International Cartographic Association
Association Cartographique Internationale

Groth's algorithm to detect the possible presence of landmines using changes in the reflection of plants

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Abstract: Post-conflict reconstruction includes the removal of land mines and remnants of war. The CSIR conducted field experiments to determine the impact of TNT in the soil on plants as a possible means to detect landmines. All the leaf clip readings were done using a spectrometer to determine reflection and absorption of light at one micrometre intervals between 350 to 2500 micrometre. Laboratory analysis such as UPLC qTOF MS indicated that the TNT have an influence on the plants. Several indices such as Modified Red Edge Normalized Difference Vegetation Index (mNDVI705), Red Edge Position (REP) and Moisture Stress Index (MSI) did not show any significant differences between control plants and experimental plants with different TNT concentrations. Groth's pattern matching algorithm designed to match several photographs of the same part of the universe. A set of triangles using dominant stars are created for each photograph and matched using an error band. If the selected triangles from the two photographs fit within the error band, then they are from the same section of the universe. Bands for the Pléiades instruments were simulated using the data from the spectrometer for each plant. The reflectance value of the band and the normalised midpoint wavelength of each Pléiades band were used to construct the triangles. The control plant triangle is then matched with the experimental plant and if the triangles do not match, then the effect of TNT on the plant is significant. The initial results with the control plants and experimental plants are positive.

Keywords: landmines, detection, clearing operations, reflectance, simulation

1. Introduction

1.1 Background

Landmines are explosive weapons used in conflict situations. They are intentionally hidden and are used as "booby-traps", with the aim of damaging, disabling or killing what or whoever triggered it, slowing down the progress of troops and vehicles (Keely: 2003). The two common types of landmines are anti-personnel (AP) and anti-tank mines (AT). The key components of both versions are the same: a casing, a firing mechanism or trigger, and an explosive charge, often 2,4,6-trinitrotoluene (TNT) (Robledo, *et al.*,2009; Makki, *et al.*, 2017).

They are placed randomly, and unfortunately, after the resolution of the conflict, any landmines laid are usually not recovered. These abandoned minefields not only pose a serious threat to people who come into immediate contact with them, but they could also prohibit access to critical resources, such as water or medical services (Oppong and Kalipeni: 2005; Makki, *et al.*, 2017). If an individual triggers a landmine, the consequences can be severe. Damage to the muscular or skeletal system of the individual can render him/her disabled and may even lead to death. These problems also occur with unexploded ordnance (UXO), abandoned explosive ordnance (AXO) improvised explosive devices (IEDs) and other explosive remnants (UNMAS 2019a).

Because of the threat landmines in particular pose to civilian society, efforts to find and safely remove landmines are often made by organisations such as the United Nations Mine Action Service (UNMAS)[1] and the Geneva International Centre for Humanitarian Demining (GICHD)[2]. It is a tedious process, with many risks, and extremely high costs.

Several methods of detection have been used such as prodders, metal detectors, ground penetrating radar, dogs, African giant rats, thermal neutron activators, and hyperspectral remote sensing methods (Bruschini and

[1] https://www.unmas.org/

[2] https://www.gichd.org/

Advances in Cartography and GIScience of the International Cartographic Association, 4, 17, 2023.
31st International Cartographic Conference (ICC 2023), 13–18 August 2023, Cape Town, South Africa. This contribution underwent double-blind peer review based on the full paper. https://doi.org/10.5194/ica-adv-4-17-2023 |

Gros, 1998; Makki *et al*., 2017; Bajić & Bajić 2021). Dogs, African giant rats and biometric sensors rely on the leakage of low amounts of the chemical constituents used to develop the explosives (Makki, *et al*., 2017). These various methods could be used for a technical survey (UNMAS 2019b) to define better where explosive ordnance contamination occurs.

Hyperspectral remote sensing refers to a system of sensors which are used to detect the spectral reflectance of target objects. These objects can include anything that reflects light. The reflectance of certain bands of the electromagnetic spectrum and the absorption of others gives an object a spectral signature. This signature can be used for object identification, and in objects such as plants, it can be used to identify plant health. Sensors are available that can detect thousands of wavelengths. Makki, et al. (2017) give a discussion on various hyperspectral remote sensing projects that were undertaken to detect landmines. From their discussion dedicated sensors, some of them in-house sensors, are required to do the detection of landmines. To date, it appears that the focus has been on using multispectral sensors for the direct detection of explosive targets (Bajić & Bajić 2021).

The aim of this project is to develop a methodology that can use off-the-self sensors or high-resolution satellite imagery such as the Pléiades satellites with a 50cm resolution and Pléiades Neo with 30cm resolution or airborne sensors that are currently used in precision agriculture (Airbus 2022).

