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Sommario

Abstract

The Mine Identification and Neutralization Database (MIND) introduces an innovative, integrated, and scalable approach to landmine detection and management. It leverages commercially available drones equipped with thermal imaging sensors to detect buried landmines by identifying temperature anomalies in the soil. The captured data, including GPS coordinates, is then uploaded to a cloud-based platform, where advanced detection algorithms analyze the images to confirm potential threats. The results are stored in an open-source database, making the information accessible to humanitarian organizations, military personnel, and local authorities.

Unlike traditional demining techniques, which are often expensive, time-consuming, and hazardous, MIND democratizes mine detection by enabling non-specialists to contribute data through a community-driven model. This open-source and crowdsourced approach significantly expands the coverage area and accelerates mine detection efforts. Additionally, by relying on cloud computing for data analysis, MIND eliminates the need for high-end processing hardware, ensuring accessibility for users with limited resources.

Key Innovative Aspects:

- Scalability and Accessibility: Utilizes affordable, off-the-shelf drones with thermal imaging to lower financial and technical barriers to entry.
- Cloud-Based Processing: Allows for efficient, large-scale analysis without requiring expensive hardware for end-users.
- Crowdsourced Intelligence: Empowers individuals, NGOs, and military teams to collaboratively contribute to landmine detection efforts.
- Real-Time Feedback and Decision Support: Provides immediate threat assessments, enabling quicker and more effective demining operations.
- Open-Source Database: Serves as a centralized, up-to-date mapping tool for suspected landmine locations, enhancing operational planning and safety measures.

MIND represents a game-changing solution to the persistent issue of landmine contamination in post-conflict regions. By blending cutting-edge aerial thermographic imaging, machine learning-based detection algorithms, and cloud computing, this system maximizes efficiency while minimizing risk. Furthermore, its community-driven model fosters local engagement, allowing affected populations to play an active role in enhancing their own safety and security.

Introduction & Background

Current challenges in mine detection

Landmines and explosive remnants of war (ERW) continue to pose significant humanitarian, environmental, and socio-economic challenges worldwide.

According to the *Landmine Monitor 2024* [1], at least 58 states and other areas suffer from landmine and ERW contamination. These hazardous materials remain in roads, agricultural fields, forests, residential areas, and border zones, significantly restricting mobility and economic activities.

Heavily Affected Regions includes Ukraine, Myanmar, Syria, Afghanistan, and the Sahel that have the highest levels of contamination.

In 2023, at least 5,757 casualties were reported, including 1,983 fatalities and 3,663 injuries. Civilians constituted 84% of all casualties, while children accounted for 37% of civilian victims. These figures highlight the indiscriminate nature of landmines and ERW, disproportionately affecting non-combatants.

The consequences are heavy. The affected regions are paralyzed due to:

- Agricultural Disruption: Contaminated land reduces arable farming areas, leading to food insecurity.
- Restricted Movement: Fear of mines limits access to education, healthcare, and economic opportunities.
- Healthcare Burden: Mine-related injuries place immense pressure on medical systems, particularly in low-income and war-torn regions.

Despite significant progress and efforts - International contributions for demining surpassed $1.03 billion in 2023 - landmines and ERW continue to pose severe threats to civilians worldwide. The humanitarian and socio-economic impacts remain substantial, particularly in regions with ongoing conflicts.

Current methods of landmine detection and their drawbacks

According to "Detection of "legbreaker" antipersonnel landmines by analysis of aerial thermographic images of the soil" by Forero-Ramírez et Al. [2] the primary techniques employed for detection include Ground Penetrating Radar (GPR), Metal Detectors (MD), Multispectral Cameras, and Infrared (IR) Cameras. The first two methods utilize the principle of electromagnetic coupling, whereas the others focus on analyzing digital images captured across various spectral bands. Studies that incorporate GPR highlight that these methods are more effective in detecting mines buried at depths greater than 10 cm, making them unsuitable for surface mines like the "Legbreaker" type. Additionally, GPR inspections require close proximity to the ground, which increases the risk for both operators and detection equipment.

Research involving MD indicates that this method is effective for detecting metallic and surface mines but is significantly less efficient for mines with minimal or no metal content, as expected. Meanwhile, Multispectral Image Analysis presents a promising approach and remains under development for mine detection. While detection success rates using this method exceed 70%, the high cost of multispectral cameras continues to hinder their widespread application.

