The relevance, strength and likelihood of occurrence of the minefield indicators and signatures used in the airborne and space-borne remote sensing of mine contaminated areas

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ABSTRACT: The contamination by land mines and unexploded ordnance (UXO) is an extremely difficult problem that requires engagement of all national resources of the afflicted country, and wide international support. Indeed the main problem is large contaminated area that is not in normal use, this produces very strong impact in the social, economic, political, humanitarian and other domains. In Croatia, in 1996, an area of 12000 km² was suspected to be contaminated by landmines (assessment of the UN Mine Action Center Croatia), and in 2003 this area is 1600 km². Experience in Croatia from 1996 to 2003 shows that only 10 % of the suspected area is really contaminated. Similar ratio of the contaminated and the suspected area was assessed in several other countries contaminated by landmines. It therefore follows that a strategic problem for the countries that are contaminated by landmines is to reduce the suspected area urgently and proceed by demining in a sustainable manner. Remote sensing technology has potentials for this application. Several international projects were realized or are under way, with the aim of applying remote sensing technology and methods to help the humanitarian mine action (several European countries - Pilot project Mozambique; European Commission – PARADIS, ARC, SMART; European Commission and USA - Satellite based GIS for mine action; private consortium – MineSeeker). The actual available airborne sensors cannot detect landmines that lay in the ground and are covered by soil and by weeds (wild vegetation) for a long time (e.g. in Croatia from the year 1991). Several former scientific projects aimed to detect landmines and UXO (Pilot project Mozambique, MineSeeker), but this ill-posed problem was redefined and following projects had more realistic and affordable goals. In this paper, we consider the use of the physical entities (term of reference - minefield indicators) that indicate the presence of contamination by landmines or absence of the contamination, the related features and the electromagnetic signatures. The identification of the minefield indicators started in the project SMART by fieldwork in 48 km² of the minefields and the suspected areas, in which different experts collected the relevant information, data and knowledge. This process continued in several iterations from 2001 to 2003, while the evolutionary analysis, approval and improvement were applied. The data, information and knowledge that were collected in real contaminated areas were compared with the data contained in imagery and data collected by the airborne passive and active sensors and with the contextual information, data and knowledge. The active sensor was four bands polarimetric Experimental SAR (DLR), while passive electro-
optical sensors were multi-spectral scanner Daedalus (DLR), digital matrix camera in visible and near infrared bands (CROMAC), thermal infrared camera (CROMAC), hyper spectral line scanner for visible and near infrared bands (CROMAC). Several steps of the analysis of minefield indicators based on sensor images and data were foreseen: the enhancement of the features; extraction of the features; derivation of the signatures; ranking in accordance to the probability of the detection and their reliability (the confusion matrix and distance metrics); the analysis of the relevance, strength and likelihood of occurrence.

1 INTRODUCTION

The contamination by land mines and unexploded ordnance (UXO) is an extremely difficult problem that requires the engagement of all national resources of the afflicted country, and wide international support. Indeed the main problem is a large contaminated area that is not in normal use, this produces very strong impact in the social, economic, political, humanitarian and other domains. In Croatia, in 1996, an area of 12000 km² was suspected to be contaminated by landmines (assessment of the UN Mine Action Center Croatia), and in 2003 this area is 1600 km². (www.hcr.hr). Experience in Croatia from 1996 to 2003 shows that only 10% of the suspected area is really contaminated. A similar ratio of the contaminated and the suspected area was assessed in several other countries contaminated by landmines. It therefore follows that a strategic problem for the countries that are contaminated by landmines is to reduce the suspected area urgently and proceed by demining in the sustainable manner (ARIS 2000), (Bajic M., 2000).