This article is based on the abstract submission and presentation at the 2022 Society of South African Geographers (SSAG) Biennial Conference in Pretoria, 12 to 14 September 2022 (Schmitz *et al* 2022).

1.2 Previous research

The CSIR has an explosive testing range at Paardefontein, north of Pretoria. Two studies were conducted at this site, the first in 2013 and the second from 2015 to 2017 using the same trees. The trees, indigenous to Southern Africa, used in the study are River Bush Willow, Soap Dogwood, Sweet Thorn, Wild Olive, White Stinkwood, and Cape Holly. However, in the second round we only had five species of trees available since the Cape Holly perished shortly after the 2013 study for some unknown reasons. These trees in 2013 were all approximately 4 years old. Two trees acted as control samples and 5 trees for each specie were contaminated in 2013 with various concentrations of TNT, namely 30mg TNT/kg soil, 300mg/kg, 600mg/kg, 1200mg/kg and 5000mg/kg based on the studies by Ali, *et al.* (2006); Naumann, *et al.* (2009) and Zinnert, *et al.* (2012). The second study was expanded to include shrubs and grasses using the same concentrations of TNT per kilogram of soil. All plants were kept under semi-natural conditions, meaning they were kept in pots and were irrigated weekly, but exposed to the weather and not kept under greenhouse conditions. We used only the data of the trees for this paper. The reason was that the Ultra Performance Liquid Chromatography Quadrupole Time of Flight of mass spectrometry (UPLC QToF) tests were done on the trees to determine the effect of TNT on the plants (Peter, *et al*., 2019). The results do indicate that TNT has an impact on the vegetation as shown for the White Stinkwood (SW) in figure 1.

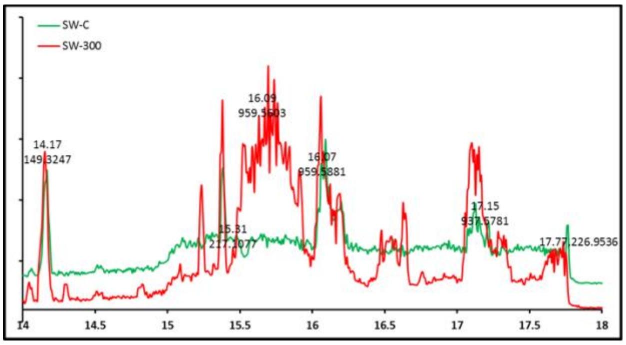

Figure 1. Impact of TNT on White Stinkwood tree.

The red line shows the impact of the TNT on the tree. The concentration was 300mg TNT per kilogram of soil (SW-300). The green line (SW-C) shows the analysis of the control tree that was not contaminated (Peter, *et al*., 2019). The challenge is to develop a methodology that could detect the change and indicate the presence of a landmine.

All the data in both studies were obtained using the leaf clip functionality of the ASD Field Spectrometer. The readings were from 350 µm to 2500 µm with a 1 µm interval. These two studies looked at seven vegetation indices, namely: red-edge position (REP) – best indicator however, it requires specific wavelengths, first derivative reflectance (FDR), normalised difference water index (NDWI), moisture stress index (MSI), water-band index (WBI), photochemical reflectance index (PRI), and nitrogen index (NI). The REP was the best indicator, but it requires specific wavelengths. In addition to the indices, two statistical tests were conducted on the data namely, F-Test Two Sample for Variances, and T-Test: Two sample assuming unequal variances. However, these indices and statistical tests gave mixed results for the different species and mixed results within a species between the control plants and the different concentrations of TNT in the same species (Smit, 2013; du Plooy, 2018).

1.3 Problem statement

At the 2014 UNMAS/GICHD bi-annual technology workshop some delegates at the workshop highlighted the high costs and difficulty of proposed equipment and application thereof by research institutions thus making it difficult for field applications. Both of our 2013 and 2015-2017 research projects did not provide conclusive results using indices and statistical analysis. Most indices use specific wavelengths and may require purpose designed sensors which are expensive. However, the UPLC QToF tests do show that the plants are affected.

 https://doi.org/10.5194/ica-adv-4-17-2023 |

The aim is to find an algorithm that could be used to indicate possibility of landmine (or explosive) presence using off-the-shelf data such as those from high resolution satellite imagery and aerial imagery.

