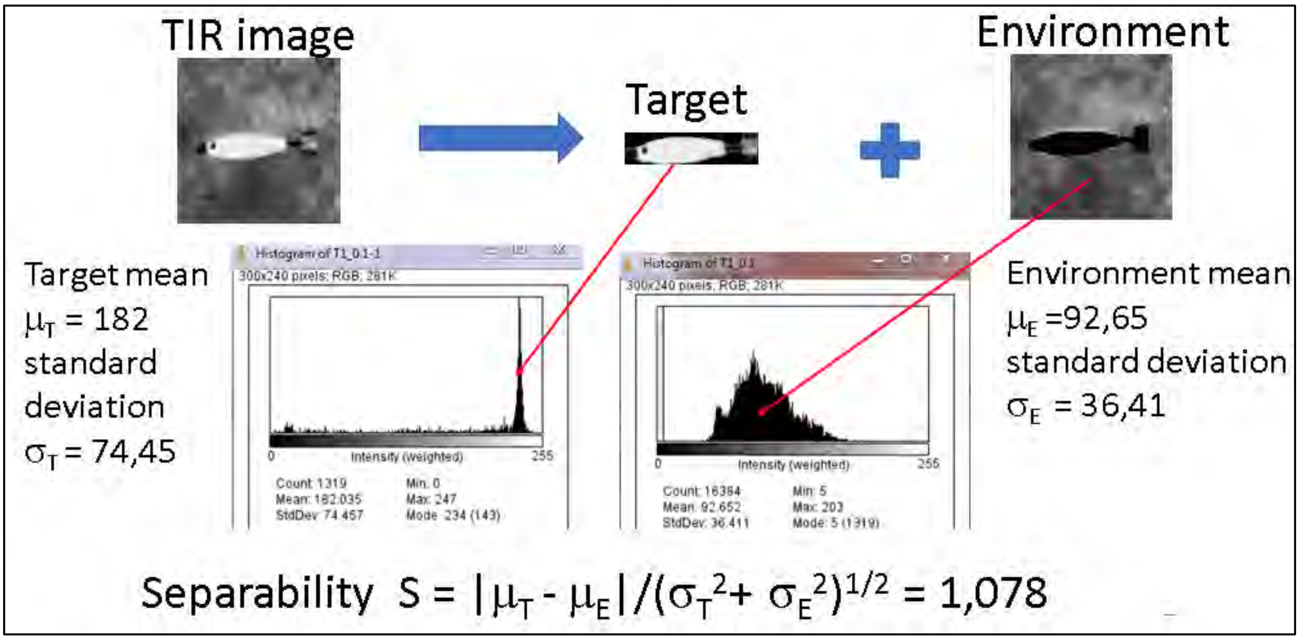
Norwegian People's Aid

Report

Testing of remotely piloted aircraft systems with a thermal infrared camera to detect explosive devices at contaminated areas and validation of developed standard operational procedures

Milan Bajić



Report

Testing of remotely piloted aircraft systems with a thermal infrared camera to detect explosive devices at contaminated areas and validation of developed standard operational procedures

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Milan Bajić

Foreword February 2021

Testing of remotely piloted aircraft systems (RPAS) with a thermal infrared camera to detect landmines and unexploded ordnance (UXO) has been done in the years 2018, 2019, and the NPA report was finished on 2nd February 2020. In the meantime appeared several new contributions relevant to this topic, [1], [2], [3], [4], [5], while some of earlier references became interesting, [6], [7], [8], [9], [10]. In [2] was used term “unconventional minefields”, which can be correlated with cluster munition remnants described in [11]. This “new” situation is not a clear post-conflict one, the efforts to build a sustainable humanitarian mine action system, [12], [13], [14], [15], [16] have many obstacles.

The most significant new contributions are given in [1], where is used longwave infrared (7,5 – 13,5 μm), multispectral, green(530-570 nm), red (640-680 nm), red edge (730-740 nm), near-infrared (770-810 nm) channels and supervised learning algorithms using a Faster Regional-Convolutional Neural Network (Faster R-CNN).

Interesting facts about scatterable plastic landmines PFM-1 (“butterflies”) is their thermal behavior in terrain without vegetation, after night, expressed by statement catch the “butterflies” in the morning. The PFM-1 can be detected during the early-morning hours when the thermal flux is high, [2], [3]. The PFM-1 mines have a higher thermal conductivity and their temperatures rise earlier than that of the soil around them. In the NPA report, the problem of thermal contrast is analyzed in chapter 4 (pp. 36-43) for 11 different metallic and plastic landmines and UXOs on the surface of the soil. In [5] is analyzed the dependence of thermal signatures on the soil surface, of buried nonmetallic landmines on soil physical parameters, moisture, types of contents of landmines and are shown daily changes for two different soil types, Sarajevo and Kuwait. Here are compared differences between one numerical and analytical model and the possibility to predict daily thermal variation on the soil surface, if soil parameters are known. This direction of research should be followed and included in a set of tools for longwave infrared landmine and UXO detection.

Detection of ferromagnetic UXO is a constant problem and advancements in detection technology are welcomed, [2], [6]. A new actual case from Ukraine [2], [4] defines as “unconventional minefields”, the areas contaminated with explosive warheads of attack by Multiple Barrel Rocket Launcher (MBRL), across a wide area. The ground-based magnetometric methods, usually used in mine action, have too small capacity and surveyors are exposed to explosive threats. The aeromagnetic survey [4] has a large area capacity, and additionally, this method allows to distinguish between exploded and unexploded rounds, allowing to direct and prioritize UXO clearance efforts.

The RPAS based survey with electronically optical and magnetic sensors dominates for smaller areas, [1], [2], [3], [4], [5], [6], [7], in most published cases, but the examples of in-country assessment of suspected hazardous areas are rare, [10]. The experience from [10] encourages the application of many RPASs and survey the large areas, despite the low flight autonomy of each RPAS itself.

Implementation of machine learning, artificial intelligence, deep learning methods in RPAS based detection of UXO and landmines offers several solutions and this trend will continue, [1], [8], [9].

The new European victim of contamination by explosive remnants of war and hybrid war is Ukraine, there exist all well-known problems, [12], [14], [15], [16] but also new phenomena [13].

Zagreb 19 February 2021 Milan Bajić

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Norwegian People's Aid

Contents

Executive Summary

The Norwegian People's Aid (NPA) decided to test operationally and technically the technologies of the remotely piloted aircraft system (RPAS) with longwave infrared sensors (thermal infrared - TIR), for the non-technical survey. The aim was to advance initial competencies to the level needed to deploy these new technologies in land release (LR) projects in Iraq and other countries. Note that until 2019. in Iraq are done only surveys by RPAS with a color camera on board.

The tests are realized by the NPA Bosnia and Herzegovina (NPA BH) in seven locations in Montenegro with the cooperation of their Ministry of Interior and in nine locations in Bosnia and Herzegovina. In the test are used besides thermal infrared sensors, color sensors in visible wavelengths, and LIDAR which was not planned. The experience and skill of the NPA BH team for RPAS based surveys with color cameras, which provide images and videos, enabled very intensive field missions and collecting the operational experience in the variety of environmental conditions in European terrain types.

The new challenge was to understand the relations between the targets, environment, and modes of a thermal infrared survey, and to transform it into operational procedures. The color visible survey is almost always applicable if the light conditions are on average normal. For the thermal infrared survey, the Sun insolation is obligatory, but this is not enough, the thermal contrast Target/Environment shall be > 1. The TIR survey is additionally limited by the emissivity ε of the target, $\varepsilon<1$, and by the atmosphere attenuation which is negligible if UAV heights are lower then 10 m. The thermal contrast Tt/Te of the target Tt and the neighborhood Te shows significant daily changes.

For the reliable detection of the target, the number of pixels on its area should be high, this is defined by Johnson's model in the next chapters of the report. The landmines and unexploded targets, eleven different examples, are selected for empirical analysis and development of the criteria and procedures that can provide the needed probability of the target detection and classification. The technical mathematical Johnson's model was applied, while it links spatial resolution of the thermal infrared sensor, target dimensions, and height of RPAS during the survey.

An important outcome of the considered test is a large amount of thermal infrared, visible color images, videos, and digital surface models (DSM), collected in the suspected hazardous areas (SHA) in Montenegro and Bosnia and Herzegovina. This treasury enables to continue research of processes of RPAS based surveys with three considered sensors in a variety of scenes and the advancement of NPA standard operational procedures (SOP).

The testing was concluded by the NPA workshop in which is related to the achieved contribution with experience of NPA in Iraq, with results from RPAS based assessment of SHA in Bosnia and Herzegovina.

Several advanced sensor technologies, usable from RPAS, that can provide a positive impact on land release and detection of the landmines, the unexploded ordnance, the cluster munition, and the improvised explosive devices are presented at the NPA workshop and in this report.

1 Introduction

The general aim of testing

The NPA decided to test in several phases the technologies used for the survey via remotely piloted aircraft systems (RPAS) that could cause a positive impact on the Land Release, Fig. 1.1. Three phases of testing NPA's RPAS survey are based on thermal and color sensors, aimed for detection of the explosive devices in Bosnia and Herzegovina and Montenegro. This served to collect the experience in a variety of difficult and challenging scenarios and to influence the standard operations procedures for the surveys. During the missions in Montenegro LIDAR was added as the third sensor and was applied at one location. Later, in October 2019 LIDAR was applied in several locations in Bosnia and Herzegovina. The strategic goal of the testing in Montenegro and Bosnia and Herzegovina is to prepare RPAS based NPA mission in Iraq.

		
Thermal Imager Zenmuse XT 640 × 512 pixels, Pixel Pitch 17 µm, Sensitivity (NEdT) <50 mK at f/1.0, Photo JPEG (8 bit) / TIFF (14 bit), Video MP4,30 Hz, 720x640 pixels, Lens 9mm, Field of View 69°x56° Software FLIR tools, MapInfo, Pix4D, [1], [2].	**Color camera Zenmuse X4S** 5472 x 3648 pixels, Field of View 84° Video 3840x2160 pixels, Photo DNG, JPEG, Software Pix4D, iPad and DJI GO 4, [4].	**LIDAR on RPAS Matrice 200** Software pix4d, [5], LiDAR360 [29] https://enterprise.dji.com/news/detail/how-lidar-is-revolutionizing-mapping-and-geospatial-data http://www.greenvalleyintl.com/wp-content/GVITutorials/index.html

Figure 1.1 The sensors used in the NPA testing project

Information and data about the considered sensors, [1], [2], [3], [4], [5], are available in NPA Bosnia and Herzegovina, while basic data are shown in Fig.1.1. The color camera provides visible color images (5472 x 3648 pixels) and color video (3820x2160 pixels) in wavelengths from 400 to 700 nm. Due to the 3-dimensional gimbal, recorded data are without blurring and are very sharp, although they are collected from RPAS. The color camera has high sensitivity and is usable in a wide range of luminance levels.

The longwave infrared (thermal infrared) camera records the own radiation of objects in the longwave infrared wavelengths range from 7,5 to 13,5 μm and can be used even if Sun's illumination is absent. The radiation is proportional to the object's temperature multiplied by the emissivity (ε<=1) of the substance of the object. The recorded data depends on several influencing factors. The detection of objects depends on the thermal difference between the object and its environment, on the attenuation of the atmosphere, on looking angle from camera to object.

The detection of objects in color visible recordings is natural to human perception and is straightforward, while in the thermal infrared recordings it is not. Despite the mentioned differences, the fusion of data, information from visible color, and thermal infrared sources increase the likelihood of target detection. The report analyzed different aspects of the thermal infrared survey from RPAS, with a recommendation to the standard operations procedures (SOP) of a thermal infrared survey and proposal to use a camera in which are integrated visible color and thermal infrared sensor. Once the integrated dual-sensor camera is available, the development of fusion will be a simple step.

The LIDAR is an active sensor, in near-infrared and/or ultraviolet wavelengths. It radiates quick laser pulses and records received optical echoes from the object's surface. The received pulses form a cloud of data after processing are obtained high-resolution digital surfaces, digital terrain elevation model (DSM). LIDAR can be used at night, while it requires no external light for mapping.

The technology of RPAS based survey systems reached in years 2017-2019 mature level of full automation of mapping with each sensor. The user can plan the survey mission on a computer and conduct fully automated flights. Earlier versions of RPAS based surveys had to have the man (pilot) in the flight loop.

The considered sensors Fig. 1.1 are supported with software for RPAS survey missions (planning and performing) and for the recordings processing that enables the deminer – surveyor to produce high-quality products of the survey mission, in a short time after the mission. Due to this fact, the testing will not consider this part of the survey missions.

Opposite to this aspect, the processing of collected information and data and their interpretation are not developed yet to a similar level, especially regarding the matching thermal survey mission parameters to the targets and the thermal state of the environment.

The use of LIDAR is also implemented in NPA Bosnia for 3D analyses of the terrain for purpose of assessment of risk caused by exploded ammunition storage, [3], [16]. New use of LIDAR is initiated at the workshop, the detection of indirect indicators of the suspected hazardous areas (SHA), and the detection of the improvised explosive devices (IED) on the motorways, roads, and paths in Iraq. NPA Bosnia and Herzegovina collected on 30 October 2019 LIDAR data from mountain Vlasić and sent results on 23 January 2020, to be included in the report.

Products from recordings collected via RPAS

Raw Digital Image: is obtained without processing and is oriented in the direction of RPAS flight. Preserves the small objects.
A sequence of images: in flight direction. It must be used with flight route records.

Geocoded Image: its content is geographically oriented. Some small objects can be lost.
Digital Ortho Mosaic: many images resampled, geographically oriented, and combined into a large digital product (e.g. 893 images for Rogami ASA, Fig. 2.4, Fig. 2.5). Geocoded to the topographic maps. Some small objects can be lost, [17].
Digital Surface Model: digital data present a relative height of the surface including trees, forests, man-made objects. A difference between DSM and the official digital elevation model (DEM) can be significant, depends on the difference between the ellipsoid used in GPS and the geoid of the Earth.
Digital Elevation Model: digital data present the height of the ground surface without trees, forests, man-made objects and are used in a topography map.
Digital Video: shows a ground surface beneath the RPAS in the direction of the flight. It must be used with flight route records.
LAS: is a dataset that stores reference to one or more LIDAR data sets, [29].

Phases of testing

The first phase was realized in 2018 in Bosnia and Herzegovina and it plunged the NPA team in the thermal aspects of a survey from RPAS. In this phase the critical factors for the survey are recognized, [18]:

- Thermal contrast between a target and a ground,
- a suitable part of the day,
- a minimum number of pixels for reliable detection of the target.

The second phase was realized in two steps. The first step was in June – July 2019 in Montenegro in a variety of terrain types. Their Ministry of Interior defined regions for survey by RPAS, provided data and information about the unexploded ordnance, cluster munition, exploded ammunition depot, and participated in the survey missions. This step resulted in several kinds of products, section 1.2, Tab. 2.1.

