Journal of the Korean Nuclear Society
Volume 33, Number 3, pp.349~354, June, 2001

《Technical Note》

Advanced Technology Trends in Development of Land-Mine Detection Systems

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(Received August 21, 2000)

Abstract

While the United Nations (UN) agencies work to restrict the manufacture, sale, and use of land-mines worldwide, a massive clean-up effort is needed to find and destroy the estimated 100 million land-mines still buried around the world. Land-mines left behind from wars worldwide are one of the past century's main unsolved problems of war and remain the focus of humanitarian land-mine detection and removal primarily in Europe, Africa, Asia and Central and South America. For example, approximately 1 million anti-personnel mines and other various kinds which have been buried in the 249.4 km (155 miles) demilitarized zone (DMZ) of the Korean peninsular should be completely removed in historical process of the peaceful unification between South and North Korea. In this regard, the current trends of technologies linked to land-mine detection systems are surveyed.

Key Words : Land-mine, 252Cf, ILDS, LANDMARC, ground penetrating radar, nuclear quadrupole resonance, portable isotopic neutron spectroscopy, SQUID, micropower impulse radar

1. Introduction

There are over 100 million land-mines currently deployed in over 60 countries around the world, with a growth of about 2 million each year [1]. The consequences by them are often serious injuries or tragic losses of life. To help prevent such tragedies, nuclear scientists in the Defence Research Establishment Suffield (DRES) teamed up with Defence Research Establishment Ottawa (DREO) to develop a rapid and effective way to create a safe path through land-mine fields for both people and vehicles. Land-mine clearance is normally broken into three stages: detection, removal and disposal. Current detection methods range from high-tech (applications of ionizing radiation, ground penetrating radar, infra-red imager, magnetic resonance imaging, and nuclear quadrupole resonance) to biological detection schemes (dog sniffers and insects), to simple brute force detonation methods (flails, rollers and plows), and the use of hand-held mechanical prodders. Most of these methods are very slow and/or expensive and suffer from a high false alarm rate.

Therefore, some advanced technologies to make land-mine detection further more practical are surveyed and described.

2. Advanced System Developments

2.1. Land-Mine Confirmation System Using ^{252}Cf Neutron Source

The Californium User Facility (CUF) for Neutron Sciences was established at the Radio- chemical Engineering Development Center of the Oak Ridge National Laboratory (ORNL). The CUF can provide a cost-effective option for research with ^{252}Cf sources and reduce the regulatory burden for ^{252}Cf users. Use of neutrons as a probe to confirm the presence of land-mines demonstrates the versatility of ^{252}Cf. The Canadian Defence Research and Development Branch carried out their researches on confirmatory land-mine detection [1,2].

The applications of ^{252}Cf were a thermal neutron activation (TNA) system as a confirmatory non-metallic land-mine detector and second-generation thermal neutron activation sensor for confirmatory land-mine detection under the Improved Land-Mine Detection Project (ILDP) by the Canadian Department of National Defence (DND). The Improved Land-Mine Detector System (ILDS), a vehicle-mounted nonmetallic land-mine detector, was developed by Defence Research and Development (DRD) in Canada. The ILDS consists of a custom teleoperated vehicle carrying an infra-red imager, an electromagnetic induction detector, and a ground proving radar which scan the ground in front of the vehicle [3]. The confirmation detector of the ILDS involves positive detection of land-mines, using TNA and subsequent detection of bulk nitrogen gamma-rays. In the field tests by the U.S. government in summer of 1998, the advanced development model (ADM) of ILDS placed first or second out of five competitors on every test [4]. The TNA confirmation detector, unique to ILDS, provides the capability of lowering the false alarm rate that all vehicle-mounted detectors require for practical use.

According to the ILDP, four ILDSs are to be delivered to the Canadian Forces in April 2001. The ADM TNA system of ILDS consists of the components as listed in Table 1 [2].

The neutron source is incorporated into a central shielded core, which can be easily removed from the main shield, allowing interchange of ^{252}Cf or accelerator source using D-T neutron generator. The computer code MCNP 4A [5], which was available through the Radiation Safety Information Computational Center (RSICC) at Oak Ridge National Laboratory as code package CCC-200, was used to ascertain the effects of various combinations of shielding materials. The electronic systems of the ILDS were designed to handle the very high count rates since the higher allowed count rates can be used to reduce land-mine confirmation time or increase land-mine confirmation confidence.

2.2. Land-Mine Detection Advanced Radar Concept (LANDMARC) System

The LANDMARC system' s enabling technology is micropower impulse radar (MIR), which was invented in Lawrence Livermore National Laboratory (LLNL) in 1993 as an outgrowth of the Nova Laser Program (NLP) [6]. The invention led directly to a battery-operated pulsed radar which is remarkably small and inexpensive, has a wide frequency band, and works well at short ranges [7]. All those attributes are necessary for land-mine detection systems.