Remote sensing technology has potentials for this application, several international projects were realized or are under way, with the aim to reduce the suspected area. These are: Airborne minefield detection pilot project Mozambique (ITC, 2000), funded by several European countries; European Commission funded – PARADIS (M. Acheroy, V. Lacroix, et al., 2001), ARC (M.M. Eisl, M. Khalili, 2003), SMART (Y. Yvinec et. al., 2003); European Commission and USA - Satellite based GIS for the mine action (ITF, 2004); private consortium funded – MineSeeker (MineSeeker 2003). The actual available airborne sensors cannot reliably detect landmines that lay in the ground (below the surface), covered by soil and by wild vegetation (weed), particularly if they were laid a long time ago (e.g. in Croatia in the year 1991). Several former scientific projects were aimed to detect landmines and UXO (ITC, 2000), (MineSeeker 2003) but this ill posed problem was redefined and following projects had more realistic and affordable goals (Y. Yvinec et. al., 2003), (M.M. Eisl, M. Khalili, 2003). The starting hypothesis was that in the mine suspected area there exist physical objects which indicate that this area is possibly contaminated or on the contrary that this area is not contaminated, and they were named minefield indicators (ARIS 2000), (M. Acheroy, 2000), (ETRO-VUB, 1999). Excellent research was performed with the aim to assess multi spectral signatures of landmines by ground based sensors (J.T. Dean, Editor, 2002), although available, the use of these data is limited to researchers and developers of mine detection equipment and was not applied to the airborne survey. The existence of the minefield indicators is well known in humanitarian demining practice, but for first time is foreseen the airborne acquisition of minefield indicators in a standard operating procedure of a general mine action assessment (CROMAC, 2003). If the basic sources are unreliable, when they contain errors (coordinates, azimuth, missing the stable or fixed reference for orientation and missing other reference points, poor copies of the minefield records, concealed basic information, deceived data), the most reliable data and information are minefield indicators and their electromagnetic signatures. The comparison of the understanding and application of the minefield indicators in 2000 (ARIS 2000) and in 2004 (R. Sapina, 2003) shows significant advancement and novel approaches and this is the main content of the current paper. The importance of the contextual information was recognized as critical for assessment of mine contamination (Y. Yvinec et. al., 2003). The spatial relations between minefield indicators were used in (M.M. Eisl, M. Khalili, 2003), but only four spectral channels in visible, near infrared and thermal infrared wavelengths provide a limited number of degrees of freedom.
Besides the use the **minefield indicators** (physical objects) in (Y. Yvinec et. al., 2003) was proposed and applied complex analysis of their features and electromagnetic signatures and introduced detection of **anomalies**. This was enabled due to the high number of degrees of freedom of the used spectral channels (12 passive and 8 active) and due to application of polarimetric microwave sensors. The change of the vegetation structure was approved as a very useful type of indicator of the mine suspected area, that was cultivated (agricultural) before the contamination by landmines and UXO.

Short information in chapter two describes the airborne acquisition of the minefield indicators for the humanitarian counter mine action performed during 1999 – 2003. The list of minefield indicators from (SMART, 2002) is discussed in the third chapter. Examples of the determination of the electromagnetic signatures of the minefield indicators and anomalies is considered in fourth chapter and a conclusion is given in a chapter six.

2 AIRBORNE ACQUISITION OF THE MINEFIELD INDICATORS, THEIR FEATURES AND ELECTROMAGNETIC SIGNATURES

Ground based multi sensor mine detection systems and related problems were and are the focus of attention of the R&D community and industry, mainly due to defense needs, whereas for the humanitarian demining there have been only four international projects about aerial minefield detection. Three of them finished (ITC, 2000), (Mineseecker 2003), (M.M. Eisl, M. Khalili, 2003), and last (Y. Yvinec et. al., 2003) will finish in October 2004. A significant amount of colour infrared aerial photography of minefields and mine suspected areas were collected in Mozambique, a number of thermal infrared and radar images of landmines were collected in Belgium (ITC, 2000), a list of minefield indicators was derived (ETRO-VUB, 999), both with lack of rigorous operational approval. In (Mineseecker 2003) were collected aerial color television images and aerial radar images (ultra wide bandwidth synthetic aperture radar) of surface laid landmines and UXO in Kosovo, without rigorous operational approval. In projects about airborne remote sensing of mine suspected areas and minefields, funded by European Commission, was mandatory to provide very rigorous approval and this was performed in several field missions and trials, (Y. Yvinec et. al., 2003), (M.M. Eisl, M. Khalili, 2003), with independently collected ground truth images, data and information and the final independent operational validation of results (receiving operating curves – ROC, Confusion matrix, omission and commission errors, cost benefit analysis).