The second step of the second phase was realized in Bosnia and Herzegovina at the end of July 2019 and in cooperation with the consultant. It introduced very determined procedures and criteria for a reliable thermal survey, Chapter 6, Fig. Tab. 3.1. Although not planned before, in October 2019 continued testing of LIDAR surveys, TIR surveys in Bosnia and Herzegovina, initiated by the information and conclusions of the NPA workshop. 16-17 October 2019.

The testing surveys in Bosnia and Herzegovina and Montenegro resulted by a significant quantity of the visible color images and the videos in wavelengths from 400 to 700 nm (visible), longwave infrared (LWIR, instead of acronym LWIR, we will use an acronym TIR - thermal infrared) images and video recordings in wavelengths from 7,5 to 13,5 μm and of LIDAR data.

Lessons learned from the previous phase of the trial, conducted in 2018, in Bosnia and Herzegovina, have shown that the height of RPAS flights is a critical factor for thermal surveys. The considered targets (landmines, UXO) are not visible on TIR images and videos obtained from 15 m and 30 m flight heights. Because of that, testing of acquisition of TIR images and videos was changed. For selected eleven targets it was done systematically in Blagovac NPA test site in Bosnia and Herzegovina. Thermal images and videos are collected at flight heights from 2 m to 10 m, by step 1 m, with additional TIR markers for spatial resolution calibration. This set of data enabled deeper analysis of TIR surveys of the landmines and the UXO on the ground surface and was crucial for the assessment of TIR survey procedures, which shall be added as an annex to NPA's standard operations procedures (SOPs) for RPAS survey.

Besides the color visible and thermal images and videos, the NPA Bosnia and Herzegovina team initially collected LIDAR data at several locations, from Fig. 3.8 to Fig. 3.17, for further analyses. This set of LIDAR data can serve for research and development of the future LIDAR application for targets survey (landmines, UXO, improvised explosive devices). This is initiated at the mentioned NPA workshop.

1.4 General resume and comparison with country assessment of suspected hazardous areas in Bosnia and Herzegovina

The reported NPA testing was focused on the survey by the thermal sensor (and later added LIDAR) and is aimed to advance detection of the explosive devices at contaminated areas in Montenegro and validation of developed standard operational procedures. Two kinds of outcomes are the results:

- collected experience in NPA about the thermal infrared survey by RPAS in a variety of complex situations in the European environment,
- sets of collected thermal infrared and LIDAR data, a treasury for the advancement of the processing and interpretation for the needs of a Land Release.

If considered and compared with results of country suspected hazardous areas for Bosnia and Herzegovina, D. Lisica in [6], the following could be concluded:

- detection of the explosive targets is the main topic in NPA testing,
- in 1030 km^2 SHA country assessment in Bosnia and Herzegovina, data on mines and explosive devices cover 9,4 %,
- in SHA country assessment all Non-Technical Survey (NTS) methods are applied and RPAS at 115,5 km^2 only with a color sensor.
- Regarding the explosive objects (landmines, unexploded ordnance, improvised explosive devices) in Iraq can be expected a different situation, according to data and information provided at the NPA workshop by Mats Hektor in [7].
- All mentioned was done to prepare a third NPA phase of testing and the deployment of a thermal survey from RPAS in Iraq. The crucial feedback from NPA Iraq was initiated and started at the workshop, the first inputs are included in this report, [7].

At the workshop are derived following conclusions:

- Training of staff of NPA Iraq should be focused more on processing, analyzing, and interpreting recorded data than on the flights' skills. There is a need for training of Ops management for planning purposes.
- The nature of the contamination in Iraq (IED mixture with landmines) and the security situation will require more effort in the planning and execution of the trial.
- The scientific/ expert support in the planning and implementation of the third phase of the UAV trial in Iraq should be more intensive.

2 Overview of the regions, situations, recordings in Montenegro

The testing of RPAS based thermal infrared surveys is conceived in cooperation with the Ministry of Interior of Montenegro. The proposed locations provided data, and information about the possible existence of the unexploded ordnance, cluster munition, exploded ammunition storage, provided field support, and participated in RPAS based surveys.

The testing of RPAS in Montenegro includes 7 locations where the presence of cluster munition and explosive remnants of war were indicated (Tab. 2.1, Fig.2.1).

Table 2.1 Overview of results of RPAS survey in Montenegro

Name	Color visible			LIDAR	Thermal infrared	
	Video	Images	Mosaic	DSM and LAS	Video	Images
Vranske njive	1 file 1,56 GB	19 files 129 MB	-	-	-	8 files 5,83 MB
Rogami settlements	-	627 files 5 GB	1 file 1,07 GB	5 files 3,04 GB	-	-
Rogami Ammunition Storage Area	-	894 files 9,43 GB	1 file 663 MB	5 files 3,08 GB	-	-
Plav Prokletije Plav Murino	7 files 18,58 GB	229 files 1,85 GB	-	-	-	-
Lovćen, 6 km from a car, 10 kg, summit of steep mountain	2 files 1,74 GB	7 files 56,6 MB	-	-	2 files 206 MB	54 files 42,6 MB
Verige	2 files 3,9 GB	9 files 52,2 MB	-	-	-	45 files 34,5 MB
Arza	1 file 3,81GB	5 files 23,3 MB	-	-	1 file 45 MB	-
7 locations	**13 files**	**1781 files**	**2 files**	**10 files**	**3 files**	**107 files**

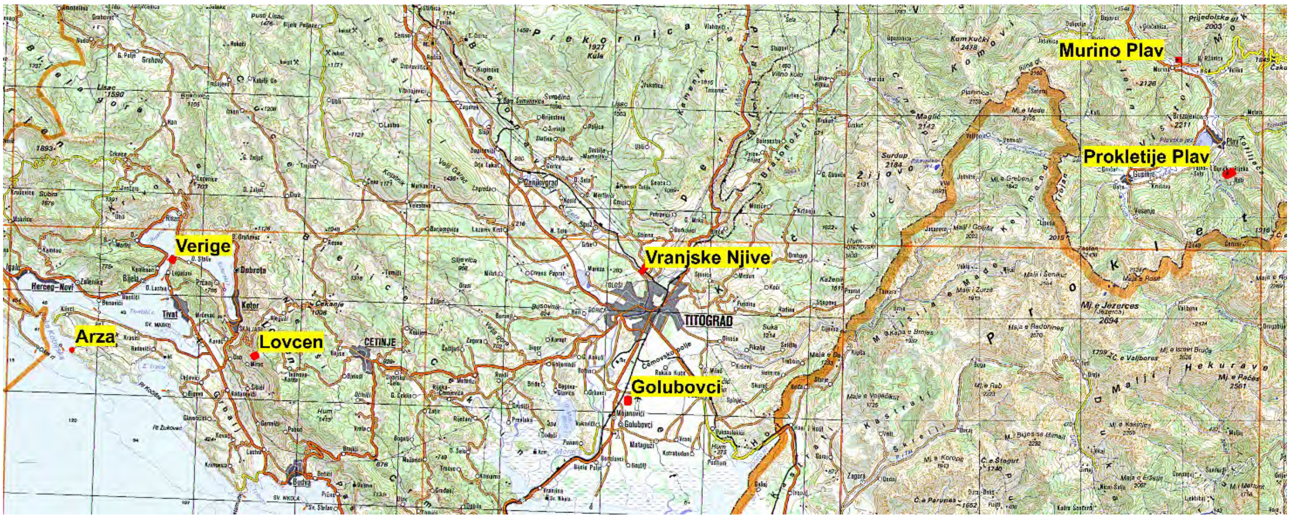


Figure 2.1 Overview of selected location for RPAS testing in Montenegro. [NPA Bosnia and Herzegovina].

The collected color visible, thermal infrared and LIDAR recordings enabled the development of the following products: color mosaics, digital surface model (DSM) from LIDAR recordings, thermal images, and video. The flight height for the thermal survey in June – July 2019 was too high for searched explosive targets. There is a plan to repeat in 2019 the survey with needed heights in regions where exist or are expected remains of UXO, cluster submunition if weather conditions allow. In repeated surveys should be applied procedure developed for TIR survey, flight height and thermal contrast should match the dimensions of targets.

2.1 Vranske Njive

Initial information: North of capital Podgorica (former Titograd). Ammunition from I and II World War. The dropped explosive items in this area are partly in the river, partly on the bank. Information about explosive targets in the database of the Ministry of Interior of Montenegro was collected from citizens. Suspected Hazardous Area 9,000 m^2. Was planned survey with color visible and thermal sensors, from RPAS at flight height > 30m.

Outcome: The area is overgrown and detection of explosive targets was not possible, although visible color and TIR recordings are collected. The high water level of the river Zeta caused an interruption of a mission. The survey should be repeated at the lower flight height and a lower level of Zeta.

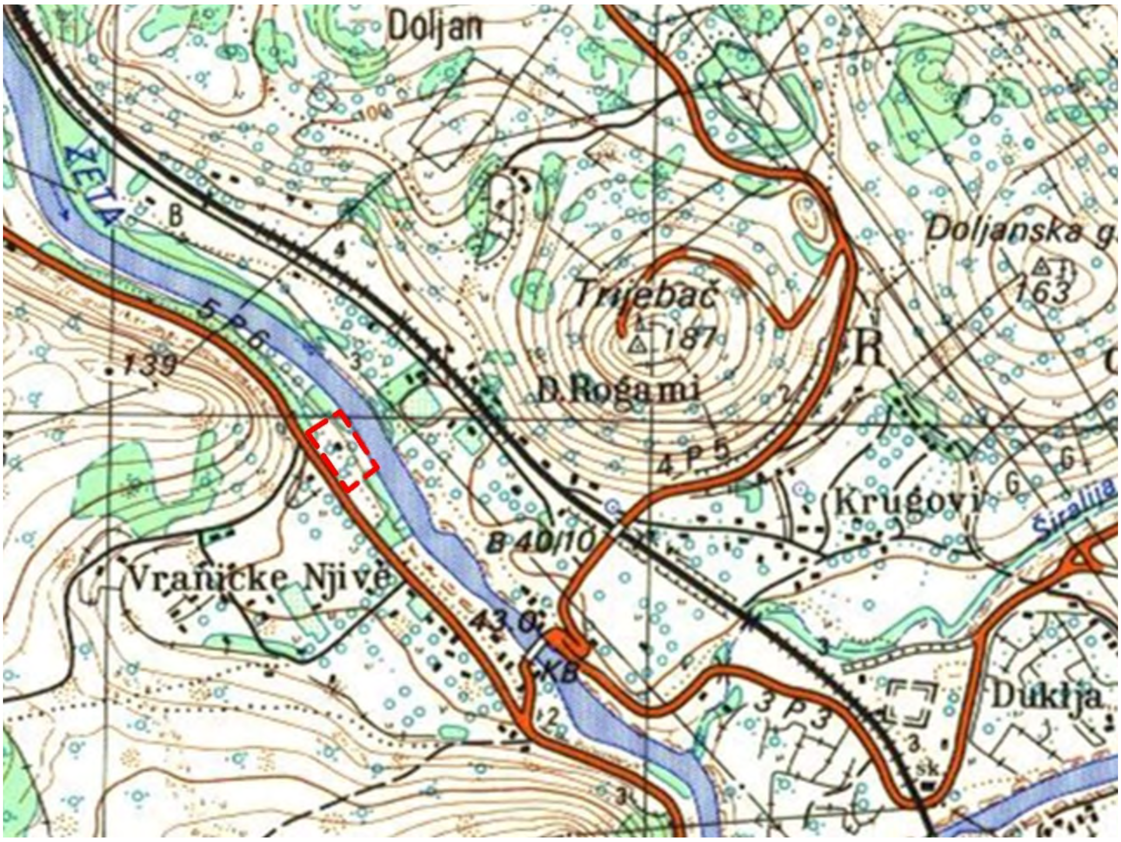


Figure 2.2 Map of Vranske Njive. [NPA Bosnia and Herzegovina]

2.2 Ammunition storage and settlements Rogami

Initial information: North of capital Podgorica (former Titograd). The ammunition storage area and the exposed settlements cover 880.000 m^2, while the ammunition storage area is 50.154 m^2. A risk assessment of the ammunition storage site and exposed settlements is needed.

Outcome: The flight height was matched to terrain, < 50 m, flight speed 2m/s. The most valuable survey in Montenegro has been done on this exploded Ammunition Storage Area Rogami (ASA Rogami) and settlements around it, [3], [16], Fig.2.3. In the survey are collected visible color images and LIDAR data and produced visible color mosaics, Fig. 2.4, Fig. 2.5a, and digital surface model (DSM), Fig. 2.5b. The color visible mosaic provided data about the current situation in ASA Rogami and the nearest settlements. The 3D model was developed from DSMand it enabled the risk assessment for populated places in the vicinity of the ASA, [16]. This is one of the most valuable outcomes from RPAS tests in Montenegro.