It is also important to note that numerous studies explore the use of Unmanned Aerial Vehicles (UAVs) equipped with IR cameras, multispectral cameras, or GPR to minimize direct contact with the ground during inspections. Additionally, some research has investigated infrared thermography as a Non-Destructive Testing (NDT) technique for detecting anti-personnel landmines (APL). However, these experiments have primarily been conducted under controlled laboratory conditions or on pre-prepared terrain to ensure uniformity, meaning that the results may not accurately reflect real-world field inspections.

Given these limitations, there is a need to develop a methodology for processing aerial thermal images captured by UAVs to facilitate the detection of "Legbreaker" APL in natural terrain with sparse vegetation under uncontrolled conditions. This would contribute to a safer detection process by eliminating direct physical contact with the ground while also making the approach more applicable to real-world inspections by accounting for essential experimental variables.

Proposed solution and its relevance

Our solution uses drones with thermal cameras to detect landmines safely and efficiently. AI processes aerial images in the cloud, identifying thermal anomalies linked to mines. The results are stored in a global, open-source database, accessible to demining teams and humanitarian organizations.

Key Benefits:

- Safe and Remote: No direct human contact with contaminated areas.
- Cost-Effective: Uses commercial drones instead of expensive equipment.
- Scalable and Collaborative: Crowdsourced data collection expands coverage.
- Fast and Intelligent: AI automates detection, providing real-time alerts.

This approach accelerates mine clearance, reduces risks, and empowers affected communities.

Technological Implementation

Introduction

The detection phase of the Mine Identification and Neutralization Database (MIND) relies on aerial thermographic imaging, leveraging drones equipped with infrared (IR) cameras to detect buried landmines based on temperature anomalies. This method exploits differences in thermal conductivity between soil and explosive devices, making use of passive infrared imaging, spatio-temporal analysis, and machine learning-based classification models. The detection phase consists of image acquisition, preprocessing, feature extraction, and classification, with a primary focus on minimizing false positives and improving detection efficiency.

Image Acquisition Using Aerial Thermographic Imaging

Thermal Signatures of Buried Landmines

Buried landmine detection using IR imaging is based on the fundamental principle that landmines alter the thermal properties of the soil above them due to differences in thermal conductivity and specific heat capacity. As highlighted by Khanafer and Vafai (2002) [3], buried objects such as landmines create distinct thermal signatures that vary throughout the day due to diurnal heating and cooling cycles. These thermal contrasts can be effectively captured using UAV-mounted IR cameras, allowing for high-resolution imaging over large areas.

UAV-Based Image Capture

The use of drones for landmine detection provides several advantages, including the ability to safely survey hazardous terrain, collect high-resolution thermal images, and cover large areas efficiently. Forero-Ramírez et al. (2022) [4] demonstrated that images acquired at 1-meter altitude achieved 97.1% detection accuracy, confirming that UAVs equipped with thermal imaging can effectively distinguish landmines from natural background variations.

Data Preprocessing and Thermal Image Enhancement

Eliminating Environmental Noise

Environmental factors such as soil moisture, vegetation, and surface roughness can introduce noise in thermal images, potentially reducing detection accuracy. According to Tabassum et al. (2024) [5], preprocessing steps such as radiometric calibration, noise filtering, and contrast enhancement are essential for improving image clarity. Techniques such as histogram equalization and adaptive thresholding help enhance the visibility of potential landmine signatures.

Spatio-Temporal Analysis for Improved Accuracy

Spatio-temporal analysis plays a critical role in differentiating true landmine signatures from transient thermal anomalies caused by environmental changes. Liu et al. (2021) [6] demonstrated that using multiple thermal images over time reduces false positives by identifying stable temperature anomalies. The MIND system incorporates similar methodologies by continuously monitoring suspected areas and flagging only those anomalies that persist over time.

Feature Extraction and Classification

Machine Learning-Based Classification

The integration of machine learning algorithms enhances the detection process by automating the classification of thermal anomalies. Forero-Ramírez et al. (2022) [4] used a Multilayer Perceptron (MLP) classifier to identify landmines with high accuracy. The classifier was trained using a dataset of thermal images, with extracted features including mean intensity, texture contrast, and temperature gradients. The study found that MLP-based classification significantly improved the precision of landmine detection compared to traditional thresholding methods.

