Beyond the Visible - Multispectral & TIR sUAS Minefield Mapping

Lessons Learned from the Successful Deployment of MS & TIR Imaging Over Live Minefields

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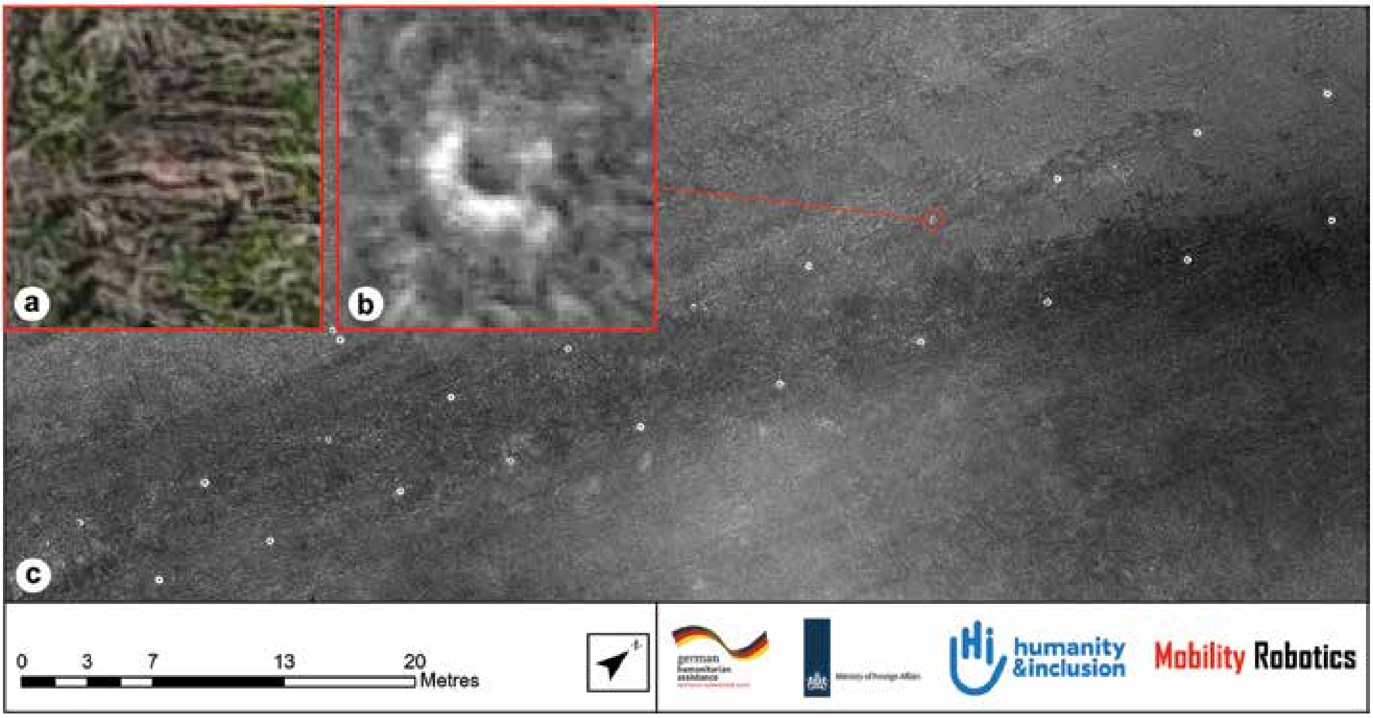

Figure 1. Above are parts of a sUAS minefield map created in May 2023 from an altitude of 25m at a live site in Ukraine (c). This shows how MS imaging can help better visualise plastic TM-62 P3 AV landmines in an environment of wild grass and weeds. Zooming in to an individual TM-62 P3 AV landmine in the map, (b) shows how the technique can help to visualise landmines that are obscured by such vegetation, making the target seem more obvious than imagery of the same device captured with a standard RGB camera (a). The technique also has camouflage-reduction properties: note how the influence of the vegetated background is reduced when visualising the twenty-three AV landmines in (c).

