the characteristic signatures occur in one location, this indicates a high likelihood of a mine being present at that location.

All data are registered in a common reference frame so that they can be evaluated for spatial correspondence. The data sets from each detector in the sensor suite are used in data fusion and spatial correspondence algorithms to provide a physical location with a high probability of containing a landmine. The location can be provisionally marked, either physically or using DGPS, to indicate the possible location of a landmine.

The next step is to confirm the presence of a landmine through thermal neutron analysis. Note: TNA is the only detection method that measures the single constituent that is common to all landmines, i.e. the high explosive material. All other sensors detect materials and/or conditions that *may* be associated with a land mine being present.

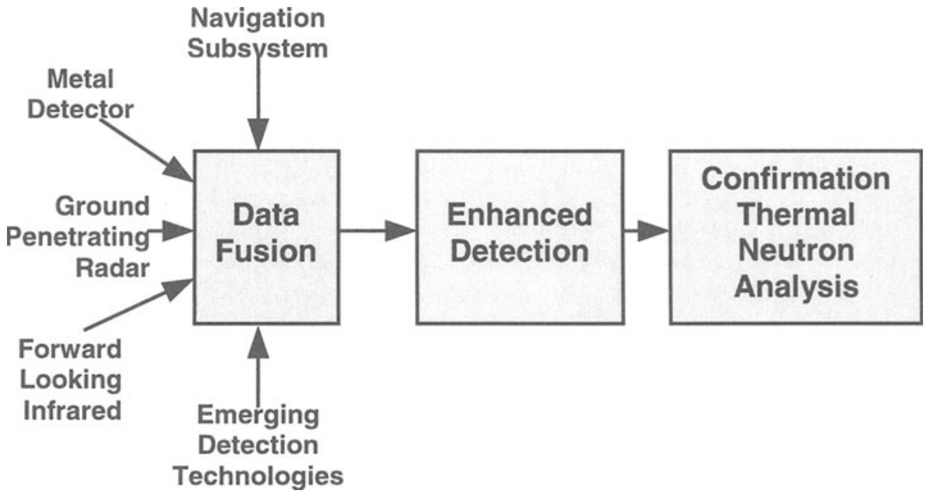

Figure 3 Data analysis process.

Figure 3 contains a block diagram of the data processing sequence. Data fusion uses information from the three scanning sensors, as well as from the navigational subsystem. Furthermore, the system has been designed so that advanced sensor technology can be easily added as new sensors are developed. The block labeled "Enhanced Detection" denotes the result from the data fusion process.

The following block, "Confirmation Thermal Neutron Analysis", is the final component in the analysis process which confirms the presence or absence of nitrogen associated with high explosives. The confirmation measurement is made with the vehicle stopped and the TNA device accurately placed over the location considered to contain the landmine. Measurement times are less than one minute. This confirmation allows final marking (physical and electronic) for subsequent mine removal/destruction.

DISCUSSION

This paper presents the description of a fully integrated system for the detection of anti-tank landmines. Data from three state-of-the-art area survey sensors (MMD, GPR, and FLIR) are used with advanced data fusion to identify and mark those locations with a high probability of containing a landmine. The unique feature of this system, compared to other mine detection systems, is the use of thermal neutron analysis as a confirmation tool to reduce the number of false indications. Furthermore, differential GPS electronic marking and physical marking clearly indicates the location where a mine is likely to be found. Through the use of this system, landmines can be located with a high degree of confidence associated with a high probability of detection and a low false alarm rate.

Although designed for large anti-tank mines, much of the technical approach and methodology could be used for other types of landmines and for unexploded ordnance.

Results of recent field tests have shown that a system similar to that described in this paper can meet and exceed the goals of a high probability of detection (>95%) while retaining a low false alarm rate (<0.03 per meter of forward progress). This testing included both on-road and off-road scenarios using real, unfuzed anti-tank mines and inert mine surrogates. Additional details from these tests are available from the author.

Efforts continue to further improve the system performance and increase the inspection speed.

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