A huge contamination with landmines and a very large suspected area (in 1998 it was 12 000 km$^2$) motivated proactive actions regarding the application of airborne remote sensing of the minefields (Bajić M., 1999a), (Bajić M., 1999b). The first flights above minefields started in 1999 with analog and digital television cameras and with thermal infrared camera Agema FLIR 570 (Bajić M., Gold H., Franjković D., 1999). Later were used high resolution camera in visible and near infrared wavelengths and thermal infrared camera Agema THV-1000 on board of helicopter Bell-206, for the aerial survey of the mine contaminated and mine suspected mountainous terrain (Bajić M., Gold H., 2002) and of high tension electricity networks (M. Bajić, T. Tadić, 2002).

In the frame of project ARC, (M.M. Eisl, M. Khalili, 2003), aerial images and data, ground based images, data and information about minefield indicators were collected and analyzed in 2001, 2002 and in 2003. The seven electro – optical cameras in visible, near infrared and thermal infrared wavelengths, were tested, on board of helicopters Mi-8 and Bell-206, on the sky lift Denka. The hyperspectral line scanner in visible and near infrared wavelengths was used on an armoured ground vehicle Wolf and on helicopter Bell-206. For the final use on board of unmanned aerial rotating wing vehicle were selected two cameras with only four wavelengths (green, red, near infrared and thermal infrared). The spatial resolution of sensors used on helicopter Bell-206, at height 130 m above ground level, was from 4.5 cm (visible and near infrared) to 7.5 cm in infrared thermal images and data and minefield indicators were collected in areas named Milekovići (in the region of village Glinska poljana, near Petrinja), Vrankovići and Pupovac Pristeg (in the region...
Pristeg, near Vransko lake). The most valuable images and data collected in the frame of project ARC are thermal infrared that were supported with very promising method of the inverse reconstruction of thermal history of landmines in the soil, (S. Sjokvist, A. Linderhed, S. Nyberg, M. Uppsall, 2004).

A comprehensive collection, analysis and validation of aerial images and data, as well as of minefield indicators were performed in the frame of project SMART (Y. Yvinec et. al., 2003); in field preparation mission in Spring 2001; aerial acquisition mission in August 2001; first field mission in 2001; second field mission in 2002; during the collection of ground truth data in 2003 after demining or general or technical surveys. Total analyzed area is 48 km$^2$, and covers regions with different terrain, climate, vegetation, mine contamination, each of them approximate dimensions 3x4 km. They are Glinska poljana (near Petrinja), Pristeg (near lake Vransko jezero), Čeretinci (near Vinkovci), Blinjski kut (near Sisak). For the first time for humanitarian mine action was applied airborne active sensor (DLR experimental synthetic aperture radar E-SAR, working at four wavelengths, fully polarimetric for two bands) and multi spectral twelve channels line scanner Daedalus (five visible channels, five near infrared channels, two thermal infrared channels). By this system were provided twenty images of each test region (eight radar and twelve optical) with spatial resolution one m for optical and two or four m for radar data and images. Besides the images of a single polarization and polarimetric images (combined polarized components), were derived additional kinds of radar data (single look complex data, coherence map, entropy, alpha, anisotropy) that contain unique physically based information about the structure and features of a mapped area (Y. Yvinec et. al., 2003). Contextual information and expert knowledge about the mine contamination, about quality (completeness, reliability, imperfection) of the available data and information in a mine information system were collected as well as additional ground truth data and information about considered areas. All kinds of data (sensor, contextual, expert knowledge, ground truth) are included in the data fusion process, (Y. Yvinec et. al., 2003). The minefield indicators and anomalies play a very important role, while they provide key information for the assessment of the degree of danger in output of SMART system, named danger map (SMART, 2002).

3 LIST OF MINEFIELD INDICATORS

The most comprehensive list of objects, that are minefield indicators was published in (SMART, 2002), it was derived for applications in test regions Glinska poljana, Pristeg and Čeretinci. Minefield indicators have different priority (higher, lower) or may require other information. For each minefield indicator were estimated possibility of occurrence on test regions, relevance (strength) and a priori detection likelihood by use of multi spectral Daedalus data or by use of E-SAR data. This estimation was made based on general knowledge about sensors and on data and information about objects – mine field indicators that were collected in the mentioned test regions and is naturally conservative. The list of minefield indicators is in continuous development, improvement and validation and will be finalized at the end of project SMART (two examples follow in next chapter).