This paper presents key lessons learned from the use of small uncrewed aircraft systems (sUAS) for minefield imaging with multispectral (MS) sensors in the visible to near infrared (NIR) light bands, and thermal infrared (TIR) sensors.

The ethos was to conduct brief baseline trials in controlled environments, and then deploy in the real world during operational deployment with humanitarian mine action (HMA) teams at live minefields.

MS imaging was employed in Ukraine to locate surface and partially buried metal and plastic anti-tank/anti-vehicle (AT/AV) landmines which were obscured by long grass and weeds, beyond the clear visibility of a standard (RGB) camera.

TIR technology was utilised in the Sahara Desert in Chad to locate buried plastic anti-personnel (AP) and AV landmines[1].

Work took place as part of the Odyssey 2025 project, led by Handicap International/Humanity & Inclusion (HI), with Mobility Robotics responsible for research and development and conducting sensor trials. The project has been made possible by the German Federal Foreign Office (GFFO) and the Ministry of Foreign Affairs of The Netherlands (BUZA) as donors.

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Materials and Methods

Two different use cases are presented:

(1) Using MS imaging to reduce the camouflage effect of surface landmines obscured by grass and weeds in vegetated environments, providing better visualisation than a regular RGB camera (Figure 1 (a) vs (b), and Figure 4).

(2) Using TIR to locate buried landmines in the desert.

There are multiple segments in the infrared (IR) light range (Figure 2). This indicates that MS and TIR sensors operate differently.

Various sUAS have been deployed over the last five years. Currently, the DJI Mavic 3 Enterprise Multispectral (M3M)[2] is used for MS imaging/ mapping, while the DJI Mavic 3 Enterprise Thermal (M3T)[2] is utilised for TIR work.

Pix4D Mapper[3] and DJI Terra[4] were used for stitching imagery and data processing, with ArcGIS Pro[5] used for mapping, analysis, post-processing, visualisation, and planning. An Ocean Optics USB2000 handheld spectrometer[6] was used for creating a spectral reflectance reference library.

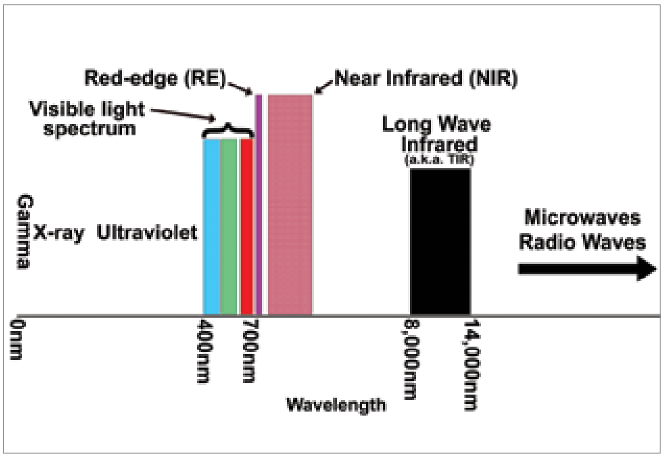


Figure 2. Above is a simplified diagram showing physics/ remote-sensing concepts where visible and infrared wavelengths appear along the electromagnetic spectrum (using a modified log scale). We are referring to the visible light spectrum (just over 400nm to just under 700nm) to NIR sector when referring to MS imaging/mapping in this article.
TIR is different, with such sUAS sensors capturing temperature, in the 8,000nm to 14,000nm range.