Image Segmentation and Region of Interest (ROI) Selection

Selecting the correct regions of interest (ROI) is crucial for reducing computational complexity and improving detection reliability. As described by Khanafer and Vafai (2002) [3], segmentation techniques such as edge detection and morphological filtering help isolate potential mine locations. The MIND system employs a hybrid approach that combines edge detection with thermal contrast analysis to accurately delineate suspected landmine sites.

Reducing False Positives and Enhancing Detection Reliability

Addressing False Alarms

A major challenge in thermal imaging-based landmine detection is the occurrence of false positives caused by surface objects such as rocks, vegetation, or buried metallic debris. Tabassum et al. (2024) [5] suggest that combining thermal imaging with additional sensors, such as multispectral cameras or ground-penetrating radar (GPR), can enhance detection reliability. The MIND system integrates multi-sensor fusion techniques to cross-validate thermal detections with other sensing modalities.

Validation Through Controlled Experiments

To validate detection performance, experimental field tests were conducted with artificial landmines buried at different depths. Forero-Ramírez et al. (2022) [4] reported that UAV-based thermal imaging successfully identified shallowly buried mines at depths of 1-5 cm, but detection rates decreased for mines buried deeper than 10 cm. These findings guide the operational parameters of the MIND system, optimizing detection settings for different soil conditions and burial depths.

Community-Driven Collaboration in MIND

Introduction

One of the most groundbreaking aspects of the Mine Identification and Neutralization Database (MIND) is its ability to integrate contributions from a diverse pool of users. This community-driven approach transforms landmine detection from an exclusive, resource-intensive process into an inclusive and scalable system. By leveraging the collective efforts of individuals and organizations worldwide, MIND significantly expands its coverage area and accelerates demining efforts while ensuring that critical data remains open and accessible to all stakeholders.

Inclusive Crowdsourced Intelligence

Unlike traditional mine detection efforts that rely solely on specialized teams, MIND embraces a crowdsourced model that enables a broad range of contributors to participate. Humanitarian organizations, local authorities, and civilians with commercially available drones can collect thermal imaging data and upload it to the cloud-based MIND platform. This collaborative approach not only democratizes mine detection but also reduces operational costs and improves efficiency.

Role of NGOs and Authorities

Non-governmental organizations (NGOs) leverage MIND's open-source database and affordable drone technology to map hazardous areas and provide real-time threat assessments. Local authorities and military personnel utilize this aggregated data to coordinate clearance efforts, cross-verify detections, and enhance national demining strategies, fostering a proactive and efficient approach to landmine removal.

Civilian Participation and Decentralized Detection

MIND empowers civilians in affected regions to contribute valuable data using commercial drones without requiring specialized training. This decentralized detection network extends coverage, especially in remote or conflict-affected areas where traditional demining efforts may be limited. The platform provides intuitive tools and training resources to ensure safe participation while maintaining standardized data collection protocols.

Cloud-Based Collaboration and Data Verification

To maintain the accuracy and reliability of the crowdsourced data, MIND employs a cloud-based verification system powered by advanced detection algorithms. When a contributor uploads thermal imaging data, AIdriven models analyze the images for potential threats, flagging suspicious areas for further review. Verified detections are then made available in the open-source database, where stakeholders can cross-reference and validate findings. This process ensures data integrity while minimizing false positives, creating a robust and dependable detection network.

Cost-Benefit and Ethical Analysis of MIND Technology Compared to Classical Detection Methods

Introduction

Landmine detection remains a critical global challenge, requiring cost-effective, efficient, and ethically sound solutions. The Mine Identification and Neutralization Database (MIND) represents a technological breakthrough by integrating drone-based thermal imaging with cloud-based processing to enhance landmine detection accuracy and accessibility. Traditional demining methods, while already well established, suffer from high costs, slow operational speeds, and significant safety risks. This chapter provides a comparative analysis of the cost-benefit and ethical considerations between MIND technology and classical detection methods, drawing on existing scientific literature.

Cost Analysis

The financial burden of landmine detection is substantial. Traditional methods rely heavily on manual demining, mechanical systems, and canine detection, all of which incur significant operational costs. The cost of clearing a single mine ranges between $300 and $1,000 depending on terrain and false alarm rates [7]. Therefore, mechanical demining systems require substantial investment in equipment, maintenance, and logistics [8].