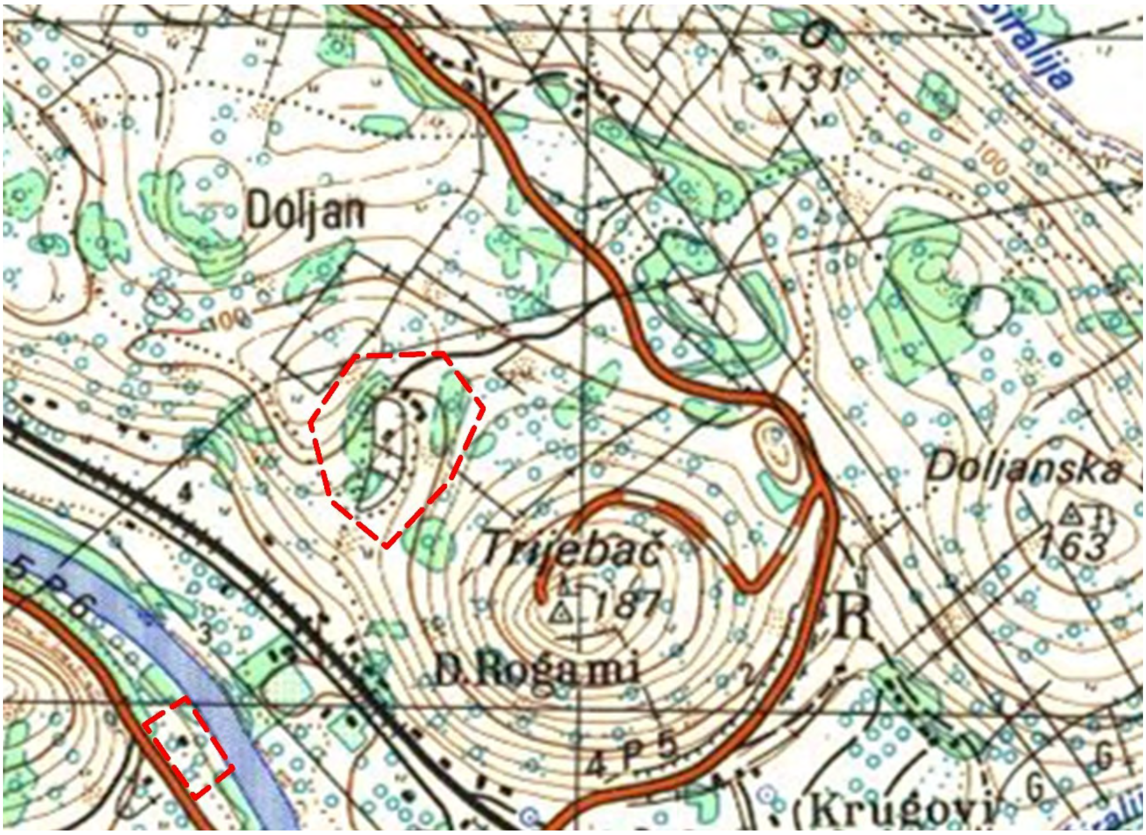
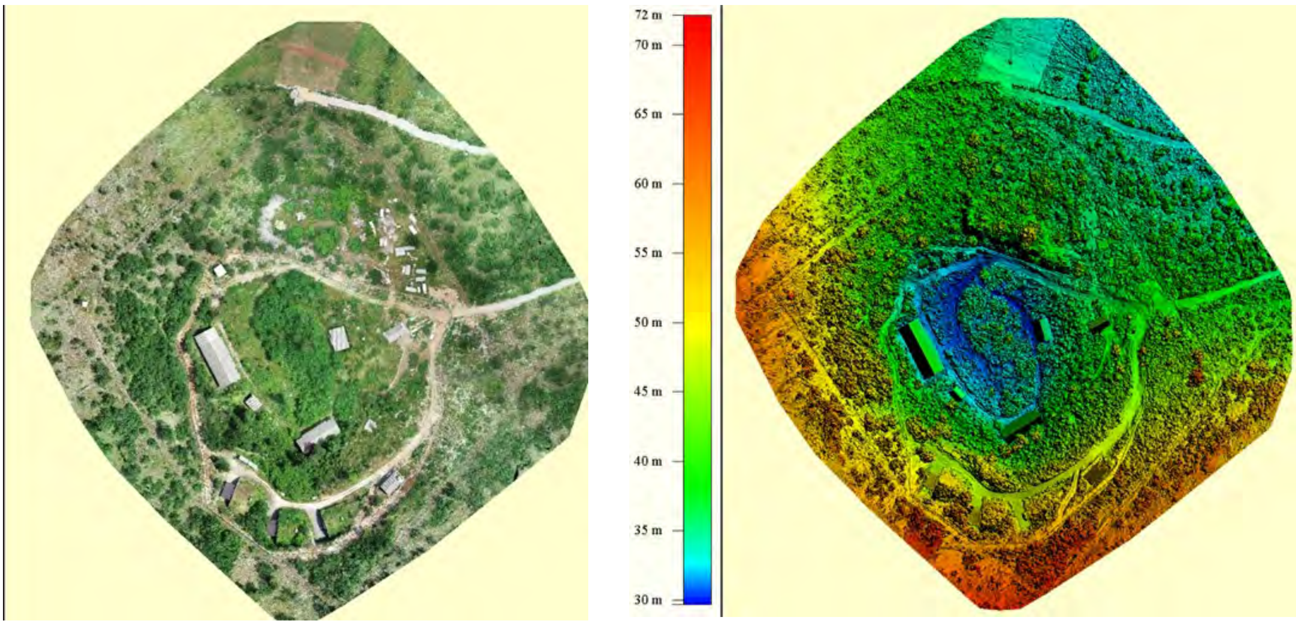


Figure 2.3   Map of Rogami. [NPA Bosnia and Herzegovina]

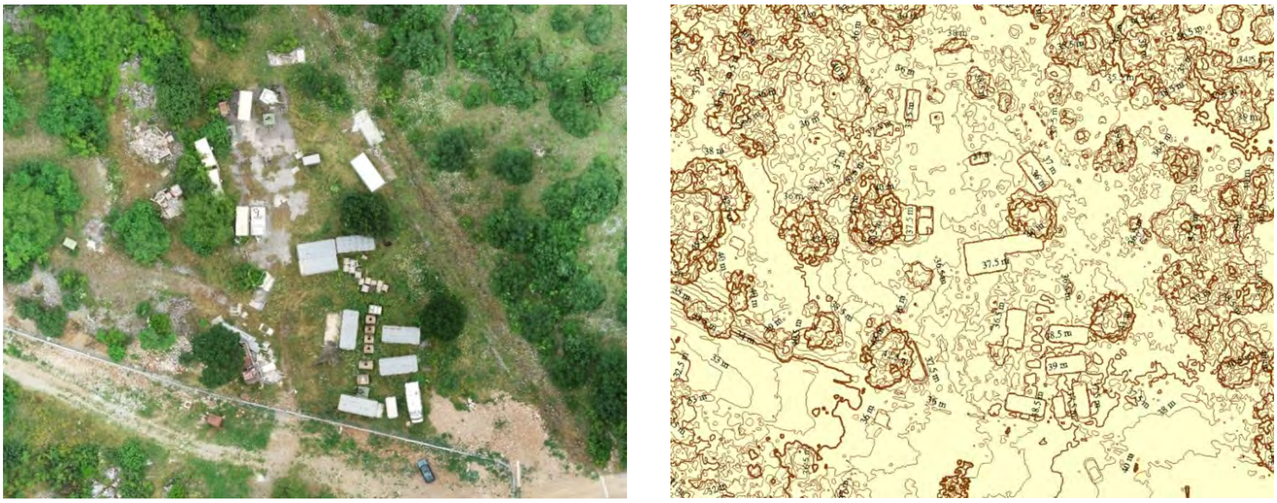
The LIDAR data have the potentials to advance RPAS based detection of the explosive remnants of war, the engineering objects, Fig. 2.6, Fig. 2.7, the cluster munition on the land surface, the traces of buried improvised explosive devices. Since the plan to use LIDAR on RPAS in Montenegro was not known to the author of the report before 16.10.2019 (NPA workshop in Montenegro), it was not possible to prepare data acquisition for cases from the former sentence. Nevertheless, NPA BH collected LIDAR data later, from several locations in Bosnia and Herzegovina, Tab.3.1, figures from Fig.3.9 to Fig.3.17.

Figure 2.4 The color visible mosaics of the settlements near ASA Rogami. [NPA Bosnia and Herzegovina]



a b

Figure 2.5 a) Color visible mosaic, b) digital surface model (DSM) of the ASA Rogami. [NPA Bosnia and Herzegovina]



a b

Figure 2.6 a) Part of the color visible mosaic of the eastern part of ASA Rogami, b) contour lines derived from DSM of the same area. The contour lines show the relative heights of surface objects.

Figure 2.7 The contour lines overlapped onto the color visible mosaic.

2.3 Community Golubovci

Initial information: Community Golubovci near Airport Podgorica was contaminated with remnants of the cluster munition. Information and data about the suspected region are provided by the Montenegro Ministry of Interior, for example in Fig.2.8. Recording by RPAS was aimed to examine evidence by the visual checks on the existence of mines and cluster munition remnants (CMR). Recording of the given directions of search should provide additional data that could not be collected through past non-technical survey activities. Flight height was planned to be < 15 m, flight speed 2m/s.

Outcome: RPAS flight-tested but forbidden, due to restricted zone for RPAS flights of the nearest airport.

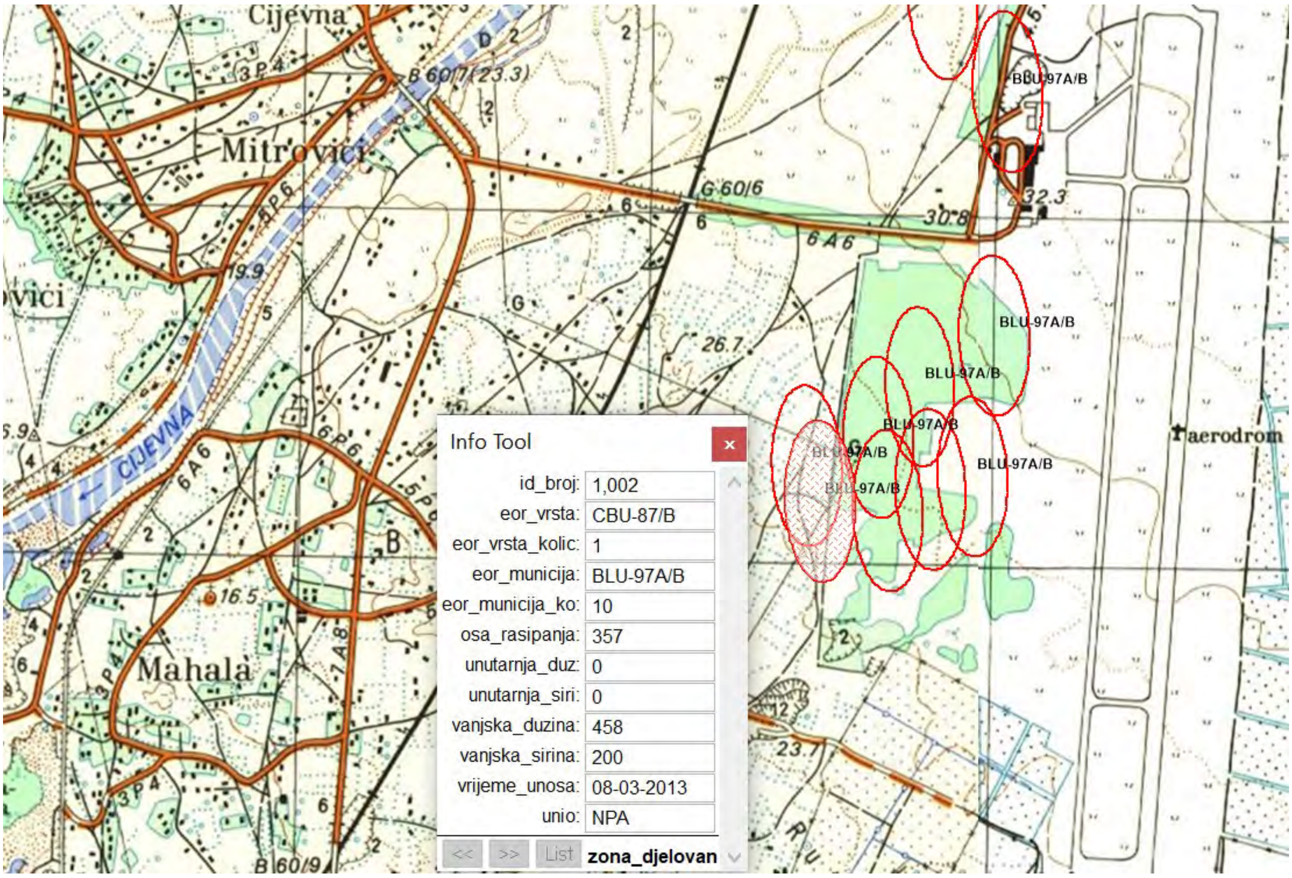


Figure 2.8 Map of selected cluster munition strike for RPAS survey near Airport Golubovci. [NPA Bosnia and Herzegovina]

2.4 Prokletije Plav

Initial information: Municipality of Plav, Fig.2.9. Information on possible cluster munition strikes was collected from citizens by the Montenegro Ministry of Interior. The RPAS mission was aimed to investigate the area for a non-technical and technical survey of cluster munition remnants at contaminated area Plav.

Outcome: The color visible images and videos are collected only. A thermal infrared survey was interrupted due to rain. No traces of cluster munition are detected.

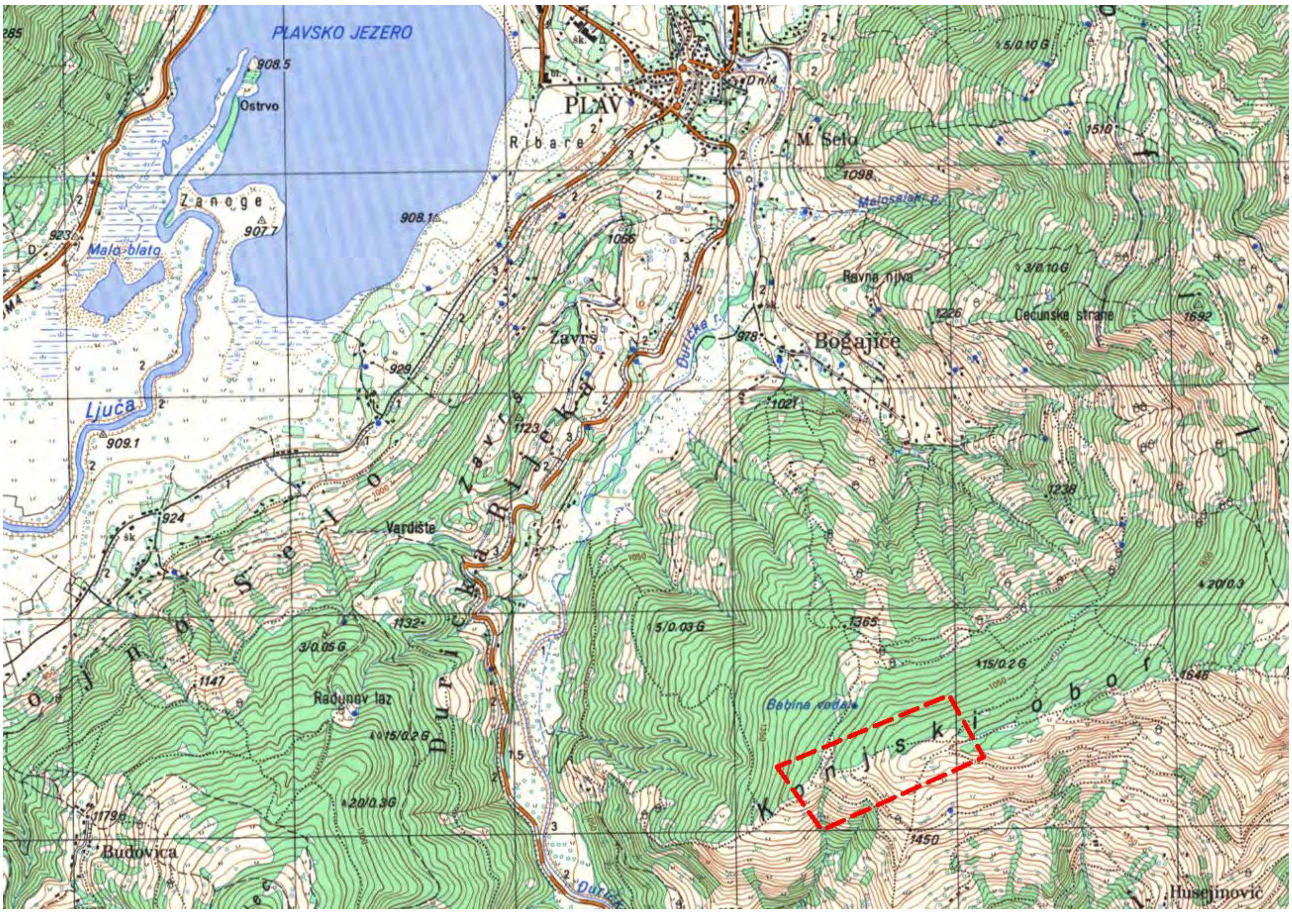


Figure 2.9 Map of Prokletije Plav. [NPA Bosnia and Herzegovina]

2.5 Murino Plav

Initial information: Municipality of Plav, Fig.2.10. Information on possible cluster munition strikes collected from citizens by the Montenegro Ministry of Interior. The aim of the mission with RPAS was the investigation for a non-technical and technical survey of cluster munition remnants at the contaminated area Murino Plav.