1.4 Groth's algorithm

Groth's algorithm is a pattern-matching algorithm using 2D coordinate lists of listed bright stars that occur in two or more photographs of the same region in the sky. These coordinates are used to establish a list of triangles for the different photographs. The coordinates are transformed to create a single dimensionless coordinate system that is applicable to the different photographs (Groth, 1986). The methodology followed by Groth (1986) is first to establish the points (stars) that need to be matched; generate the lists of triangles using the identified points; match the triangles; reduce the number of false matches; assign the matched points using the matched triangles; and the last step is repeat the process to eliminate possible spurious assignments which are matches using different points are used that are listed but are not in common with the pre-selected list of bright stars.

Each triangle has a set of three vertices (1, 2, and 3) and the corresponding coordinate pairs (x_1,y_1); (x_2,y_2); and (x_3,y_3).

The tolerance is similar to an error band in which it is acceptable to match two triangles: if the triangles are outside this tolerance, then they do not match. Groth (1986) gave the tolerance (ε) of 0,001 as a default value. This value was used in this study. All the equations listed below are by Groth (1986). Any other equations will be referenced individually.

To be able to match the triangles (A and B) one needs to calculate the ratio (R) of two vertices namely 2 and 3 and the cosine (C) of the angle at vertex 1.

$$R = r_3/r_2 \tag{1}$$

where,

$$r_3 = \sqrt{\Delta x_3^2 + \Delta y_3^2}, \Delta x_3 = x_3 - x_1, \Delta y_3 = y_3 - y_1 \tag{2}$$

$$r_2 = \sqrt{\Delta x_2^2 + \Delta y_2^2, \Delta x_2 = x_2 - x_1, \Delta y_2 = y_2 - y_1} \tag{3}$$

The tolerance in R is calculated as follows:

$$t_R^2 = 2R^2\varepsilon^2\left(\frac{1}{r_3^2} - \frac{C}{r_3 r_2} + \frac{1}{r_2^2}\right) \tag{4}$$

C is the cosine of the angle at vertex 1.

$$C = 2S^2\varepsilon^2(\Delta x_3 \Delta x_2 + \Delta y_3 \Delta y_2)/r_3 r_2 \tag{5}$$

and the tolerance in C is:

$$t_C^2 = 2S^2\varepsilon^2\left(\frac{1}{r_3^2} - \frac{C}{r_3 r_2} + \frac{1}{r_2^2}\right)$$

$$+3C^2\varepsilon^2\left(\frac{1}{r_3^2} - \frac{C}{r_3 r_2} + \frac{1}{r_2^2}\right) \tag{6}$$

where S is the sine of the angle at vertex 1.

These values are used to match the triangles, or in our study to determine whether the triangles do not match to indicate the effect of TNT on the trees (that is, the reverse Groth's algorithm). The matching is done whenever:

$$(R_A - R_B)^2 < t_{RA}^2 + t_{RB}^2 \tag{7}$$

and

$$(C_A - C_B)^2 < t_{CA}^2 + t_{CB}^2 \tag{8}$$

where A in this study is the triangle of the control tree and B are the trees that have been contaminated with TNT. If one of the conditions in equations 7 and 8 are not satisfied, it means that the triangles cannot be matched, and it indicates in this study that the TNT had a significant impact on the trees. Please note that this algorithm indicates an impact but not the magnitude thereof.

The advantage of using Groth's algorithm is that it is insensitive to coordinate translations, rotation, inversion, etc. and tolerant to random errors and distortions (Groth, 1986). Figure 2 illustrates the concept.

Applications of Groth's algorithm outside of astronomy are in ecology where it is used to match different photographs of whale sharks to determine if it is the same whale shark which aids in the tracking of these whale sharks. Another application is to use it on photographs showing the spot patterns around the mouth and nose of a polar bear as shown in figure 3 (NASA, 2012). The use of Groth's Algorithm in ecology gave the idea to test it on determining the impact of TNT on plants and the possibility to use it to detect landmines especially after many years after the war ended.

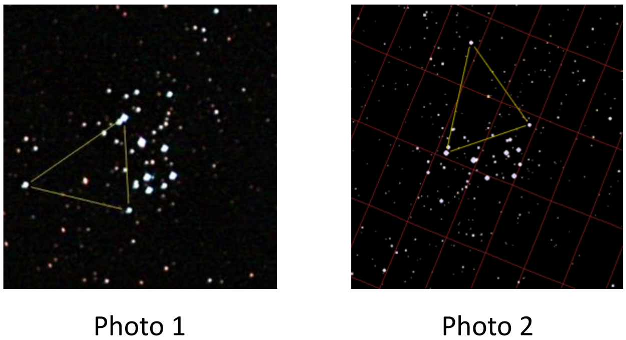

Figure 2. Matching the two photographs of the same region of the sky (Marszalek and Rokita, 2004).