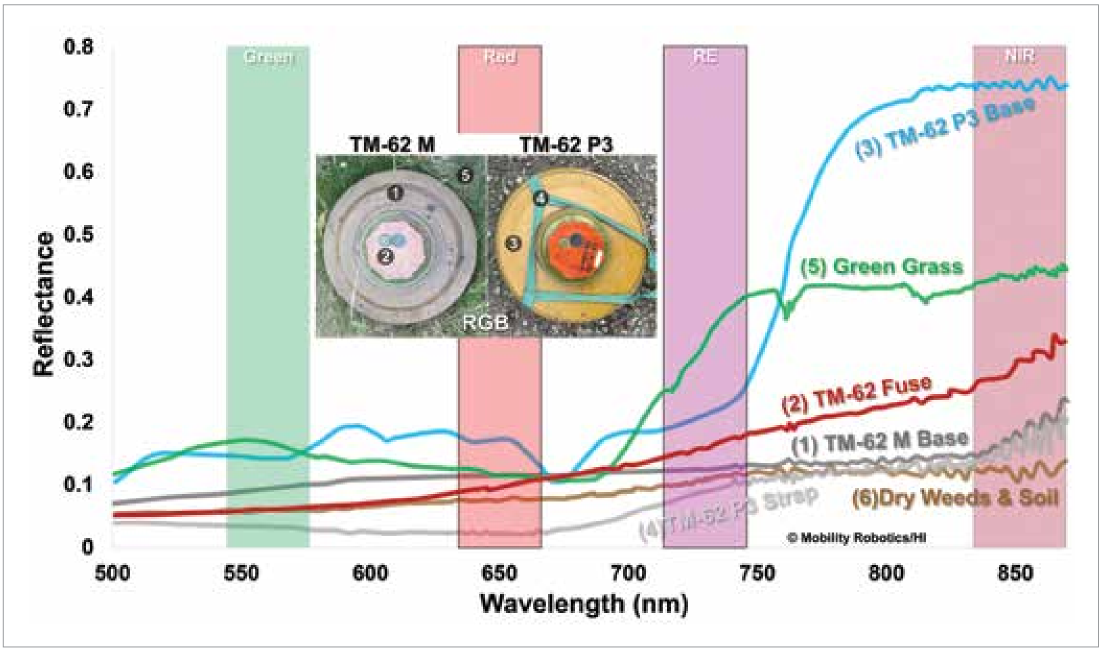


Figure 3. Above are spectral reflectance curves for metal TM-62 M and plastic TM-62 P3 AV landmines from our library. These help to explain the how each component has a different spectral reflectance signature for insight into how to post-process MS imagery from the DJI M3M. Shaded background columns have been included to show the bands at which the DJI M3M's four MS cameras capture calibrated imagery.

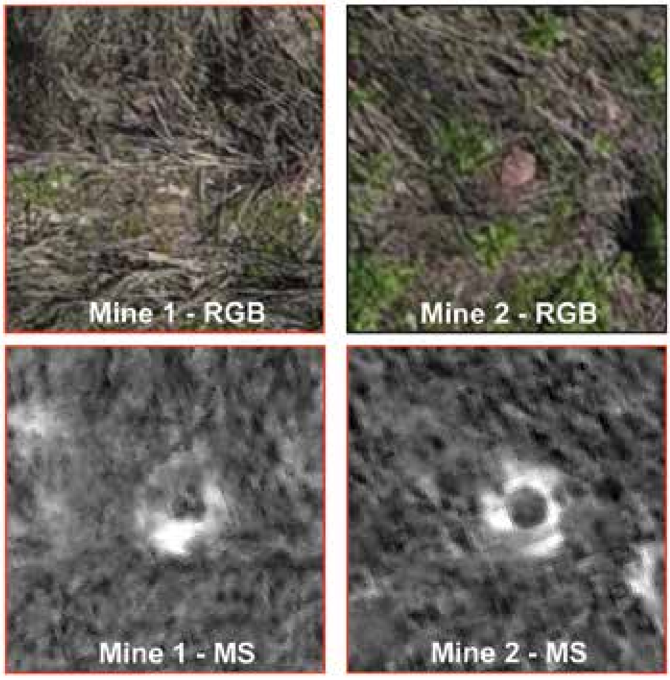


Figure 4. Above are two TM-62 P3 AV devices which are covered by grass/weeds at a live minefield in Ukraine. The top row shows the two landmines from a map layer created from a standard RGB camera, with the same landmines shown below in the post-processed MS map layer. You can see how the MS visualisation is more obvious in this scenario.

Lessons Learned - MS Mapping/Imaging

MS imaging helped reduce the camouflage effect of, and concealment by thin vegetation in two ways. First, it improved visibility of individual landmines that were partially covered by thin vegetation, making them easier to locate compared to a regular RGB camera (Figure 1 (a)). Second, it reduced the visual prominence of the surrounding vegetation, making the targets stand out more clearly against the background (Figure 1 (c), Figure 4).