Outcome: Collected color visible images and color video only. The thermal infrared acquisition was interrupted due to rain. No traces of cluster munition are detected.

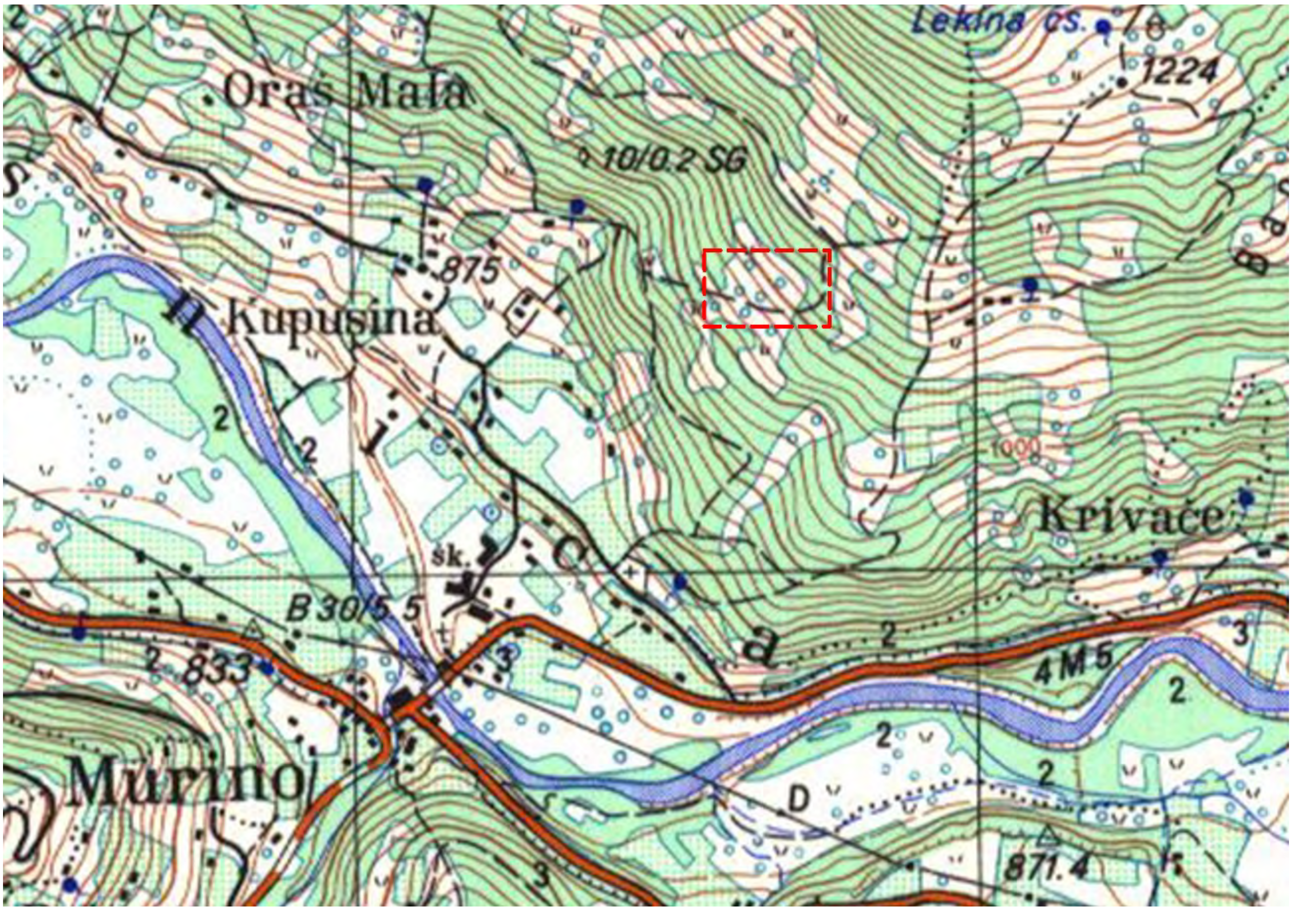


Figure 2.10 Map of Murino Plav. [NPA Bosnia and Herzegovina]

2.6 Lovćen

Initial information: A mountain above the Bay of Boka-Kotor, Montenegro, Fig. 2.11, Fig.2.12. Unexploded ordnance - a cannon grenade from an Austro-Hungarian ship in the 1st World War. The aim was recording by RPAS to examine the evidence (visual checks on the existence of unexploded ordnance. Recording of the given directions of search that may provide additional data that could not be collected through past non-technical survey activities.

Outcome: Collected color visible and thermal infrared images and videos. Detected the unexploded ordnance - a cannon grenade from an Austro-Hungarian ship in 1st World War, Fig.2.12. Flight height matched to terrain, <15 m, flight speed 2m/s.

NPA planned to repeat the survey in 2019 despite the difficult access if weather conditions allow. Flight height and thermal conditions shall be matched to expected targets and environments.

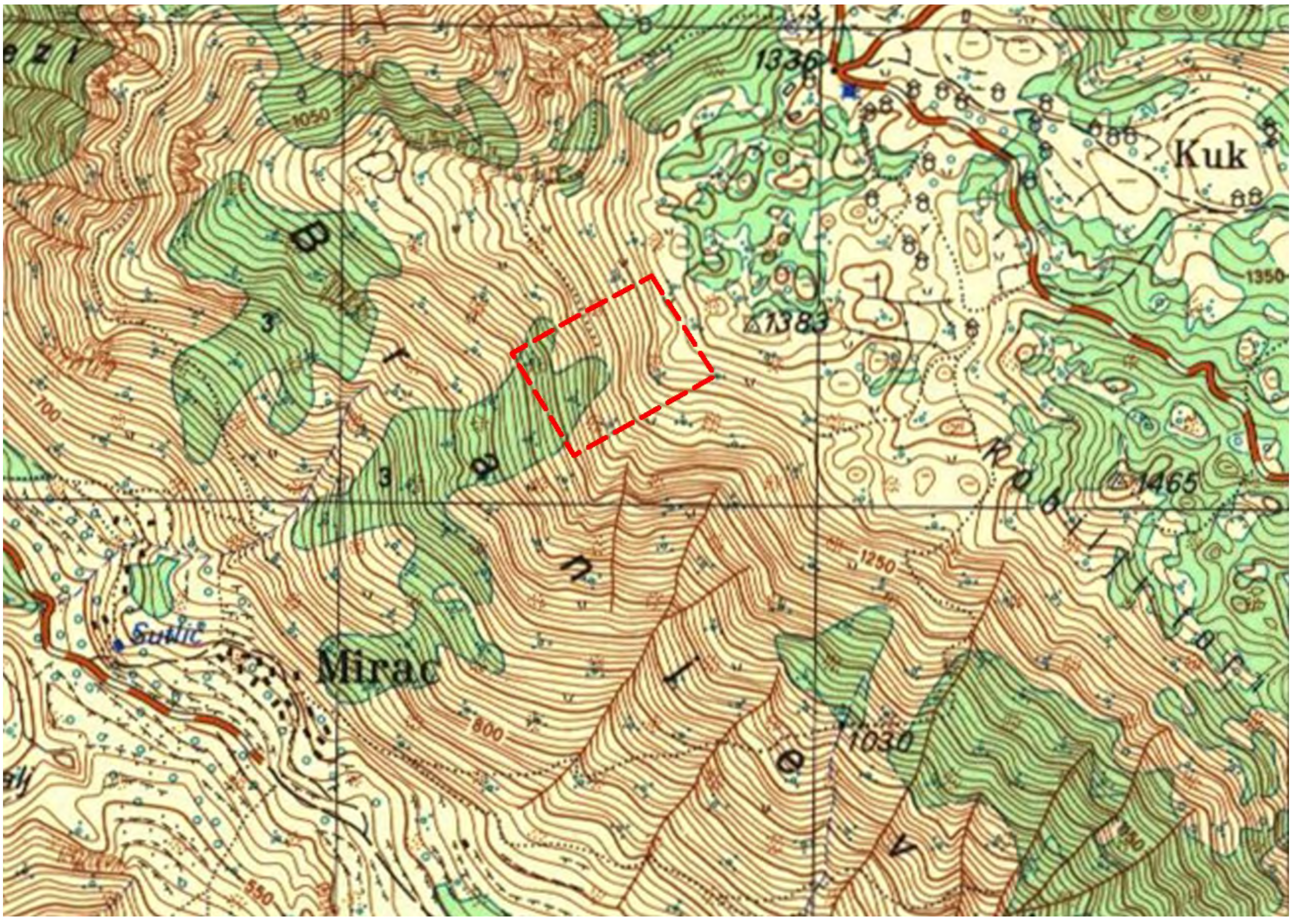


Figure 2.11 Map of Lovćen. [NPA Bosnia and Herzegovina]

a

b

Figure 2.12 a) Color visible image of the detected target. b) TIR image of the same target. Note that thermal contrast is to low and is not positive in favor of target. [NPA Bosnia and Herzegovina]

2.7 Verige

Initial information: Survey with RPAS after an unplanned explosion of an ammunition storage area 96.000 m^2. The risk assessment of populated places in the vicinity of an ammunition storage site was anticipated. The flight height was matched to terrain, < 50 m, flight speed 2m/s.

Outcome: Color visible images and video and TIR images are collected. Interrupted due to rain. No detection by color and thermal recordings. Should be repeated with flight matched to targets and the terrain.

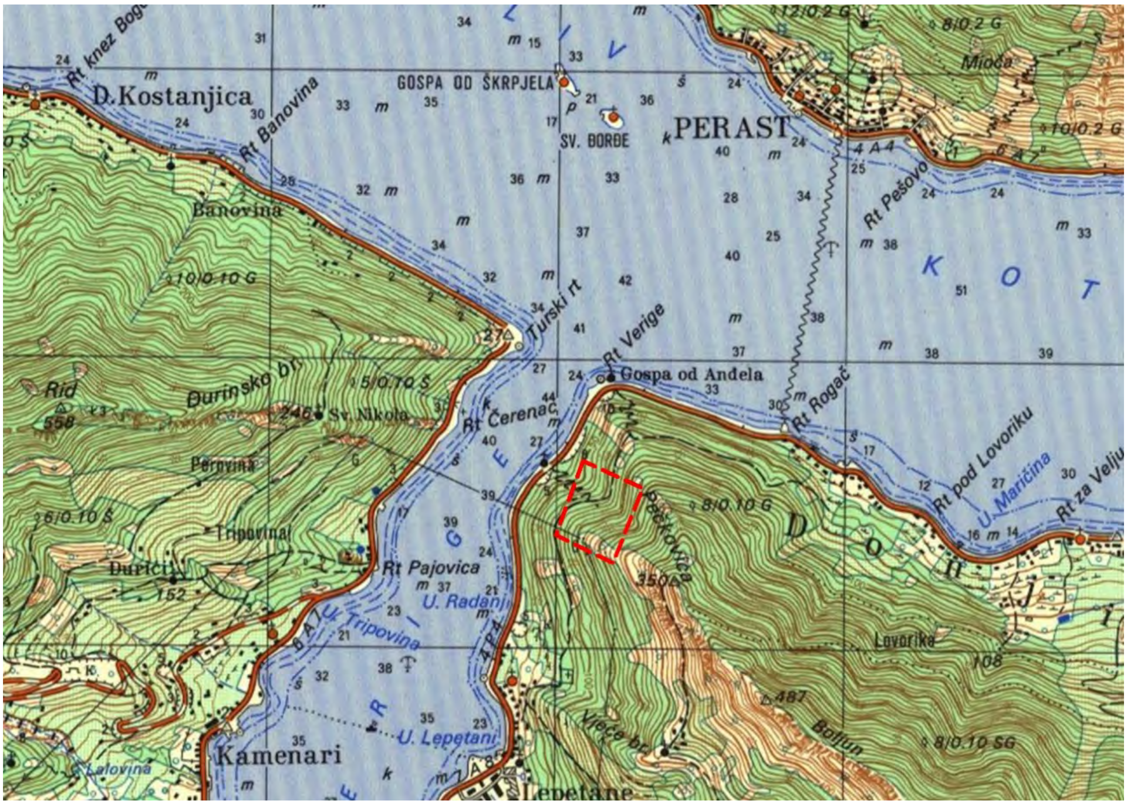


Figure 2.13 Map of Verige. [NPA Bosnia and Herzegovina]

2.8 Arza

Initial information: Non-technical survey is planned. The recordings by RPAS should be done to examine the evidence (visual checks on the existence of cluster munition remnants). Recording of the given directions of search that may provide additional data that could not be collected through past non-technical survey activities.