Livermore' s LANDMARC team combined MIR units with a high-performance imaging system which used sophisticated computer algorithms to convert large amounts of raw wave form data from the MIR units to high resolution two- and three-dimensional images of the sub- surface [8]. This was one of LANDMARC' s chief contributions to land-mine detection technology. The prototype systems enable users to visualize both anti-tank and anti-personnel mines and to differentiate them from rocks and other clutter of similar size and shape by the reflected MIR signal. LANDMARC prototypes have multiple MIR units which are either configured in a hand-held wand, much like that used for simple metal detectors, or mounted on a small robotic cart. The LANDMARC system has the power to process raw radar data into two-dimensional tomographic images of anti-personnel and anti-tank mines in a few seconds. In the same time frame, it can also process three-dimensional renderings of, in this case, a buried anti-tank mine. On the system currently under development, the images will appear on either a laptop computer or the operator' s headset screen. LANDMARC innovations provide a great improvement in sorting out clutter which is the most difficult of the imaging tasks and in lowering the false alarm rate. The comprehensive signal and noise models being developed by the LLNL' s team are central to perfecting LANDMARC' s imaging capabilities.

More important, the models are used to design algorithms to help reduce the false alarm rate and increase the positive identification rate in laboratory and field tests, both of which, in turn, improve LANDMARC' s ability to discriminate between land-mines and clutter. In field tests, funded by the U.S. Defense Advanced Research Projects Agency (DARPA), the system performed well, though at a slow pace. Through the field tests, areas for additional refinement such as using higher frequencies, that is, wider bandwidth to improve resolution and better distinguish land-mines from clutter, and providing the system with a means of communicating a more accurate field

Table 1. ILDS - ADM TNA System Components

Neutron Source Type	^{252}Cf
Neutron Source Strength	2.0×10^8 n/s
Gamma-Ray Detector Type	7.6 cm × 7.6 cm (3" × 3") NaI(Tl)
Number of Detectors	6 @ every 60o
Size of ADM TNA Head	0.9 × 0.9 × 0.6 m^3 and 320 kg
Source-To-Detector Distance	30 cm

position of the imaged mines were indicated. A combination of technologies from LLNL has been directed toward the most daunting challenge presented by land-mines. LANDMARC, which the LLNL' s patented micropower impulse radar (MIR) and advanced imaging technology (AIT) were combined in a practical system, is making pivotal advances in meeting the challenge of land-mine detection.

2.3. Stand-Off Ground Penetrating Radar Mine Detection System

JACOR [9], that is a wholly owned subsidiary of JAYMARK, has developed a proof-of- principle and prototype stand-off mine detection system funded by the U.S. Department of Defense (DoD) through U.S. Army Communications and Electronics Command (CECOM). The JACOR (Federal Systems), 25 Years of Innovative Solutions, has expertise in the design and manufacture of electronic and electro-optic systems. The JACOR system is the only known system that can detect and identify mine types at a substantial range, up to 30 m, with a low false detection rate and can detect both surface and buried land-mines. A concept vehicle has been built to allow for the demonstration and the improvement of JACOR' s concept of a stand-off mine detection ground penetrating radar (GPR). The total concept system' s weight is about 90.7 kg (200 lb), and current version of the system is constructed on a Hummer (all-terrain vehicle).

The radar has been developed using only commercial-off-the-shelf (COTS) available components. This JACOR system uses a stepped continuous wave (CW) signal with three horn antennas. The stepped CW approach, going from 0.5 to 4 GHz, allows the system to excite the resonant frequencies of all mine targets. This stepped CW approach creates the ability to obtain detectable signals from all targets as well as the ability to identify the targets based on resonant frequencies. Of the three horn antennas, the middle one transmits, while the outside two receive, which allows for azimuth detection as well as range determination and identification. The result is a system capable of detecting, locating, and identifying targets at safe stand-off ranges of up to 30 m (100 ft). The total radiated power is 1.0 W, although there are plans to increase the power to 10 W. The JACOR system has been successfully demonstrated in several field tests in 1994. The first test was conducted by JACOR and CECOM. In 1996, the system was "blind" tested against over live but defused, metallic and plastic mines buried in various soil conditions. All of these mines were detected by the JACOR system. After a CECOM contract of the Vehicular Mounted Mine Detector (VMMD) program ended in December 1998, the new contract for the research and demonstration of a forward looking sensors package technology for the VMMD extended the program through June 2001. The improved system is designed to be packaged as a rugged system capable of operating on rough terrain and weighing less than 136 kg. If mounted on an all-terrain vehicle, this system would be capable of withstanding the extreme conditions typical of actual mine deployment situations. In the VMMD system, the stand-off ground penetrating radar (GPR), a forward looking infra-red (FLIR), computers, displays, and soft- wares are the major subparts. The stand-off GPR detection system has been integrated with a forward looking detection seeker and a passive infra-red to improve the system performance for both military and humanitarian missions. The JACOR' s new contract system goals are listed in Table 2. However, effective solution of the problem posed by land-mines means that close to 100 % of the mines in any area must be detected at the fastest rate possible and with few false alarms - i.e, mistaking a buried object, such as a rock, for a land-mine.