MIND technology significantly reduces costs by leveraging commercially available drones and cloud computing. Drones equipped with thermal imaging sensors cost substantially less than traditional mechanical demining machines. The cost of a state of the art commercial drone rages between 1000$ and 3000$ [9] and the cost of a state of the art commercial thermal camera start from 1,200$ [10]. Furthermore, cloud-based analysis eliminates the need for expensive ground-based data processing infrastructure, thereby reducing hardware investment costs. Operational expenses are also minimized, as MIND covers large areas with minimal personnel compared to manual demining, resulting in significantly lower labor costs.

Ethical Analysis

Beyond cost considerations, ethical concerns play a crucial role in demining operations. Traditional methods pose significant safety risks, environmental impact, and economic burdens on post-conflict societies.

Traditional methods subject manual deminers to high mortality rates due to accidental detonations. By contrast, MIND technology deploys drones for remote sensing, eliminating direct human exposure and dramatically reducing casualties.

Mechanical demining machines disturb soil extensively, causing erosion and disrupting local ecosystems. MIND's non-invasive approach preserves soil integrity.

Traditional demining methods require skilled personnel, limiting broader employment opportunities for local populations. MIND's crowdsourced model democratizes mine detection, allowing local communities, NGOs, and military personnel to contribute to safer environments. By reducing costs, MIND frees resources for other post-war recovery initiatives such as infrastructure development and healthcare.

Cost Efficiency Comparison

METHOD	INITIAL INVESTMENT	OPERATIONAL COST	DETECTION SPEED	SAFETY
MANUAL DEMINING	Low	High (Labor-Intensive)	Slow	High Risk
CANINE DETECTION	Medium	Medium (Training & Upkeep)	Moderate	Medium Risk
MECHANICAL DEMINING	High	High (Fuel, Maintenance)	Fast	Low Risk
MIND TECHNOLOGY	Low	Low (Cloud-Based Processing)	Very Fast	Minimal Risk

Table 1 - Cost Efficency Comparison between traditional demining techniques and MIND solution.

MIND provides a significant cost reduction per detection cycle, while expanding coverage and improving safety.

Legal and Ethical Issues Regarding Civilian Involvement

Introduction

The integration of civilians in landmine detection efforts presents significant legal and ethical challenges. While community-driven initiatives like MIND enhance the scale and efficiency of mine clearance, they also introduce concerns related to legal liability, data privacy, safety, and adherence to international humanitarian laws. This chapter explores the legal frameworks governing civilian participation in demining activities and the ethical considerations necessary to ensure responsible engagement.

Legal Considerations

International treaties such as the Ottawa Treaty (Mine Ban Treaty) and the Geneva Conventions regulate landmine clearance and dictate the responsibilities of state actors and humanitarian organizations. Civilian involvement must align with these legal frameworks to ensure compliance with international law and avoid unintended violations.

Different countries impose varying restrictions on non-governmental participation in demining operations. MIND must work within each country's regulatory environment to ensure legal adherence and avoid liability issues.

The involvement of civilians in potentially hazardous activities raises questions about liability in case of accidents or misidentification of landmines. Clear legal agreements must be established to define responsibilities, limit liability for contributors, and ensure proper indemnification for individuals and organizations involved in data collection.

Given that MIND collects and shares geospatial data, it must comply with international and national data protection laws, such as the General Data Protection Regulation (GDPR). Users must be informed about how their data is stored, shared, and used to maintain transparency and uphold privacy rights.

Ethical Considerations

One of the primary ethical concerns is the safety of civilian contributors. Encouraging untrained individuals to engage in landmine detection without adequate precautions poses severe risks. MIND must ensure that civilians are provided with training and clear operational guidelines to minimize harm.

Participation in MIND must be strictly voluntary, with full informed consent. Users should understand the risks associated with contributing data and be allowed to opt out at any stage. Ethical considerations require clear disclosure of potential hazards and benefits.

The data collected through MIND must only be used for humanitarian and safety purposes. There is a risk that geospatial data might be exploited for political, military, or economic gains, undermining the platform's ethical objectives. Safeguards must be put in place to prevent unauthorized use of civilian-contributed data.

Ensuring that all affected communities, regardless of socioeconomic status, have equal access to MIND is an essential ethical consideration. Excluding marginalized groups from participation could reinforce inequalities and limit the platform's effectiveness in high-risk areas.

Real-Life Use Case: A Community-Driven Demining Effort

Step 1: Initial Detection by Civilians

In a post-conflict region, a local farmer, Ahmed, notices a previously inaccessible area near his village. Concerned about landmine risks, he uses his commercially available drone equipped with a thermal camera to survey the land. After capturing thermal images, he uploads them to the MIND platform, where the AI-powered system analyzes the images for anomalies.