Outcome: No detection by color and thermal recordings

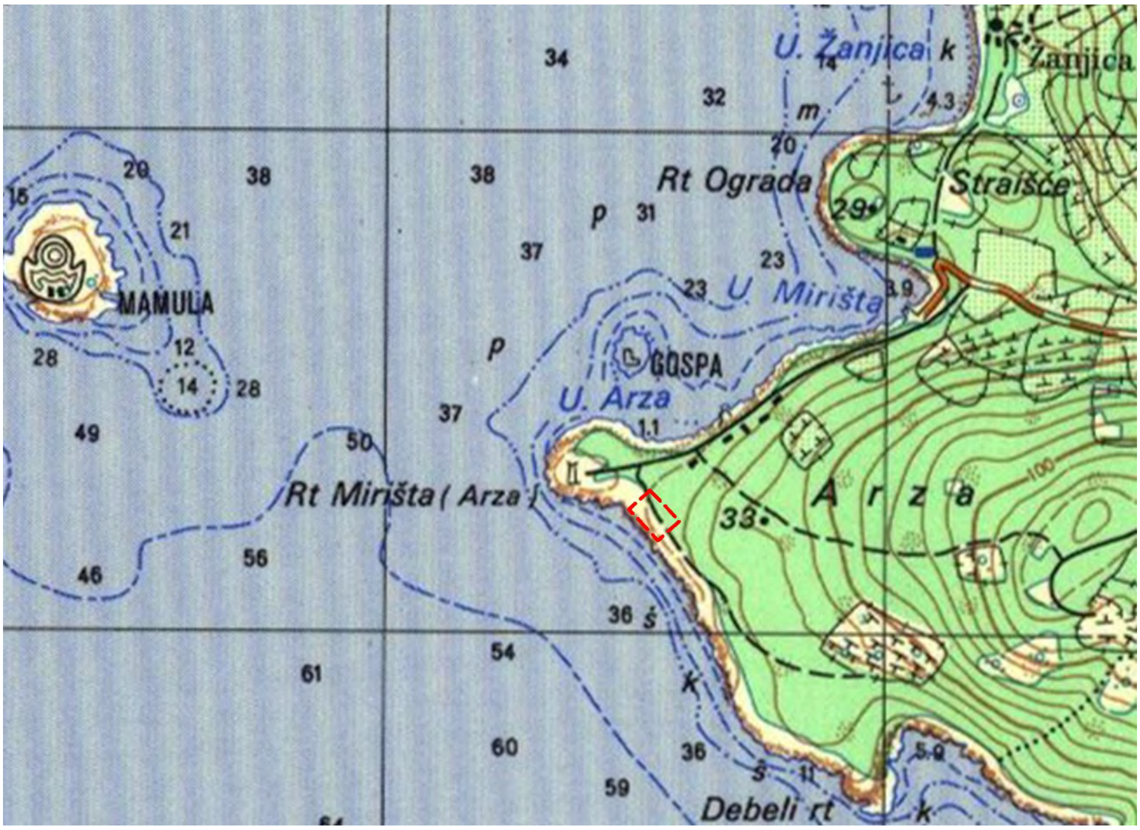
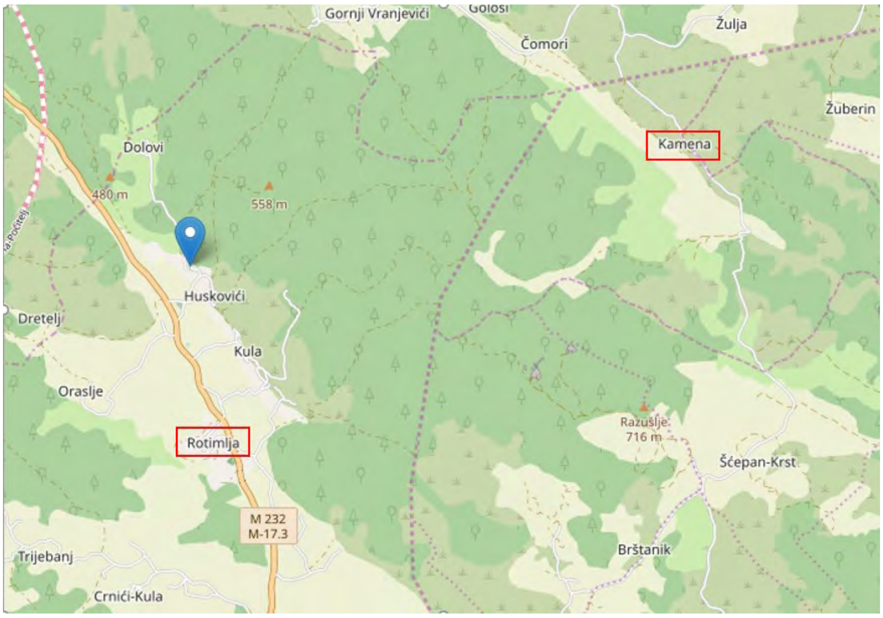


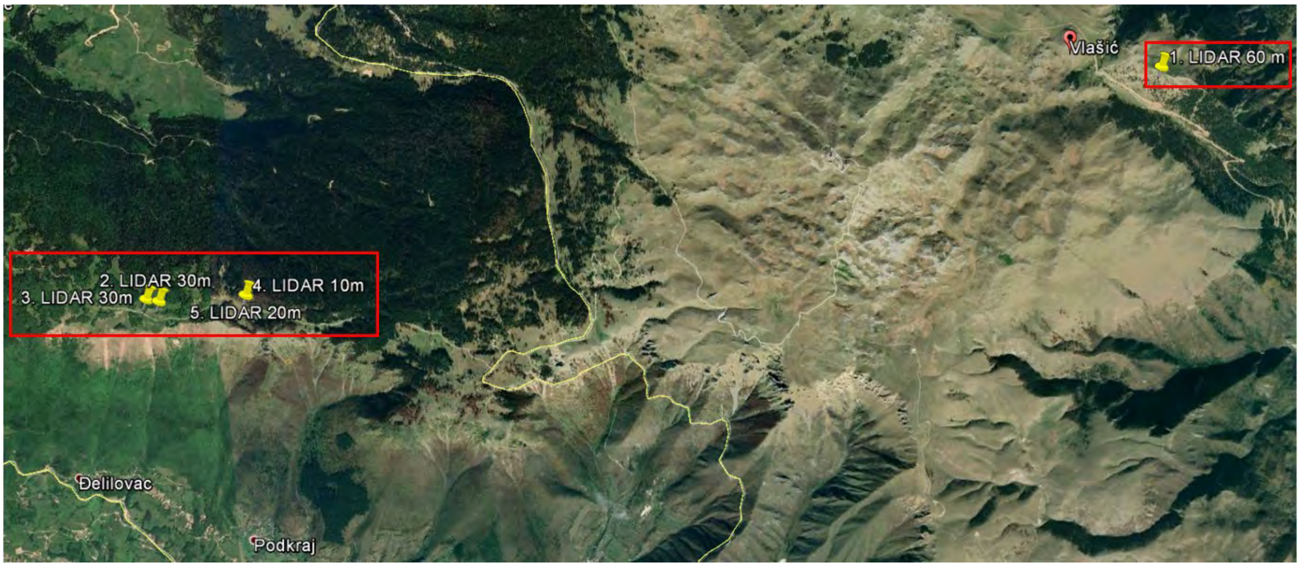
Figure 2.14 Map of Arza. [NPA Bosnia and Herzegovina]

3 Overview of the regions, situations, recordings in Bosnia and Herzegovina

Testing in Bosnia and Herzegovina has been done in several locations with different aims:
a) In NPA test site Blagovac, which is a quarter of town Vogošća (near Sarajevo), initial tests of the thermal infrared survey of targets (landmines and unexploded ordnance).
b) In minefield Rotimlja, manual search and detection of the landmines, in minefields Kamene search and detection of secondary indicators of the minefield.
c) In test site Blagovac the intensive systematic tests of the imaging from RPAS by color visible, thermal infrared, and LIDAR sensors.
d) In several locations on the mountain Vlašić, was used LIDAR for a survey from RPAS. Targets were remnants of engineering objects of the battle area.



a



b

Figure 3.1 a) Rotimlja and Kamena, southeast from Mostar, used in 2018. b) Overview of the locations on the mountain Vlašić, used for testing LIDAR on RPAS in Bosnia and Herzegovina on 30.10.2019.

Table 3.1 Overview of results of RPAS survey in Bosnia and Herzegovina

Name	Date	Color visible			LIDAR	Thermal infrared		
		Video	Images	Mosaic	DSM, LAS	Video	Images	Mosaic
Blagovac, 2018	18.10.2018 13 targets 15m, 30m	-	137 files 1,09 GB	281 MB	-	-	172 files 136,9 MB	3 files 1,65 MB
Rotimlja, 2018	16.10.2018 30m, 12 m	1 file 183 MB	40 files 323 MB	90,7 MB	-	-	306 files 236,7 MB	4,161 MB
Kamena 2018,	23.11.2018 4 km, 10 kg, hiking	2 files 5,76 GB	223 files 1,66 GB	275 MB	-	-	40 files 33 MB	1 file 2,3 MB
Blagovac, 2019	26, 30, 31 July 2019 11 targets, 2-10m	-	-	-	-	32 files 517 MB	312 files 243 MB	-
Blagovac, 2019	30.10.2019	-	-	2 files 105 MB 288 MB	DSM 58 MB, LAS 130 MB	-	-	2 files 2,756 MB 1,697 MB
1 Vlašić 60 m	30.10.2019 coniferous forest	-	-	169 MB	DSM 122 MB, LAS 423 MB	-	-	-
2 Vlašić 30 m	30.10.2019	-	-	151 MB	DSM 75 MB, LAS 270 MB	-	-	-
3 Vlašić 30 m	30.10.2019	-	-	139 MB	DSM 61 MB, LAS 175 MB	-	-	-
4 Vlašić 10 m	30.10.2019	-	-	239 MB	DSM 63 MB, LAS 154 MB	-	-	-
5 Vlašić 20 m	30.10.2019	-		310 MB	DSM 75 MB, LAS 375 MB	-	-	-
6 Vlašić slow speed	30.10.2019 coniferous forest	-	-	188 MB	DSM, 140 MB, LAS 515 MB	-	-	-
9 locations	**7 days**	**3 files**	**400 files**	**11 files**	**7 DSM, 7 LAS files**	**32 files**	**830 files**	**7 files**

3.1 Blagovac

NPA Bosnia and Herzegovina have a test site in Blagovac, Fig. 3.2. In this site, the NPA team conducted many activities, described in detail in chapters 4, 5 of this report.

Outcome: Testing in the year 2018 of the thermal behavior of 13 targets (landmines, unexploded ordnance) and the environment (ground around targets) resulted in the understanding of this key difference between thermal and color visible survey from RPAS, Fig. 4.6, Tab. 4.2 and Tab. 4.3. Testing in 2019 of 11 targets (landmines and unexploded ordnance) provided data, information, and knowledge that linked environment, targets, and thermal infrared recordings, Fig.6.1, Fig.6.2, Fig. 6.3. with models for assessment of the probability of detection and classification Fig.6.4, Fig.6.5.

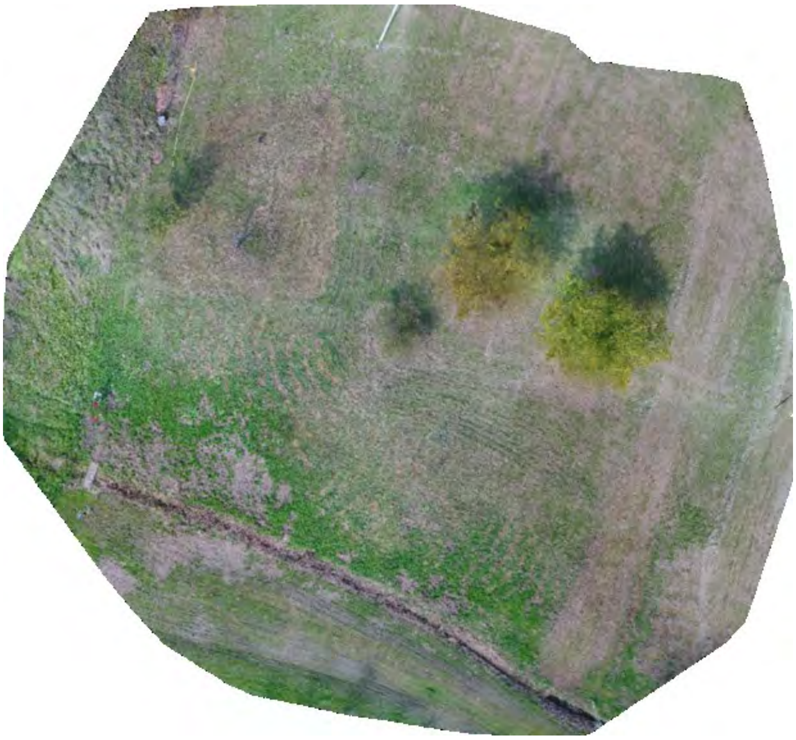


Figure 3.2 Visible images mosaic of Blagovac. Initial thermal tests of the NPA Bosnia team have been done in their test site Blagovac in 2018. [NPA Bosnia and Herzegovina]

Figure 3.3 Detection of the landmine in Blagovac, in the color visible image from RPAS. [NPA Bosnia and Herzegovina]

3.2 Rotimlja

Outcome: One of several trials to detect the landmine in the color visible image acquired by RPAS by visual search. This is an example of the primary evidence of the SHA. [NPA Bosnia and Herzegovina]

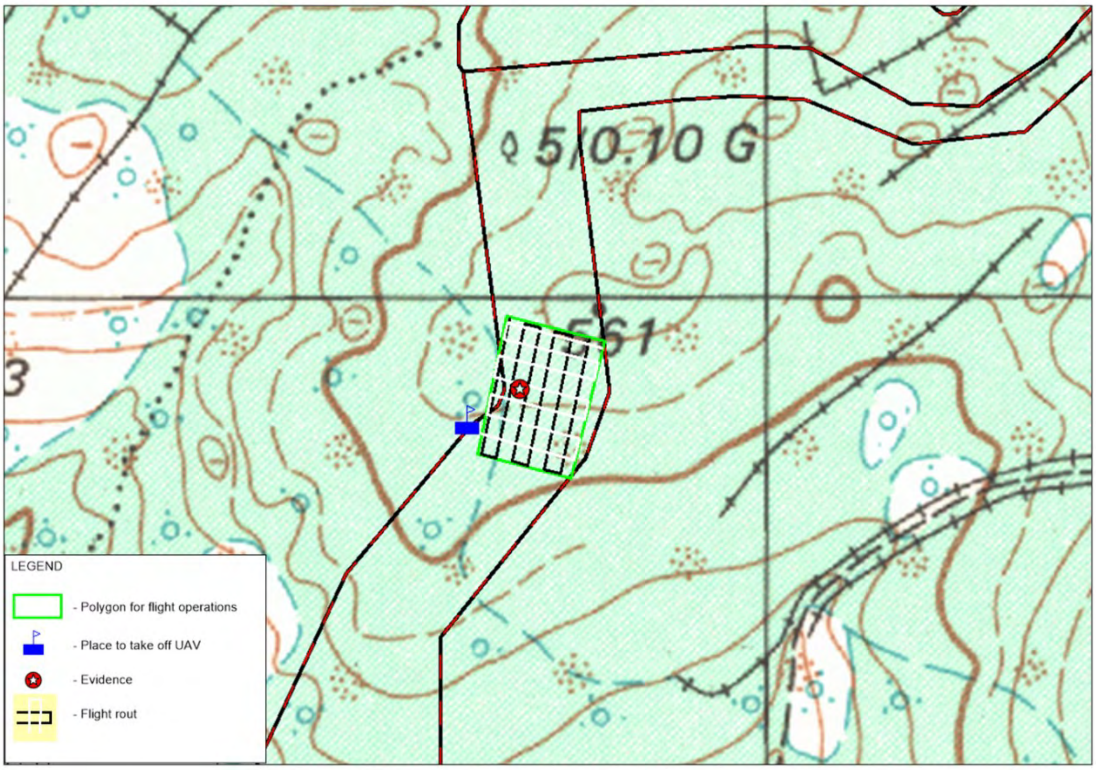


Figure 3.4 The detection of a landmine in Rotimlja, by watching the color visible images and video acquired via RPAS. [NPA Bosnia and Herzegovina]

Figure 3.5 Landmine detected in free flight. [NPA Bosnia and Herzegovina]

3.3 Kamena

Outcome: One of several trials to collect secondary indicators of the SHA in area Kamena, South of Mostar.

