

АНАЛІЗ СУЧАСНИХ МЕТОДІВ ДЕТЕКЦІЇ ВИБУХОНЕБЕЗПЕЧНИХ ПРЕДМЕТІВ ПРИ РОЗМІНУВАННІ

І. Є. Двойнікова

Харківський національний університет радіоелектроніки

Україна, 61166, Харків, пр. Науки 14

E-mail: indira.dvoynikova@nure.ua

У роботі розглянуто актуальне питання аналізу сучасних методів детекції вибухонебезпечних предметів, їхні фізичні принципи, переваги та обмеження. Використання мультисенсорних систем та алгоритмів штучного інтелекту обумовлено необхідністю підвищення точності ідентифікації загроз, мінімізації кількості помилкових спрацювань та забезпечення безпеки персоналу під час гуманітарного розмінування.

Ключові слова: Детекція вибухонебезпечних предметів, гуманітарне розмінування, електромагнітна індукція, штучний інтелект

ANALYSIS OF MODERN METHODS FOR DETECTING EXPLOSIVE ORDNANCE IN DEMINING OPERATIONS

I.Dvoynikova

Kharkiv National University of Radio Electronics

Ukraine, 61166, Kharkiv, Nauky Ave. 14

E-mail: indira.dvoynikova@nure.ua

The work addresses the topical issue of analyzing modern explosive ordnance detection methods, their physical principles, advantages, and limitations. The use of multi-sensor systems and artificial intelligence algorithms is driven by the need to increase threat identification accuracy, minimize false alarm rates, and ensure personnel safety during humanitarian demining operations.

Keywords: Explosive Ordnance Detection (EOD), humanitarian demining, Electromagnetic Induction (EMI), artificial intelligence

In the context of humanitarian and military demining, a key challenge remains the identification of explosive ordnance (EO) in complex environmental conditions. The use of a wide range of materials by manufacturers—from ferromagnets to wood and modern composite polymers—makes it impossible to apply a single universal physical principle for threat detection. Modern challenges require moving away from classic mine detectors in favor of systems capable of distinguishing objects by several physical characteristics simultaneously. That is why a comprehensive analysis of detection methods, classified by their physical nature, is critically important to ensure maximum demining accuracy and reduce the number of false alarms.

INTRODUCTION. It is necessary to investigate the key technological approaches to detecting EO and the specific tasks they solve. The main areas subject to analysis are:

- Electromagnetic induction;
- Radio-wave sounding;
- Remote sensing;
- Analytical sensing.

MATERIALS AND RESEARCH RESULTS. Electromagnetic methods based on the principle of magnetic induction remain the most common approach [1]. The essence of the process lies in generating an alternating magnetic field, which induces eddy currents (Foucault currents) in the metal elements of the munitions. The resulting secondary field is detected by a receiving coil. Despite its

high efficiency in finding metal casings (for example, TM-62M type mines), the method has a significant drawback—the "clutter effect" or high sensitivity to metal debris. Furthermore, it demonstrates low efficiency against modern plastic mines (PMN-2, PFM-1), where the metal content is limited only to a striker or detonator weighing a few grams. To overcome these limitations, radar methods are utilized with the help of Ground Penetrating Radars (GPR) [2] (Fig. 1).



Figure 1 – Ground Penetrating Radar (GPR)

Instead of searching for conductors, the system registers the reflection of ultrashort radio pulses from the boundaries of media with different dielectric permittivities. This allows for the identification of plastic casings, internal air chambers of mines, and even soil heterogeneities that indicate the emplacement of EO (explosive ordnance). However, the operation of ground penetrating radars critically depends on soil moisture and mineralization, which cause signal attenuation, requiring complex digital signal processing (DSP) algorithms to filter out noise.

Optical and thermal imaging methods are focused on detecting surface mines and tripwires. Infrared thermography is based on the difference in thermal inertia: munitions heat up and cool down at a different rate than the surrounding soil or vegetation. This creates a characteristic thermal contrast during transitional periods of the day (morning/evening). In parallel with this, LiDAR (Light Detection and Ranging) technology [3] allows the creation of high-precision 3D point clouds of the terrain. Due to its high resolution, laser scanning is capable of detecting ultrathin tripwires and specific geometric anomalies that are invisible to the human eye.

High selectivity is provided by acoustic-seismic and chemical methods. Seismic analysis utilizes laser Doppler vibrometers to record mechanical resonances. Since a mine is a hollow object with mechanical elements, its response to seismic excitation differs significantly from the response of homogeneous objects (stones, roots). Chemical detection operates on the "electronic nose" principle, using mass spectrometry or ion mobility to register explosive molecules (TNT, RDX) in vapors above the soil.

The pinnacle of technological development is the concept of Sensor Fusion [4] (Fig. 2). Modern robotic platforms integrate data from multiple channels simultaneously. When an induction sensor detects a magnetic anomaly, and GPR confirms the presence of a volumetric body of the corresponding shape, artificial intelligence algorithms (based on convolutional neural networks) classify the object. This approach allows providing the operator with a consolidated threat probability indicator, which radically reduces the number of false excavations and increases the pace of territory demining

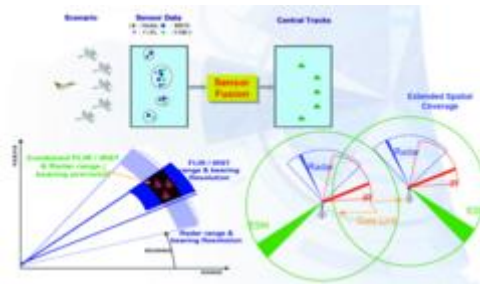


Figure 2 – Concept of Sensor Fusion

The conducted analysis confirms the global transition from single-sensor systems to multi-sensor intelligent complexes. The main vector of development is not just improving the sensitivity of individual sensors, but creating adaptive systems capable of adjusting their operation depending on the soil type and the expected type of threats. Combining different physical detection methods using AI is the only way to guarantee the safety and effectiveness of humanitarian demining processes in the modern realities of Ukraine and the world.

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Науковий керівник: Владислав Євсєєв, д.т.н., професор, професор кафедри комп'ютерно-інтегрованих технологій, автоматизації, робототехніки та безпекової інженерії (КІТАРБІ), Харківського національного університету радіоелектроніки.