Visualisation was strongest in cases when landmines and vegetation had the greatest differences in their spectral reflectance curves in the NIR band, and to some extent the RE band. This was the case with the plastic body of the TM-62 P3 AV landmine, which had a significantly higher level of spectral reflectance in the NIR band than did green grass/weeds and dry grass/weeds (Figure 3 (3) vs (5) or (6)).

Landmine spectral fingerprints can vary by model. e.g., a TM-62 M body compared to that from a TM-62 P3 (Figure 3 (1) vs (3)). It was also found that spectral reflectance curves for green plastic landmines varied by model in the NIR, and some in RE bands. Hence, different post-processing vegetation indices or algorithms may be required by landmine model or material type.

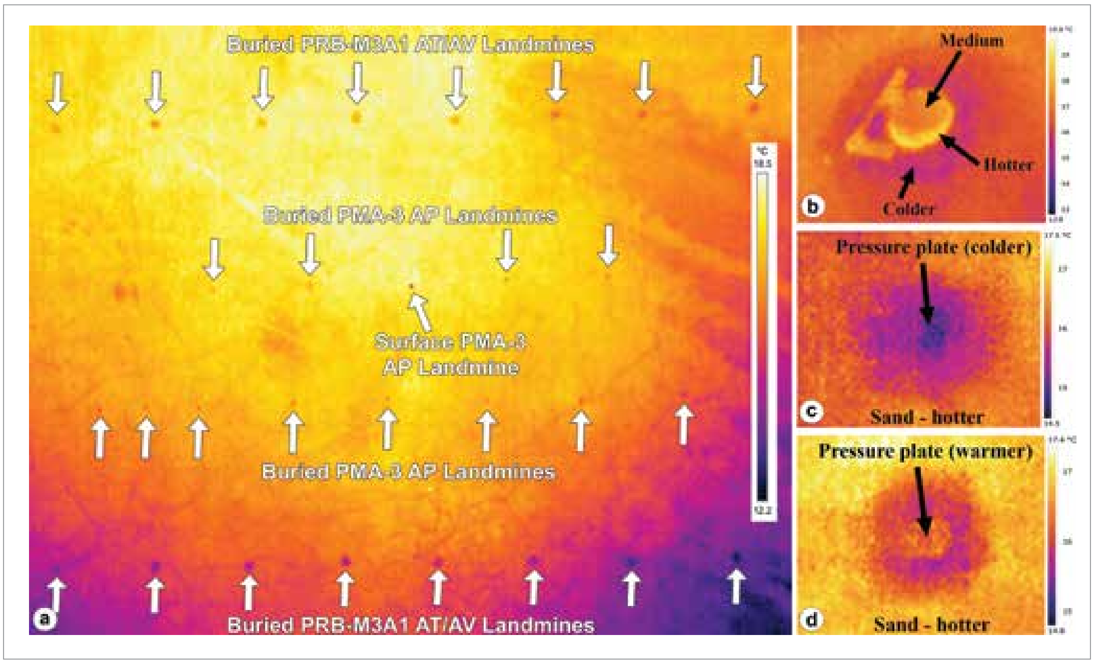


Figure 5. Above are examples of real world TIR signatures from live minefields which taught us how to interpret TIR data. Twenty-eight buried landmines are shown in (a) above. There are two rows of PRB-M3A1 AV landmines, and two rows of PMA-3 AP landmines. Each signature provides an idea regarding the landmine type and if it is buried at a shallow or medium depth. For example, the PRB-M3A1 pressure plate heated up at night when interfacing with the air – so it was warmer when buried close to the surface but cooler if deeper. (b) shows a pressure plate that is above the surface, but the device body is partly buried. (c) shows a live PRB-M3A1 that is deeper because the pressure plate is colder than the body. (d) shows a live PRB-M3A1 that is shallower because the pressure plate is warmer than the body.

Lessons Learned - TIR Mapping/Imaging

TIR data was collected from over two-thousand-five-hundred in-situ landmines at live sites, providing experience in analysing data for various landmine models found in Chad (Figure 4).