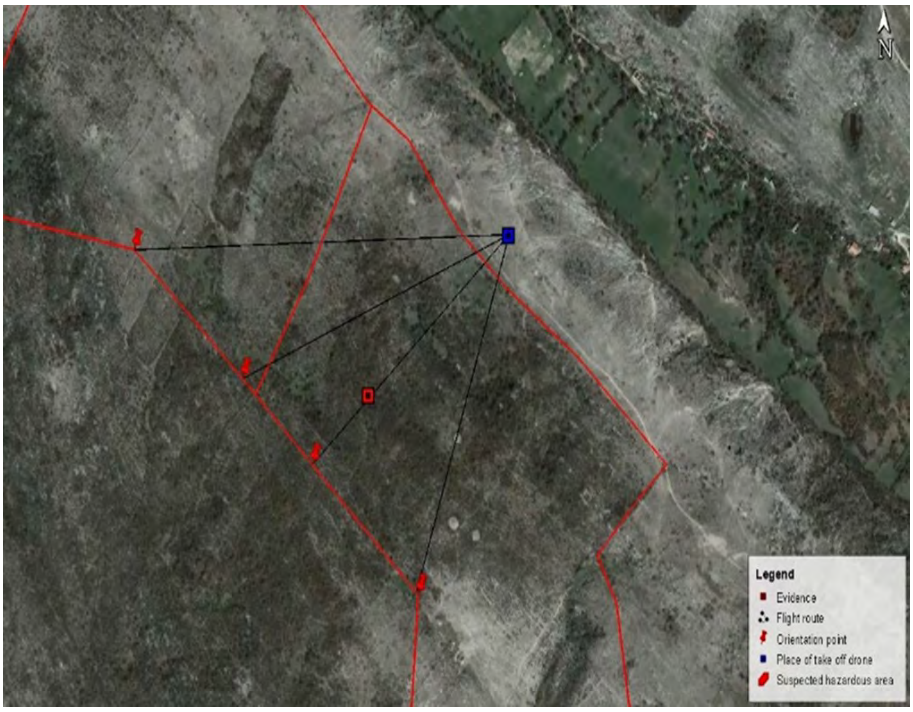


Figure 3.6 Test of the non-technical survey based on the color visible image collected via RPAS in the region Kamena. The evidence derived from this image approved the existence of the secondary indicators of the contamination, shown on the next figure, the trench, and the dry-stone wall. Image of Kamena, [NPA Bosnia and Herzegovina]

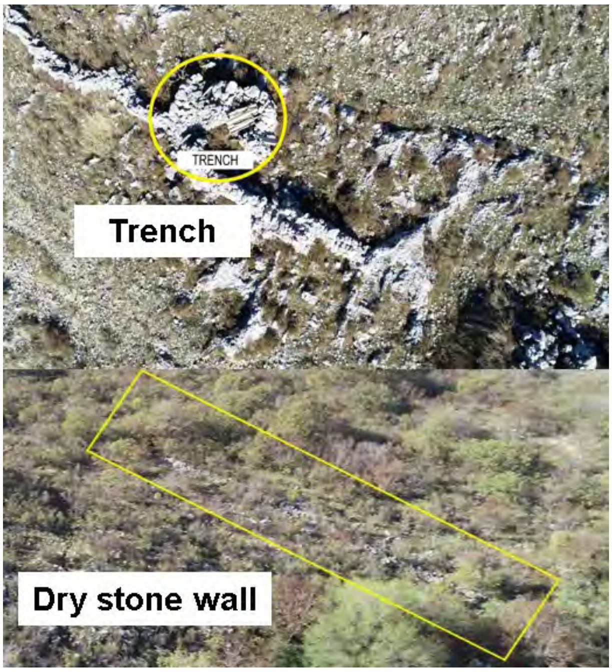
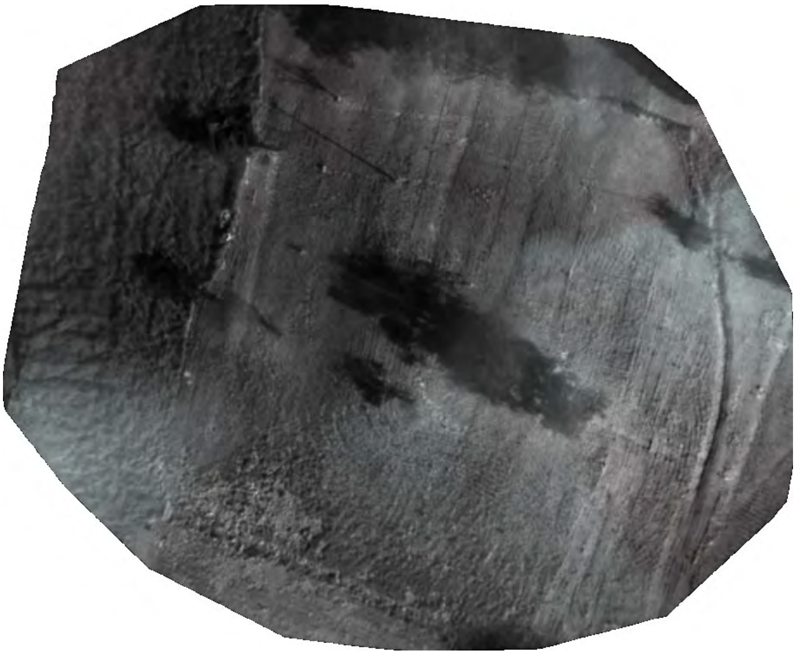


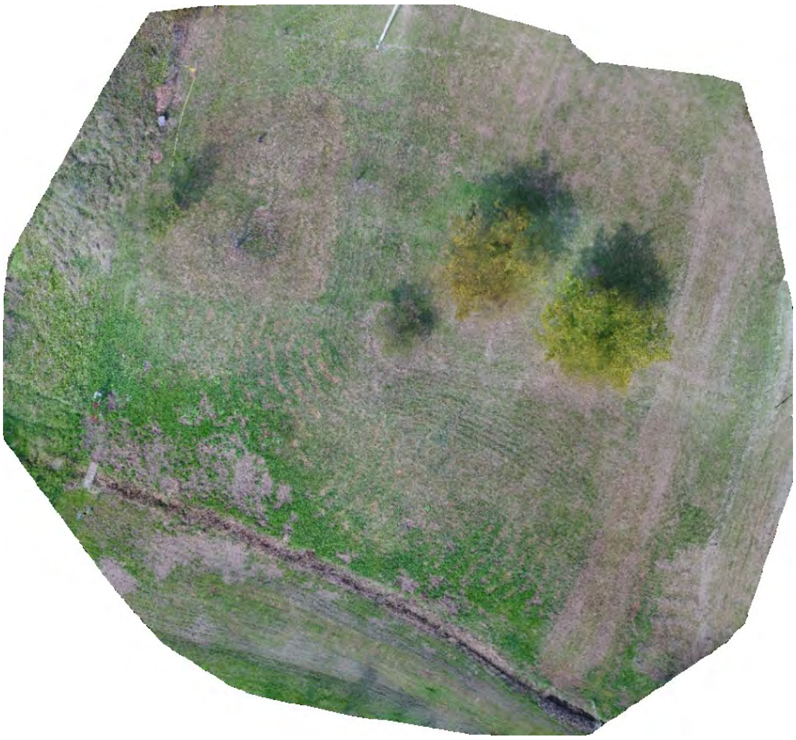
Figure 3.7 Trench and a dry-stone wall in the region Kamena. [NPA Bosnia and Herzegovina]

3.4 Blagovac 2019

For Blagovac are produced color visible mosaic, thermal infrared mosaic, digital surface model (DSM), Fig. 3.8, Fig.3.9, Fig.3.10, Fig.3.11, Fig.3.12, and Lidar LAS recording.



a



b

Figure 3.8 a) Thermal infrared mosaic of NPA Bosnia test site Blagovac, b) color visible mosaic derived from recordings acquired October 2019. [NPA Bosnia and Herzegovina].

a

b

Figure 3.9 a) Color visible mosaic of Blagovac derived from images collected via RPAS on 30.10.2019. Shows the image of the scene at nadir. b) 3D model of Blagovac derived 23.01.2020 from LIDAR *.LAS data. This is the visualization of LIDAR point cloud data. The average density of LIDAR points was 345,9 points/m^2, maximum density was 3398 points/m^2. The elements of the image are 1x1 m. [NPA Bosnia and Herzegovina].

LIDAR data are used to produce the digital surface model (DSM), Fig.3.10. From DSM are derived contour lines that describe relative heights of the mapped area, Fig.3.11, Fig.3.12.

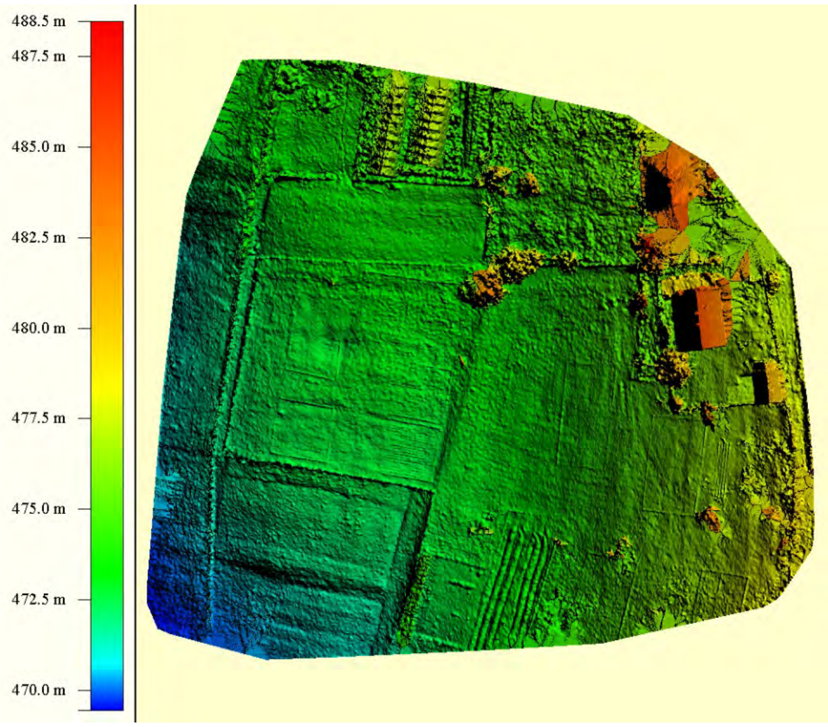


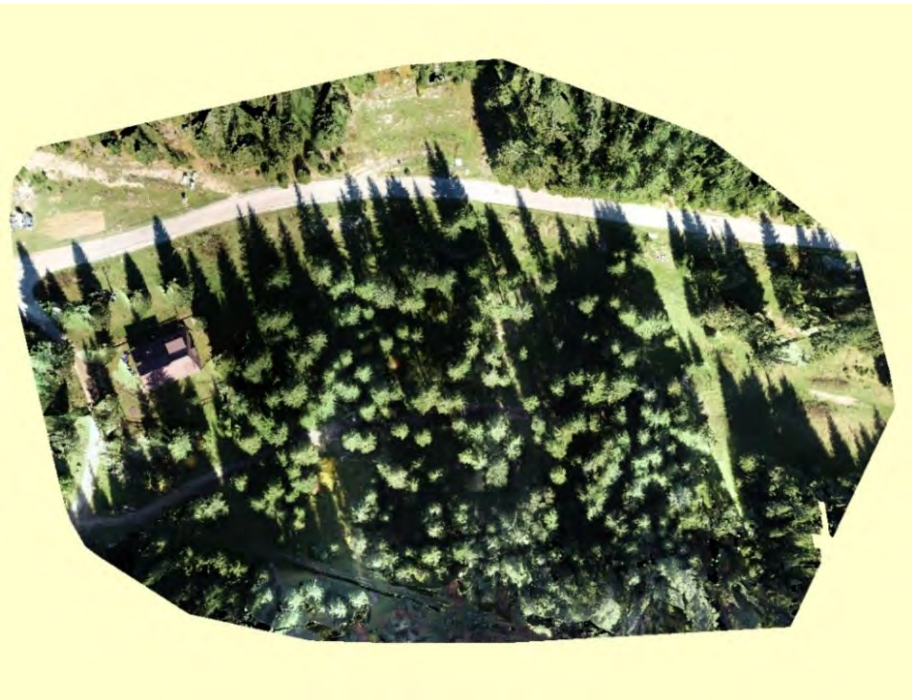
Figure 3.10 a) DSM of Blagovac derived from LIDAR recordings collected via RPAS on 30.10.2019

Figure 3.11 Contour lines of Blagovac derived from LIDAR data collected via RPAS on 30.10.2019.