Step 2: NGO Verification and Mapping

A humanitarian organization, Safe Land, receives the flagged anomalies on the MIND platform. Their trained specialists use advanced detection techniques to cross-verify Ahmed's data. After confirming suspicious signatures indicative of buried landmines, Safe Land updates the open-source database and marks the area for further inspection.

Step 3: Real-Time Hazard Alerts via MIND Mobile App

As Safe Land updates the database, the MIND mobile app detects that some children are approaching the newly marked dangerous zone. The app immediately sends an alert to their phones, warning them of the potential hazard and advising them to avoid the area. Parents and community members also receive notifications, enhancing local awareness and ensuring timely intervention to prevent accidents.

Step 4: Hazard-Aware Navigation through Mapping Services

MIND collaborates with mapping services such as Google Maps, Waze, and Apple Maps to reroute users away from dangerous roads or bridges. When a hazardous area is detected, these navigation services integrate MIND's real-time data to provide alternative, safer routes, helping drivers, cyclists, and pedestrians avoid potential risks.

Step 5: Government Coordination and Deployment

Local authorities and military demining teams access the verified data on MIND and plan a targeted clearance operation. By cross-referencing reports from multiple contributors, they prioritize high-risk zones. The government mobilizes trained personnel with specialized equipment to clear the identified landmines safely.

Step 6: Community Safety and Ongoing Monitoring

Once the demining team confirms the area is safe, MIND updates the database, removing the threat marker. A notification is sent to residents and NGOs. Farmers like Ahmed can now reclaim and cultivate the land without fear, and Safe Land continues periodic monitoring through civilian contributions.

Conclusion and Future Work

The Mine Identification and Neutralization Database (MIND) presents a transformative approach to one of the most persistent global humanitarian challenges: landmine and ERW contamination. By leveraging commercially available drones equipped with thermal imaging sensors, MIND democratizes the detection process, reducing reliance on costly and sometimes hazardous traditional methods. The core strength of this system lies in its community-driven structure, which enables individuals, NGOs, and local authorities to contribute essential data in real time. Coupled with cloud-based processing, this open-access model significantly lowers financial, technical, and logistical barriers, making demining initiatives more efficient and inclusive.

Throughout this essay, it has been demonstrated that MIND's reliance on affordable drone technology and advanced machine learning algorithms meets the dual objectives of safety and effectiveness. Thermal imaging captures subtle temperature anomalies generated by buried explosives, while spatio-temporal analyses minimize false positives. These technological advantages lead to higher detection accuracy with fewer personnel on the ground, enhancing both cost-effectiveness and operational flexibility. The open-source platform further bolsters its impact by providing a centralized database accessible to anyone, thus fostering transparency and collaboration among international stakeholders.

Equally important are the socio-economic and ethical considerations. MIND's decentralized model prioritizes local empowerment, allowing communities to identify and neutralize dangers in their immediate environment. This inclusive participation not only accelerates the data collection process but also brings tangible benefits in building trust, raising awareness, and improving community resilience. Nevertheless, the approach requires stringent legal frameworks, robust safety guidelines, and clear consent protocols to protect volunteer contributors and ensure compliance with international humanitarian laws. Upholding data privacy and preventing misuse remain critical challenges, necessitating continuous engagement with policymakers and legal experts.

Moving forward, further innovations can extend the capabilities of MIND. Combining thermal imaging with complementary sensors - such as ground-penetrating radar or multispectral cameras - may improve detection rates, especially for mines buried at greater depths or in varying soil conditions. Enhanced machine learning models can also refine anomaly detection and reduce false alarms, leading to faster turnarounds in field validation. In parallel, stronger partnerships with global mapping services can seamlessly integrate MIND's real-time alerts into widely used navigation platforms, expanding community safety measures. Finally, ongoing outreach initiatives and training programs will be essential in sustaining a vibrant contributor network, ensuring that MIND not only remains a technological solution but continues to serve as a catalyst for community-led humanitarian action.

By uniting technological innovation, collective intelligence, and ethical responsibility, MIND stands poised to reshape landmine detection strategies worldwide. Its holistic framework sets a precedent for how emerging tools can be harnessed to address critical issues in post-conflict regions offering not just enhanced security but also renewed prospects for social and economic revitalization.

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