Collecting real world data from so many targets provided valuable insight because all the variables were in place. This included 30-year-old weathered production landmines with the correct casings and explosive fills. Other factors were the correct particle characteristics for that type of sandy ground, burial depth, local weather, condensation or moisture, erosion effects and water transport in the environment. Additional variables included temperature, sunlight, cloud cover, wind, and the diurnal cycle.

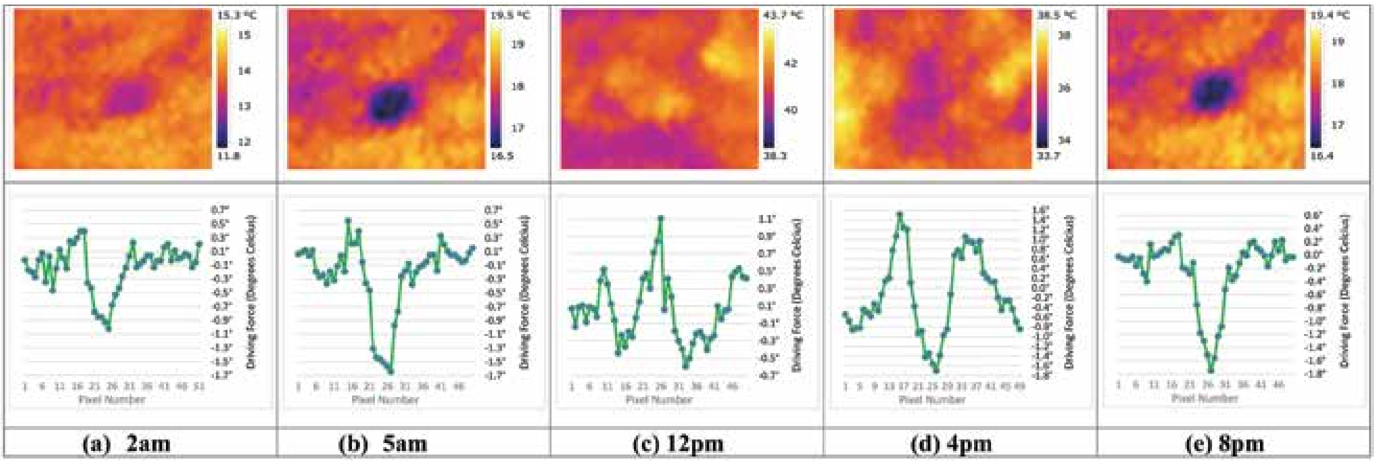
A key lesson learned from the real world was that TIR imaging was sensitive to environmental and weather variables, and worked best at night.

The diurnal cycle influenced the results, with optimal times to operate being in the hours just before sunrise and just after sunset (Figure 6 (b) and (e)).

The wind also affected TIR sensor data, with anomalies from buried landmines appearing weak or indistinguishable when experiencing windspeeds greater than a light breeze.

The impact of depth is an important consideration, which would depend on many of the complex variables such as: landmine construction - materials, size, wall thickness, and explosive fills , the environment, ground characteristics, and weather.

We found that it was possible to locate PRB-M3A1 AV and PMA-3 landmines up to a depth of around 5cm using sUAS TIR imaging at live minefields in Chad.



(a) 2am (b) 5am (c) 12pm (d) 4pm (e) 8pm

Figure 6. Above are examples of buried landmine TIR anomaly visibility by diurnal cycle. It shows that just before sunrise and just after sunset were the best times to operate (b) and (e), as TIR anomalies from a reference target at a 1cm depth were most prominent at those times.

Validation

Due to the potentially life-threatening work in the HMA sector, validation at real-world, live minefields is required to prove any research or new methodology is actually viable.

Not just to prove that a technique works, but also to gain insight in how to operationalise new methods. For example, working at night for TIR imaging is a completely new paradigm in HMA. This introduces increased security considerations and risks, meaning that it may not be feasible to work in some locations at night, or that the additional risk may not justify the effort.