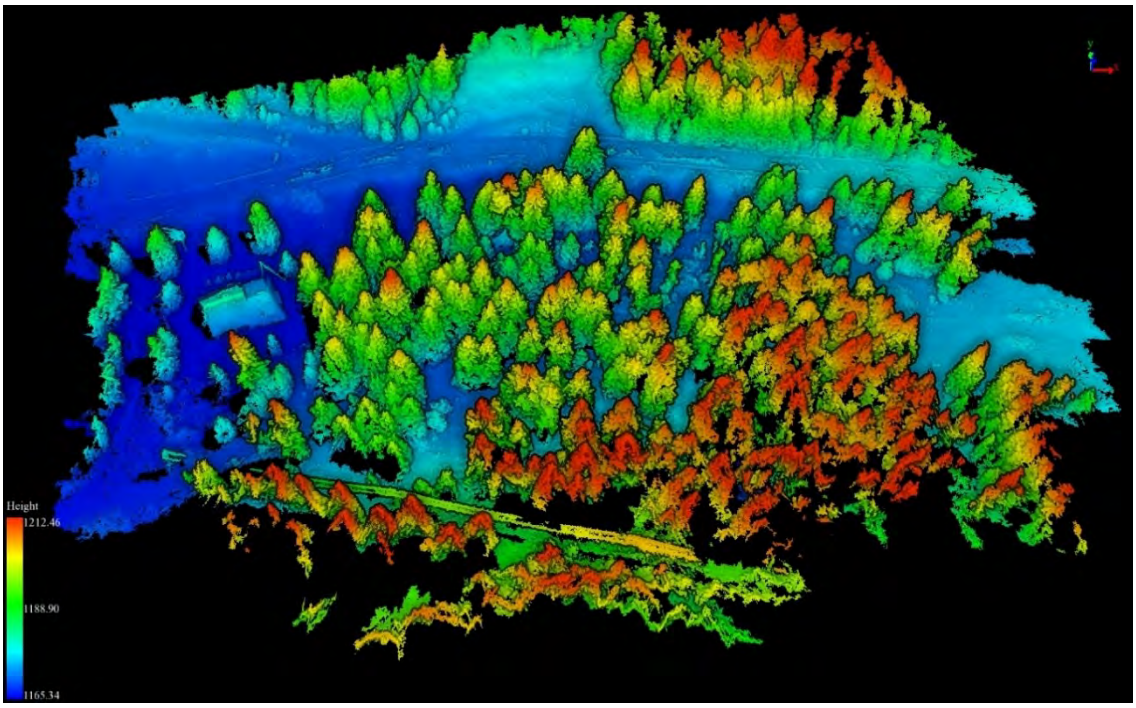
Figure 3.12 Contour lines overlaid on the color visible mosaic of Blagovac.

3.5 LIDAR Vlašić 2019

In October 2019 LIDAR on RPAS was used to collect data on several locations on the mountain Vlašić, Fig.3.1b. For each location are produced the digital surface model (DSM) and the color visible mosaics. In the following sections, are shown the color mosaics only, from Fig.3.13 to Fig.3.17. Part of the color visible mosaics and LIDAR data is corrupted and is not for use.



a



b

Figure 3.13 a) Color visible mosaic. Vlašić coniferous forest 60 m. b) The visualization of LIDAR point cloud data. The average density of LIDAR points was 343,4 points/m^2, maximum density was 4046 points/m^2. The elements of the image are 1x1 m. [NPA Bosnia and Herzegovina].

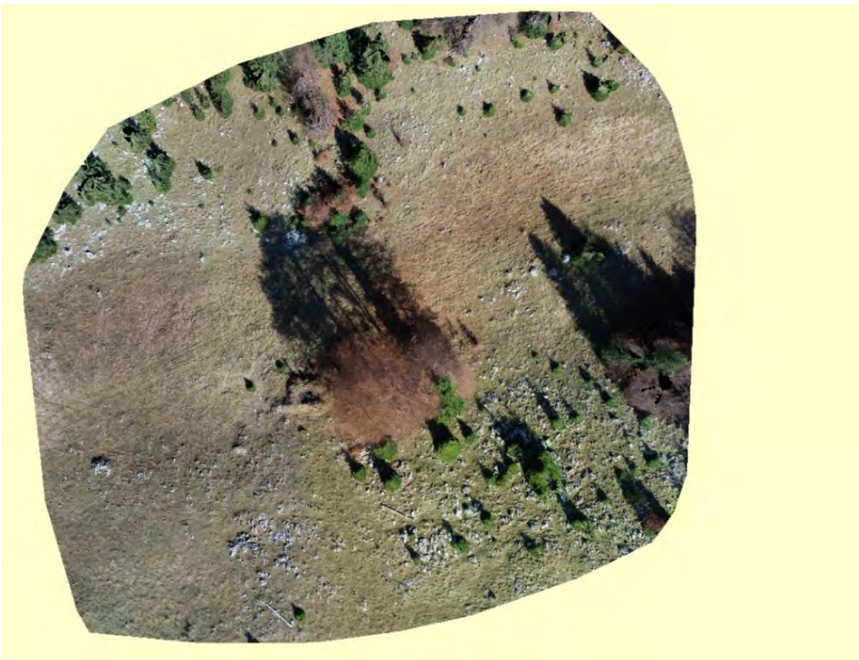


Figure 3.14 Color visible mosaic. Vlašić 30 m. [NPA Bosnia and Herzegovina]

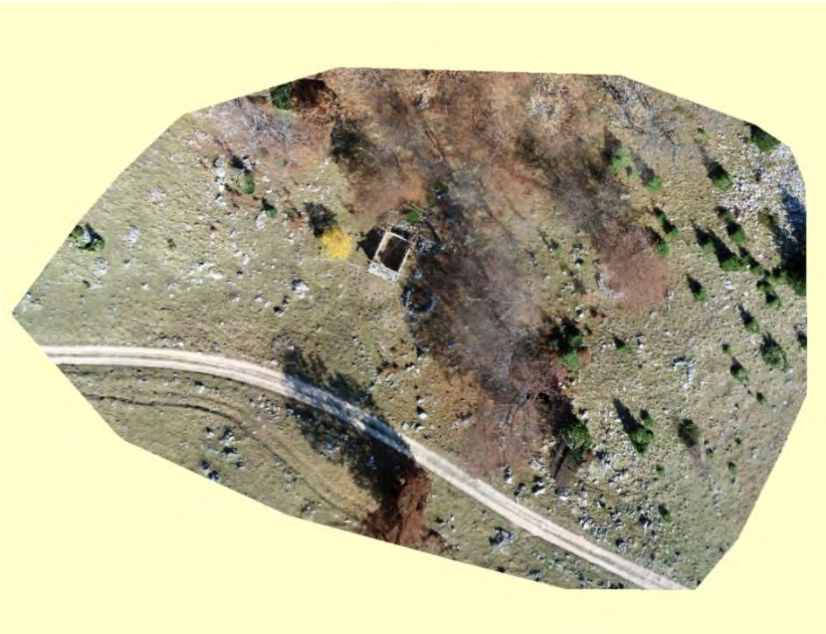


Figure 3.15 Color visible mosaic. Vlašić 2, 30 m. [NPA Bosnia and Herzegovina]

a

b

Figure 3.16 a) Color visible mosaic Vlašić 20 m. The object in a red circle could be a shelter. b) The visualization of LIDAR point cloud data. The average density of LIDAR points was 1596,7 points/m^2, maximum density was 16065 points/m^2. The elements of the image are 1x1 m. [NPA Bosnia and Herzegovina].

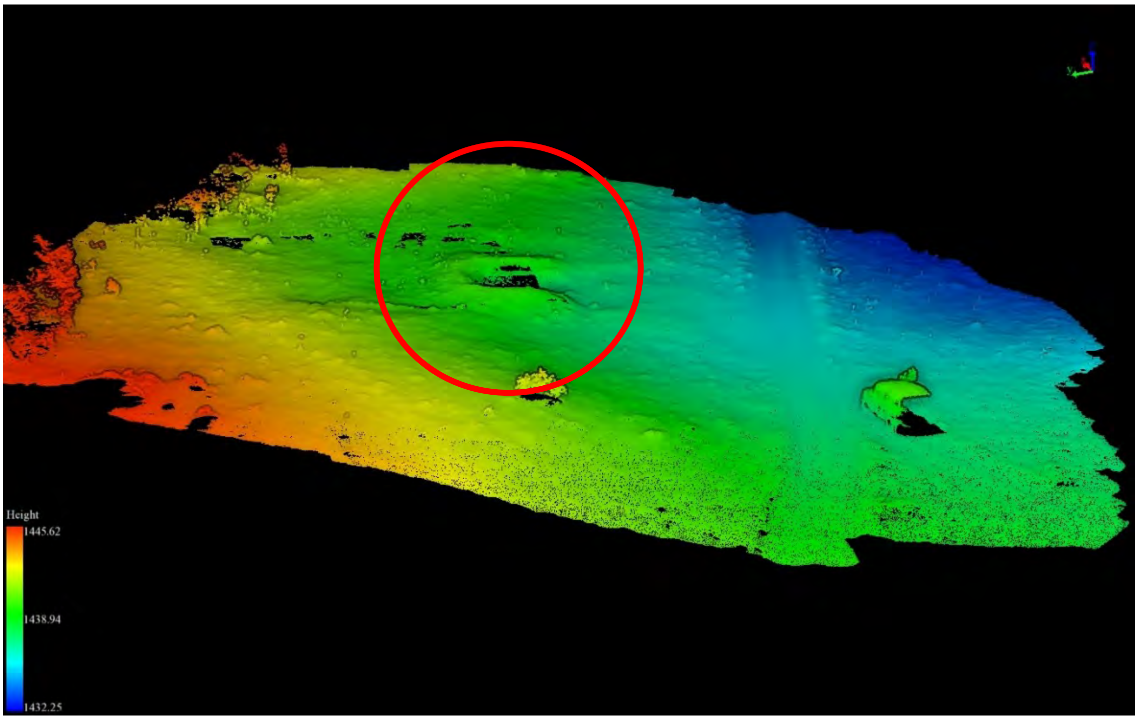


Figure 3.17 Vlašić 20 m. The visualization of LIDAR point cloud data. The shelter is approved. [NPA Bosnia and Herzegovina]

3.6 Resumee of the initial LIDAR on RPAS tests

The NPA actions with LIDAR on RPAS in Montenegro (ASA Rogami) and Bosnia and Herzegovina, (Vlašić), provided the first sets of the recorded LIDAR data of an exploded ammunition storage and of engineering objects of a former battle area. Although these limited data sets become available late (30.10.2019, 23.01.2020), after the NPA workshop, they provoke to continue further research, especially for the future detection of the improvised explosive devices, cluster munition remnants, engineering objects – secondary indicators of the battle area.

LIDAR recordings enable us to classify several classes of the surface and several classes of materials. This potential was illustrated in the frame of presentation, [16], and verified by processed data from 23 January 2020, Fig. 3.9a, 3.13a, Fig.3.16, Fig.3.17. The important factor of the LIDAR survey is spatial density, the number of LIDAR points on one square meter. The highest density was achieved in the case of the Vlašić 20 m data, 1596,7 points/m^2, while in other cases it was from 343,4 to 345,9 points/m^2. In further research and survey, development should be investigated the relation between points density and targets.

The fusion of LIDAR classification data, DSM, color visible data, and thermal infrared data, all collected via RPAS, can be very successful technology for land release, for assessment hazardous suspected area, for detection of the explosive targets on the land surface.

We propose to NPA to continue scientific consultative cooperation regarding the detection of targets by LIDAR on RPAS, to avoid wandering (Section 4.3.1) which happened in 2018 with an investigation of thermal infrared detection of landmines and unexploded ordnance.

4 A critical difference between thermal infrared and color visible survey from RPAS, matching to targets and the environment

The crucial differences between thermal infrared and color visible survey from RPAS

Here we consider, in a simple way, the main difference between the survey from the RPAS if done by thermal infrared, [18], [19], or by visible color sensors. The color visible survey is almost always applicable if the light conditions are average normal. For the thermal infrared survey, the Sun insolation is obligatory, but this is not enough, the thermal contrast Target/Environment shall be > 1. The TIR survey is additionally limited by the emissivity ε of the target, ε <1. Emissivity, reflection, imaging angle decrease the probability of the target detection & identification via the TIR measurement. The atmosphere attenuation is negligible if UAV heights are lower than 10 m. The thermal contrast Tt/Te of the target Tt and the neighborhood Te shows significant daily changes. The minimum thermal difference which can be detected by a considered sensor (Sensitivity) is <50mK. For the reliable detection of the target, the number of pixels on its area should be high, this is defined by Johnson's model in the next chapters of the report. Due to described facts, the testing of a thermal infrared survey from RPAS shall provide the following:

- Matching parameters of the TIR survey to features of the targets and the environment: landmines (LM), unexploded ordnance (UXO), in the future Improvised explosive devices (IED).
- Provision of needed detecting probability for the considered targets and the environment.
- Optimizing the UAV based TIR acquisition for Land Release, Non-technical, and a Technical survey.
- Evolutionary design of the standard operating procedures (SOP) for the TIR survey, verified in several different environments and situations.

The thermal infrared video provides the gain to the separability of the target

The used thermal camera provides recordings in two formats: thermal images, 640x512 pixels, Fig. 4.1, and in video MV4 format, Fig. 4.2, with 30 frames per second, each frame has 720x480 pixels.

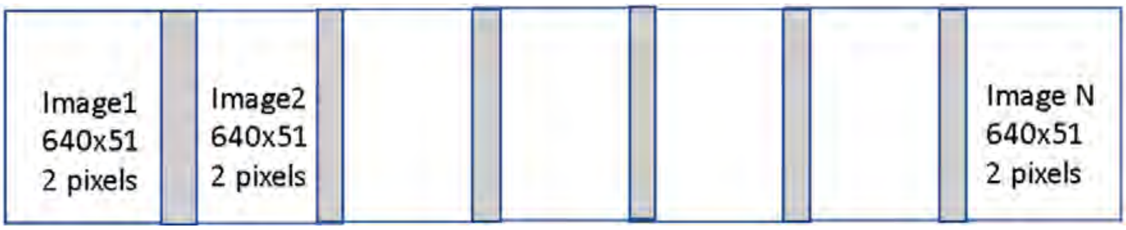


Figure 4.1 TIR images are used with overlapping, the greater overlapping the better mosaic can be produced.

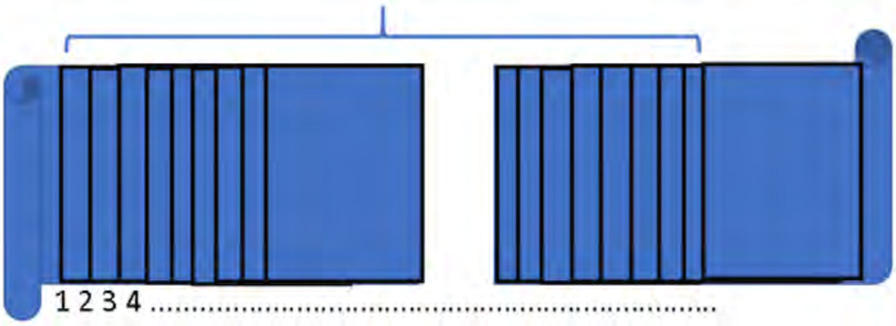


Figure 4.2 The TIR video recording can be exported into a sequence of images (frames), every frame has 720x480 pixels, with a frequency of 30 frames per second.