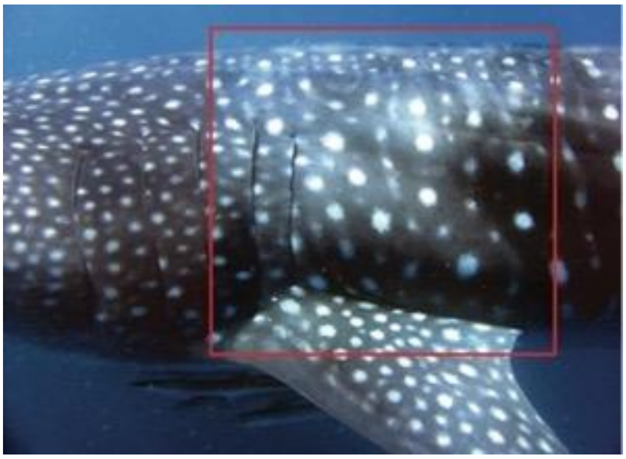

Figure 3. Spots on a whale shark (NASA, 2012).

31st International Cartographic Conference (ICC 2023), 13–18 August 2023, Cape Town, South Africa. This contribution underwent double-blind peer review based on the full paper. https://doi.org/10.5194/ica-adv-4-17-2023

2. Methodology

The methodology to determine the impact of TNT on plants using Groth's algorithm was done in two stages. The first stage was to average the readings over time and to simulate the Pléiades bands. The second step was to use Groth's algorithm in reverse, meaning if the triangles did not match, then there is a detectable impact of TNT on the plant.

2.1 Determining the Pléiades bands

To develop the triangles, the captured data over the period (2013 to 2016) was averaged to get a single value for each tree for each interval. The Cape Holly tree data was only for 2013 and is included to determine whether the TNT had an impact or not. The authors then used the Pléiades band intervals to determine the reflectance value per band. It could be that certain wavelengths within a band could have a higher weight than other, but this could not be determined[3] and it was decided to use the average for each band. An example of the simulated bands is shown in table 1.

Pleiades	Tree: White Stinkwood		mg TNT/kg soil	
bands	Range	Control	30mgTNT	300mgTNT
	430 -550	0,087724	0,098375	0,093461
	490 - 610	0,134263	0,150571	0,139979
	600 - 720	0,125150	0,143009	0,132764
NIR	750 - 950	0,491961	0,491130	0,500647
Pleiades	Tree: White Stinkwood			
bands	Range	600mgTNT	1200mgTNT	5000mgTNT
	430 -550	0,076829	0,082864	0,088414
	490 - 610	0,108559	0,123269	0,114430
	600 - 720	0,109525	0,119470	0,105791
NIR	750 - 950	0,458533	0,492476	0,474511

Table 1. Simulated reflectance values for the four Pléiades bands.

2.2 The non-matching of the triangles

The assumption is that the triangles of the control trees do not match the triangles of the contaminated trees which is to the reverse of the original design of Groth's algorithm. The reflectance value of the trees in the Pléiades bands were used as the one set of the coordinate pair, whereas the midpoint frequency was used as the second set of the coordinate pair. The midpoint frequency was normalised to be between 0 and 1 using frequency divided by 950, which is the longest wavelength of the four Pléiades bands used. Table 2 shows the normalised midpoints for each Pléiades band.

Colour	Range	Midpoint	Normalised
	430 -550	490	0,5158
	490 - 610	550	0,5789
	600 - 720	660	0,6947
NIR	750 - 950	850	0,8947

Table 2. Normalised midpoint values for each Pléiades band.

The following four triangle pairs were created namely:

- Blue-Green-Red
- Blue-Red-NIR
- Blue-Green-NIR
- Green-Red-NIR

The control tree was chosen as the first triangle (A) which is compared against the triangles (B) for each of the different TNT concentrations contaminating the tree. Figure 3 shows an example of the triangles created using the normalised midpoints and reflectance of the bands for each tree.

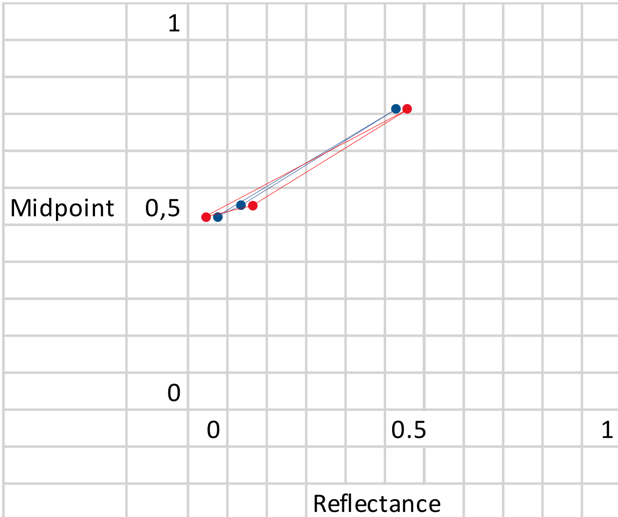

Figure 3. Constructing the triangles (Red – control tree and blue – tree contaminated with 30mg TNT/kg soil).