4 ELECTROMAGNETIC SIGNATURES OF THE MINEFIELD INDICATORS

Two examples were selected to present signatures of minefield indicators. The first example contains high spatial resolution images of the man made object (trenches), collected in four channels (two visible, one near infrared and one thermal infrared), Fig. 1, Fig. 2, Fig. 3. The second example contains vegetated area, imaged by very high spectral resolution (twelve visible, near infra red and thermal infra red channels; eight radar (SAR) images, two layers produced by use of polarized L band data), spatial resolution one m or two to four m; Fig. 4, Fig. 5, Fig. 6.
Figure 1. High resolution image of trenches acquired at height 260 m above ground mean level, in visible green, red, near infrared (spatial resolution 7.3 cm); the infrared thermal image (spatial resolution 29.6 cm) acquired at height 500 m. All images were re-sampled to 6.9 cm. Coordinate net spacing is 10 m.

Figure 2. Trenches can be detected by use of four channels. Legend: embankments – blue, shadow – light blue/green, low vegetation (mixture of grass and low bushes) – yellow. Trees, bushes and cultivated area in the lower right corner of Fig. 1, were not analyzed, while trenches are target objects.

Figure 3. Trenches – typical minefield indicator. The influence of the wavelengths (thermal infrared, near infrared, red and green) on the range of values of basic elements (embankment, shadow, grass).
Figure 4. Reference image of the second example, shown in visible wavelengths. For analysis were used twelve multi spectral images, eight radar images, two feature maps produced by enhancement of radar data in L band.

Figure 5. Twenty different spectral channels plus two features channels enabled detection of desired elements of the scene in manual and iterative mode. Legend: green – short grass, violet – ploughed area, light blue – bare land with very sparse and very low vegetation.

Figure 6. Bare land and short grass – examples of mine-suspected and safe area indicators. Used channels are shown on the horizontal axis, while response of bare land and short grass is presented by minimum and maximum values.
Images were collected by a Croatian team in the frame of the ARC project, using high resolution camera MS-3100 in visible and near infrared wavelengths and infrared thermal camera Agema THV-1000, both on board of helicopter Bell-206, (R. Sapina, 2003). In the second example were used images and data of 12 channels of the multi spectral line scanner DAEDALUS and radar images and data of four wavelengths (P, L, C and X) and different polarizations Phh, Phv, Pvv, Lhh, Lhv, Lvv, Cvv and Xvv. These images and data were provided by DLR in the frame of SMART project, (Y. Yvinec et. al., 2003). Here index h, v mean horizontal or vertical polarization. Channels ch1 to ch5 are in visible wavelengths, channels 6 to 10 are in near infrared wavelengths, while channels 11 and 12 are in infrared thermal wavelengths. Alfa and entropy are derived by DLR based on single look complex data in L band (Y. Yvinec et. al., 2003).

The simple examples of the minefield indicators show the potential of two extremes, very high spatial resolution and very large spectral resolution and different physics (active and passive, polarized, extreme different wavelengths, from ca 0.45 mm to 60 cm), while comprehensive statistical analysis is under way and will be reported elsewhere.

5 CONCLUSIONS

Intensive research of the minefield indicators is under way, mainly in the frame of EC funded project SMART and will be continued after its end. The two compared cases show that use of four radar bands X, C, L and P, (P and L polarimetric) combined with multi-spectral imagery (twelve channels) enables detection of important kinds of minefield indicators. The preliminary results approved potentials for successful discrimination of important land cover classes, of manmade objects, that are important for assessment of the mine suspected area and minefields. Extraction and statistical analysis the data about the electromagnetic signatures of the minefield indicators is under way.

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REFERENCES

ARIS 2000, Workshop on the Needs of Airborne and Spaceborne Data for Minefield Survey, Ispra (Va), Italy, 9-10 March 2000