The validity of both MS and TIR findings was confirmed through collaboration with demining personnel from various organisations, who physically verified and ground-truthed the results obtained from sUAS aerial data (Photo 1 - see on next page).

Additionally, without collaboration with a HMA organisation capable of clearance operations, the research impact may be limited due to a lack of validation at live sites.

For more information see www.mr-au.com.

Photo 1. Above is a photo of one of the PMA-3 AP landmines that was identified in sUAS TIR imagery, with validation provided by deminers who excavated to show that it was buried at a depth of 4cm depth at a live, 30-year-old in situ minefield.

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Autonomous Mobile Manipulation for Safe and Efficient Landmine Disposal

by Alessandra Miuccio[1], Timothée Fréville[2], Emile Le Flécher[1], Charles Hamesse[2], Geert De Cubber[1], Rob Haelterman[2]

Abstract

Landmines are a critical threat, endangering not only military personnel during conflicts, but also civilian population long after the conflict is over. This underscores the urgent need for safer and more efficient demining methods. In this paper, we explore solutions for the critical phase following mine detection, emphasizing autonomous collection and disposal processes performed by a robotic system. More specifically, this paper presents a theoretical framework for a novel mobile manipulation methodology for demining and explosive disposal operations. The challenges inherent in this operation are multiple, including identifying optimal grasping points, calibrating applied force, maintaining obstacle awareness, and overcoming visibility obstructions around the mine. Building upon recent developments in 3D computer vision and mobile manipulators, we propose a method for the autonomous handling and disposal of mines. The integration of a mobile manipulator combines the mobility of a mobile platform with the dexterity of a manipulator, allowing coordinated access to even the most challenging locations. The use of artificial intelligence (AI) improves scene comprehension including 3D reconstruction of the target area and the computation of the optimal gripping solution for target manipulation. By advancing these technologies, we aim to enhance the safety and efficiency of demining operations, ultimately reducing the risk to human operators and contributing to global efforts in landmine removal.

Introduction

According to the Landmine Monitor 2024, at least 5,757 casualties from landmines and explosive remnants of war occurred in 2023, with civilians comprising 84% of victims. While landmines cost as little as $3 to $75 to produce, their removal using traditional methods averages $300 to $1,000 per mine [1]. This highlights the need for safer, more efficient demining methods. After completing a Non-Technical and Technical Survey to define the minefield area, the landmine clearance process follows four main phases: land preparation, mine detection, excavation and identification, and neutralization or removal (Figure 1). To address this challenge, robotic systems have been widely explored as alternatives to human operators and other biological agents already employed in demining. Extensive research has focused on mine detection, employing multi-agent robotics system [2] [3] and learning-based methods combined with metal detectors, thermal sensors, and hyperspectral imaging [4].

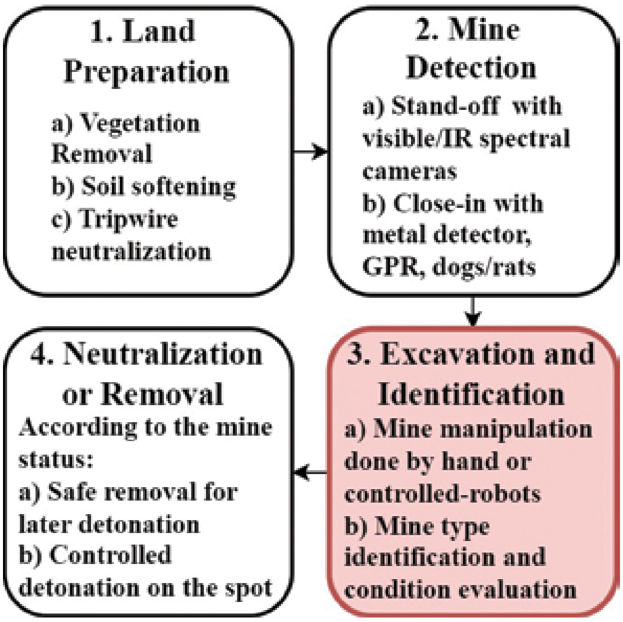

Figure 1. Phases of demining process. This paper focuses on Mine Manipulation highlighted in red.

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