Equations 1 to 8 were used in an MS Excel spreadsheet for each tree species to determine the impact of TNT on the trees. The results of the matching of the triangles are discussed in the next section.

3. Results

The results of matching the triangles are shown graphically in figures 4 to 7. The columns are the six trees that were used in the experiment and the rows represent the controls and levels of contamination for each tree species. The triangle bands are shown in the top row of the figure.

[3] S Cullen, personal communication, 2022.

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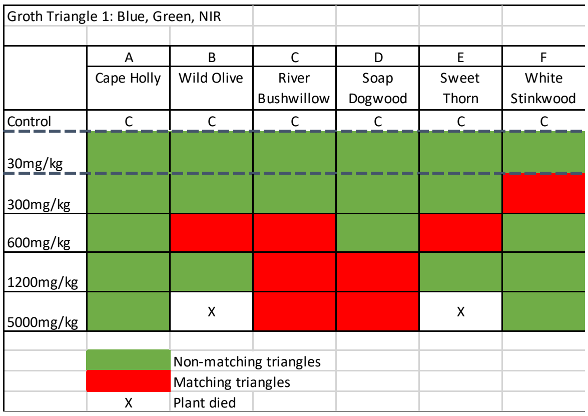

Figure 4. Matching of the Blue, Green, NIR triangles

Figure 5. Matching of the Blue, Red, NIR triangles

Figure 6. Matching of the Blue, Green, Red triangles

From figures 4 to 7 it can be determined that there are mixed results as it were with the various indices such as Modified Red Edge Normalized Difference Vegetation Index (mNDVI705), Red Edge Position (REP) and Moisture Stress Index (MSI). However, the promising outcome of this study is that three out of the four triangle combinations did not match between the control tree and the trees contaminated with the 30mg TNT/kg soil concentration. Du Plooy (2018) indicated that the Red Edge Position for the trees between the control and the 30mgTNT trees showed variable results which for some species was stronger than for the others. Three of the four triangles showed consistent change between the control tree and the trees contaminated with 30mgTNT/kg soil.

Figure 7. Matching of the Green, Red, NIR triangles

The 30mgTNT/kg soil is of significance since Ali, et al., (2006) indicate that the TNT concentration in contaminated soil is between 0,07 to 28.6 mg/kg soil. It can be assumed that the leaching from landmines would be in this range and this methodology could be applied to assist with the detection of landmines for demining purposes. However, more research and refinement need to be done on applying this methodology on remotely sensed images to assist in detecting landmines.

For the trees with higher concentrations of TNT these results are consistent with the findings of Smit (2013) and du Plooy (2018). Furthermore, Cape Holly showed that it is the tree that is most susceptible to the effect of TNT as shown in figures 4, 5, and 7. This could be a possible reason why it died out shortly after the 2013 study by Smit (2013).

Referring to figure 1 which indicates the impact of the 300mgTNT/kg soil on the White Stinkwood tree. The impact was not detected in the matching of the triangles in figures 4, 5, and 6. However, the triangle consisting of the Green, Red, and NIR bands does show the impact of the TNT on the White Stinkwood tree. This could indicate that a combination of the different triangles should be used when working with higher concentrations TNT to assist in the detection of landmines. This is an item for further research on the application of this methodology.

4. Conclusions and further research.

This methodology is a new approach in analysing the impact of TNT on plants and it is acknowledged that substantial further research is needed before it can applied operationally. Furthermore, it should not be used in isolation but in conjunction with other detection methodologies as indicated by Makki, et al. (2017). The proposed further research includes:

- Determine the impact of different tolerance bands apart from the default value of 0,001 given by Groth (1986).
- Doing a field experiment simulating the real-world using ASD leaf clip readings as well as canopy readings.

- Using Pléiades imagery of the same area of the field experiment using the ASD readings as a control to verify the process.
- Apply the methodology on other sources of imagery such as Landsat TM, SPOT, and imagery from airborne platforms.

5. Acknowledgements

The authors would like to acknowledge the support from their respective institutions, and especially the CSIR Paardefontein explosive testing range for the use of their facilities for the duration of the two studies.

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