Table 2. Technical Specifications of New Contract System Goals

Weight	136 kg (300 lb)	
	[System : 102 kg (225 lb) + Antenna : 34 kg (75 lb)]	
Range	10 m (33 ft) - 30 m (100 ft)	
	[Examine up to 60 m (200 ft)]	
Speed	16 km/h (10 mi/h)	
Power	2.0 kW	
Location Accuracy		0.25 m
Detection Probability		0.9
False Alarm Rate		1 / 50 m^2

The UN, for example, has set the detection goal at 99.6 %, and the U.S. Army' s allowable false alarm rate is one false alarm in every 1.25 m2. Where, the weight of new contract system can be reduced with further miniaturization effects.

2.4. Mine Detection System Using Nuclear Quadrupole Resonance

The Advanced Methods Group that is part of the Signal Processing and Analysis Systems Section of ORNL has recently developed and demonstrated a prototype land-mine detector based on the principle of nuclear quadrupole resonance (NQR). Since it is the explosive such as research development explosive (RDX) or trinitrotoluene (TNT) that is being detected rather than an object buried in the ground, the NQR land-mine detector has the big advan- tage in drastically reducing the false alarm rates. RDX and TNT are most typically used in land-mines as the explosive material with the NQR signals. For TNT detection, it is highly suggested to use of D.C. Supperconducting Quantum Interference Device (SQUID) and receiver ferrite antennas because SQUID detection works at lower NQR frequency and has excellent sensitivity. In this regard, the group performs their R&D needed to effectively apply new technology in signal processing, analysis, and modeling to solve difficult problems of land-mine detection. The NQR Land-Mine Detector Project is jointly sponsored by the U.S.

Defense Advanced Research Projects Agency (DARPA) and the U.S. Army. The NQR was patented by the Naval Research Laboratory (NRL) in Wsahington, D.C. and licensed to Quantum Magnetics, Inc. in San Diego, CA.

3. Conclusions

There are three categories into which present mine detection technologies fall. These are high-tech, brute-force, and hand-prodding. It should be noted, however, that metal detection is no longer a reliable method of land-mine detection since a majority of mines made today contain very little, if any metal. Various detection technologies are currently used, each with limits or flaws. Metal detectors are sensitive to metal mines and firing pins but can not reliably find plastic mines. Infra-red detectors effectively detect recently placed mines, but they are expensive and limited to certain temperature conditions. Thermal neutron activation detectors are accurate but are larger for field use, slow, and also expensive. In early attemps, ground penetrating radar (GPR) was sensitive to large mines, had good coverage rate at a distane, and with signal processing, could discriminate anti-tank mines from clutter such as rocks beneath the ground surface. This type of radar, however, remains expensive, can not detect anti-personnel mines because its resolution is too low, and frequently records false alarms from clutter sources. The limitation of common land-mine detection techniques were well discussed by Hussein and Waller [10]. The portable isotopic neutron spectroscopy (PINS) system, developed by the Idaho National Engineering and Environmental Laboratory (INEEL), which employs a ^{252}Cf neutron source for assaying chemical weapons, may be technically applied for use in land-mine detection [11]. At present, a high-tech system using proton beam from a proton accelerator (proton-gamma reaction) and secondary gamma-rays (photo-nuclear resonance reaction) is under development in the Korea Atomic Energy Research Institute (KAERI). This dual-purpose technology for the civilian and military uses can also apply for the detection system of unexploded ordnance (UXO) as well as land-mines.

This attempt is a new challenge for development of land-mine detection system in Korea. At the currently emerging circumstances in the Korean peninsular, however, the practical uses of such a technology are absolutely necessary as soon as possible. Recently, the first field test of the KAERI' s system has been successfully carried out. Meanwhile, according to the Ottawa Convention of 1997 banning anti-personnel mines (APMs), the Mines Action Initiative (MAI) in support of the Convention includes a provision for research, development, commercialization, and marketing of appropriate Canadian technologies. In addition, BBN' s Remote Mine Field Detection System (REMIDS) of the U.S. and SCHIEBEL' s Vehicular Array Mine Detection System (VAMIDS) of Germany deserve to be reviewed on the technical basis of those systems.

Acknowledgments

We thank Dr. Rodger C. Martin of the Californium User Facility at Chemical Technology Division in ORNL for his continuous support regarding technical information on "Industrial Applications of Californium-252 Neutron Sources" and the ^{252}Cf source availability from the Australian Nuclear Science and Technology Organization (ANSTO) at Lucas Heights Science and Technology Center. We also thank Dr. Robert J. Gehrke and Dr. Yale D. Harker of INEEL in Idaho Falls for their kind information concerning land-mine detection technology.

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