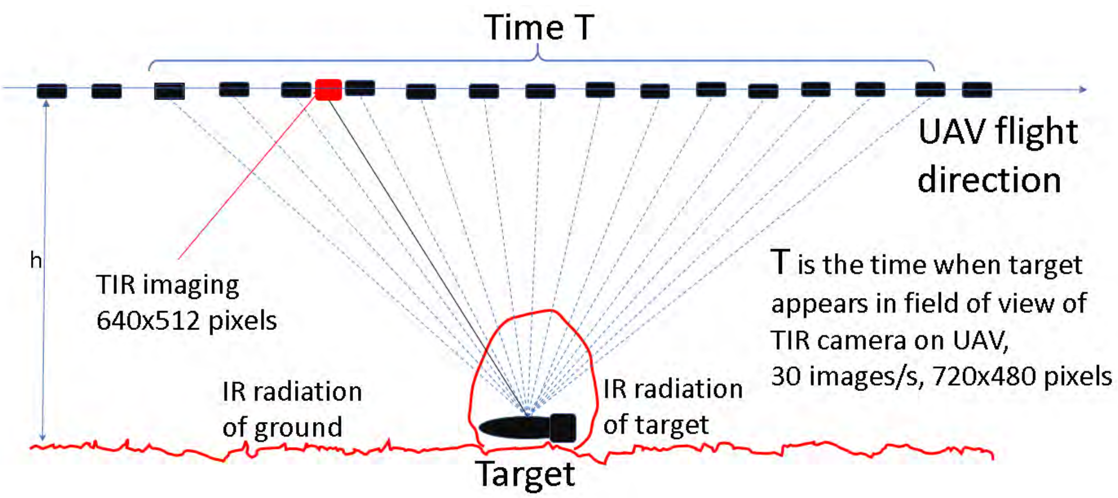


Figure 4.3 When RPAS flies at height h above the target on the ground, with speed v (m/s), the TIR sensor receives thermal infrared radiation of the target during the time T. In thermal video frames (720x480 pixels) this happens more often, see example Tab. 4.1.

Table 4.1 Number of video frames 720x480 is > 100 for h => 3m, the example from testing thermal infrared survey of eleven targets in Blagovac, 26-30-31 July 2019.

h (m)	TIR Images (640x512 pixels)	Frames from TIR video (720x480 pixels)
2	9 – 10	>68 - 136
3	7 - 8	>100
4	5 - 8	>100
5	3 - 4	>100
6	3 - 4	>100
7	3 – 4	>100
8	2 - 5	>100
9	3 - 6	>100

When RPAS flies over the target, the received infrared radiation coming from a target increases gradually to a maximum and decreases gradually. In this process exist thermal frames that have stronger recorded data than the data of the thermal image 640x512 pixels. For the understanding of the benefit, we introduced the separability S, described in Fig. 4.4.

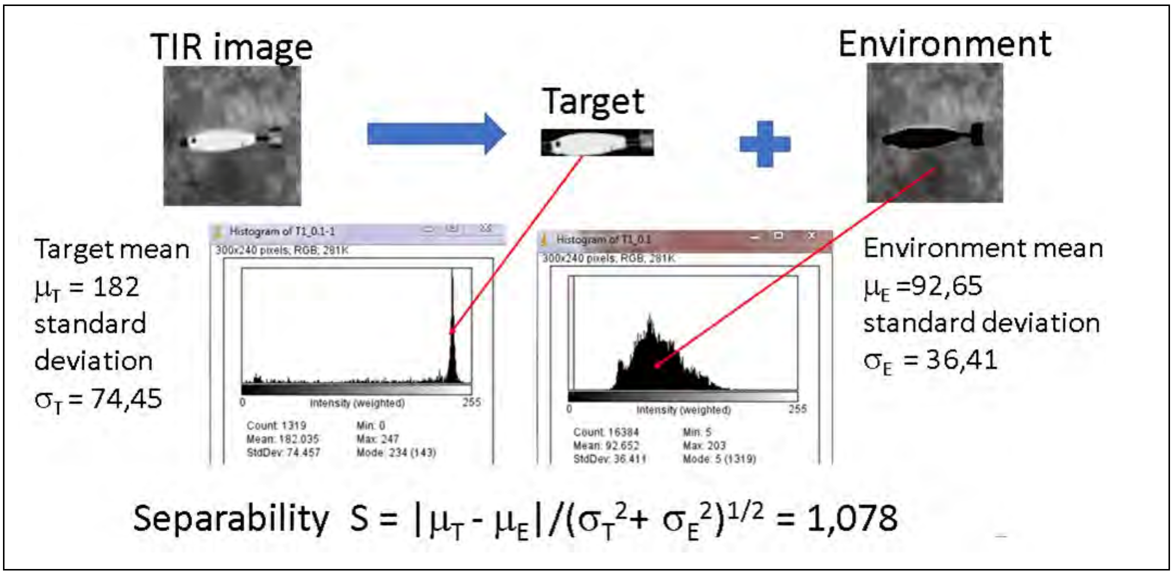


Figure 4.4 The definition of the separability and the example for the Mortar mine M 60.

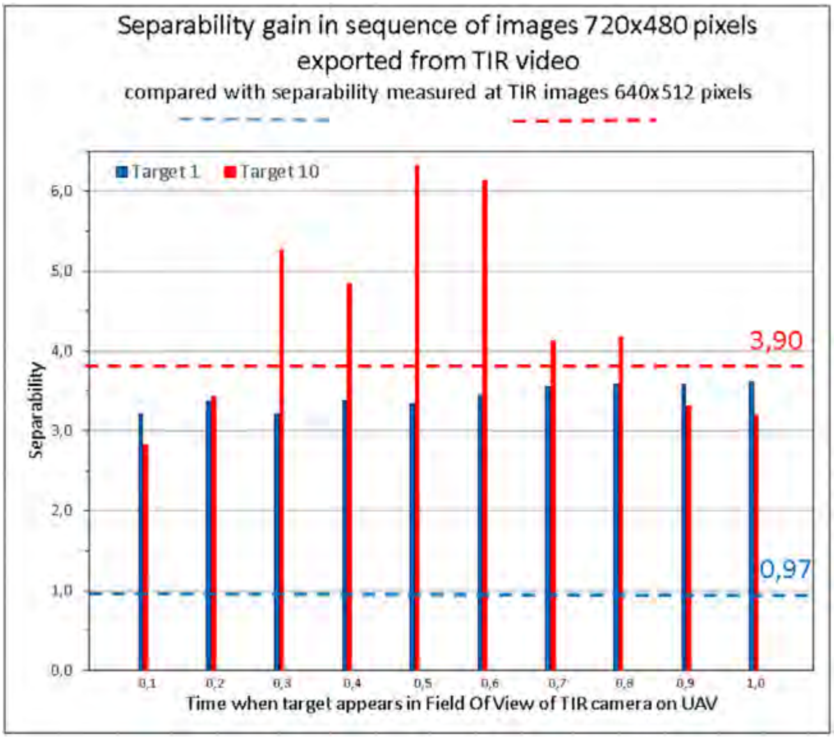


Figure 4.5 Separabilities obtained from thermal image 640x512 pixels (dashed lines) and thermal frame 720x480 pixels, vertical lines. A target 1 is a mortar mine M60 mm (blue lines), a target 10 is a land mine PROM1 (red lines).

The example for two targets obtained from thermal infrared image 640x512 pixels and thermal frames 720x480 pixels shows significant gain to their separabilities, Fig. 4.5.

During time T, when the target is visible from the thermal sensor on an RPAS, its separability obtained from thermal frames is always larger than the separability obtained from the thermal image (dashed lines).

Thermal contrast of a target to the environment – the most uncertain factor that limits survey

The role of the thermal contrast between the target and the ground surface is an important factor that limits the possibility to detect the targets (landmines, unexploded ordnance, improvised explosive devices), The analysis of the thermal contrast was done in three different approaches:

- The targets were not visible on TIR images but TIR pixels are measured at the known positions of the targets, 2018, Fig. 4.6, Tab.4.2, Tab.4.3.
- The thermal contrast was measured on selected eleven targets, visible on thermal images, in July 2019 Tab.4.7.
- Provide basic information about the thermal contrast in Iraq, from NPA Iraq, and derive the procedures for matching a thermal infrared survey from RPAS for the landmines, the unexploded ordnance, the cluster munition, and the improvised explosive devices.

4.1.1 Measurements and analysis of thermal contrast in 2018 on the pixels of a target

The NPA Bosnia team started analysis of this phenomena in the year 2018, [18] and later in 2019. The TIR images were collected at h= 15 m, and h = 30 m in Blagovac 2018. The targets were not visible in TIR images from UAV at heights h = 15 m, h=30m. TIR pixels were measured at the known positions of 13 targets. At known coordinates of targets, TIR data are measured indicating the possibility to detect a considered target, Fig. 4.6, Tab. 4.2 and Tab. 4.3

Nr.	Category	Type
1	UXO	MB M:62 mm
2	FUSE	M:125 mm
3	UXO	TTM RP
4	UXO	Hand grenade
5	UXO	Hand grenade
6	AP	PMR čapljinka
7	UXO	Bullet 20 mm
8	UXO	Bullet 30,2 mm
9	AP	PMR 2A
10	UXO	MB M:82 mm
11	AP	PMR 3
12	UXO	TTM RP
13	UXO	Bullet 40 mm

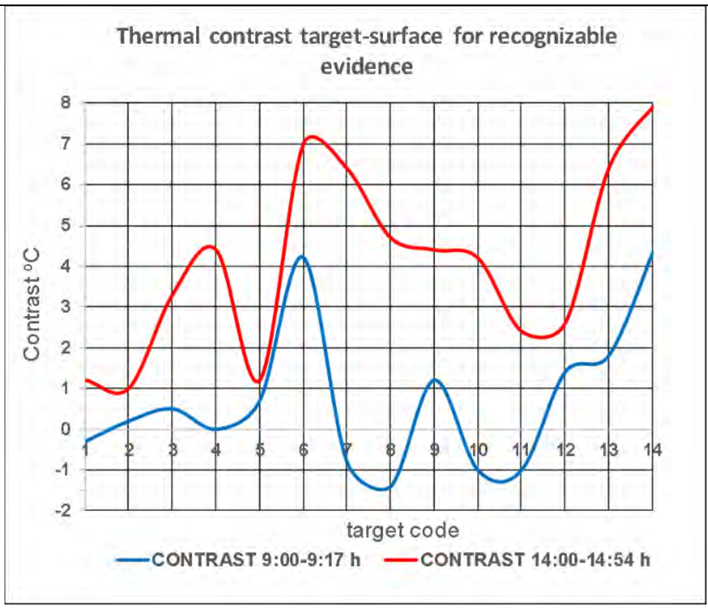


Figure 4.6 List of the targets used for testing their TIR detectability, and diagram of a measured thermal contrast between the target and the ground surface. Blagovac 2018.

Table 4.2 Basic statistical parameters of a thermal measured contrast between the target and the ground surface

Contrast	9:00-9:17 h	14:00-14:45 h
Standard Deviation	1,719	2,174
Median	0,35	4,3
Average	0,7	4,079
Max	4,3	7,9
Min	-1,4	1

In 50 % cases, the difference of temperatures targets to ground surface was 4,3 ºC in the afternoon hours, while in the morning hours it was only 0,35 ºC.

Table 4.3 Overview of measurements TIR pixels of targets in Blagovac in the year 2018.

Image	Targets description / code	h m	1	2	3	4	5	6	7	8	9	10	11	12	13
DJI_0383	(PMR 2A; MB M:82 mm).	15									1	1			
DJI_0384	(Bullet 20 mm; PMR 2A; MB M:82 mm).	15							1		1	1			
DJI_0385	(PMR capljinka; Bullet 20 mm; Bullet 30.2 mm; PMR 2A; MB M:82 mm).	15						1	1	1	1	1			
DJI_0386	(PMR capljinka; TTM RP and hand grenade).	15			1	1		1							
DJI_0387	(MB M:62 mm; TTM RP and hand grenade).	15	1		1	1									
DJI_0391	(Bullet 30,2mm, PMR capljinka)	15						1		1					
DJI_0392	(Bullet 20 mm)	15								1					
DJI_0393	(Bullet 30.2 mm)	15								1					
DJI_0394	(Bullet 30.2 mm)	15								1					
DJI_0401	(MB M:62 mm)	15	1												
DJI_0402	(MB M:62 mm)	15	1												
DJI_0421	(PMR 2A; PMR 3).	15									1		1		
DJI_0424	(Bullet 30.2 mm).	15								1					
DJI_0425	(Bullet 30.2 mm).	15								1					
DJI_0444	(MB M:62 mm; M:125 mm)	15	1	1											
DJI_0333	(Bullet 30.2 mm, TTM RP, Bullet 40 mm).	30								1				1	1
DJI_0334	(PMR capljinka, Bullet 20 mm, Bullet 30,2 mm, PMR 2A and TTM RP).	30						1	1	1	1			1	
DJI_0335	(PMR capljinka, Bullet 20 mm, Bullet 30,2 mm, PMR 2A).	30						1	1	1	1				
DJI_0336	(PMR capljinka and Bullet 30.2 mm).	30						1		1					
DJI_0337	(PMR capljinka).	30						1							
DJI_0339	(MB M:62 mm, M:125 mm, TTM RP, 2 handgrenade, Bullet 30.2 mm).	30	1	1	1	1	1			1					
DJI_0340	(MB M:62 mm, M:125 mm, TTM RP, 2 handgrenade, PMR 2A, MB M:82 mm, PMR 3)	30	1	1	1	1	1				1	1	1		
DJI_0341	(Bullet 30,2 mm, PMR 3, TTM RP).	30								1			1	1	
DJI_0342	(Bullet 30,2 mm, PMR 3, TTM RP).	30								1			1	1	
DJI_0343	By (Bullet 30,2 mm, PMR 3).	30								1			1		
DJI_0344	(Bullet 30.2 mm).	30								1					
DJI_0375	(Bullet 30,2 mm, PMR 3).	30								1			1		
DJI_0376	(Bullet 30,2, PMR 2A, MB M:82 mm, PMR 3).	30								1	1	1	1		
	SUM = 73		6	3	4	4	2	7	4	18	8	5	7	4	1

4.1.2 Measurements and analysis of thermal contrast in 2019

Note that in the described analysis from 2018, the targets were not visible on TIR images but TIR pixels are measured at the known positions of the targets. Therefore the next analysis was done on the contrast measurements on the selected eleven targets, Fig. 4.7 in three days in July 2019 in Blagovac. These data again confirmed the daily variability and caused the conclusion that in the preparation phase of thermal survey RPAS missions, it is mandatory to make measurements and estimate behavior for the time of the mission. NPA experience from testing in Montenegro and Bosnia and Herzegovina is a strong argument for this decision.

Nr.	Targets
1	Mortar mine M:60 mm
2	Fuse M:125 mm
3	Tromblon mine TTM RP
4	Hand grenade
5	AP land mine PMR čapljinka
6	Bullet 30,2 mm
7	Land mine PMR 2A
8	Mortar mine M:82 mm
9	Land mine PMR 3
10	Land mine PROM 1
11	Land mine PMA 3

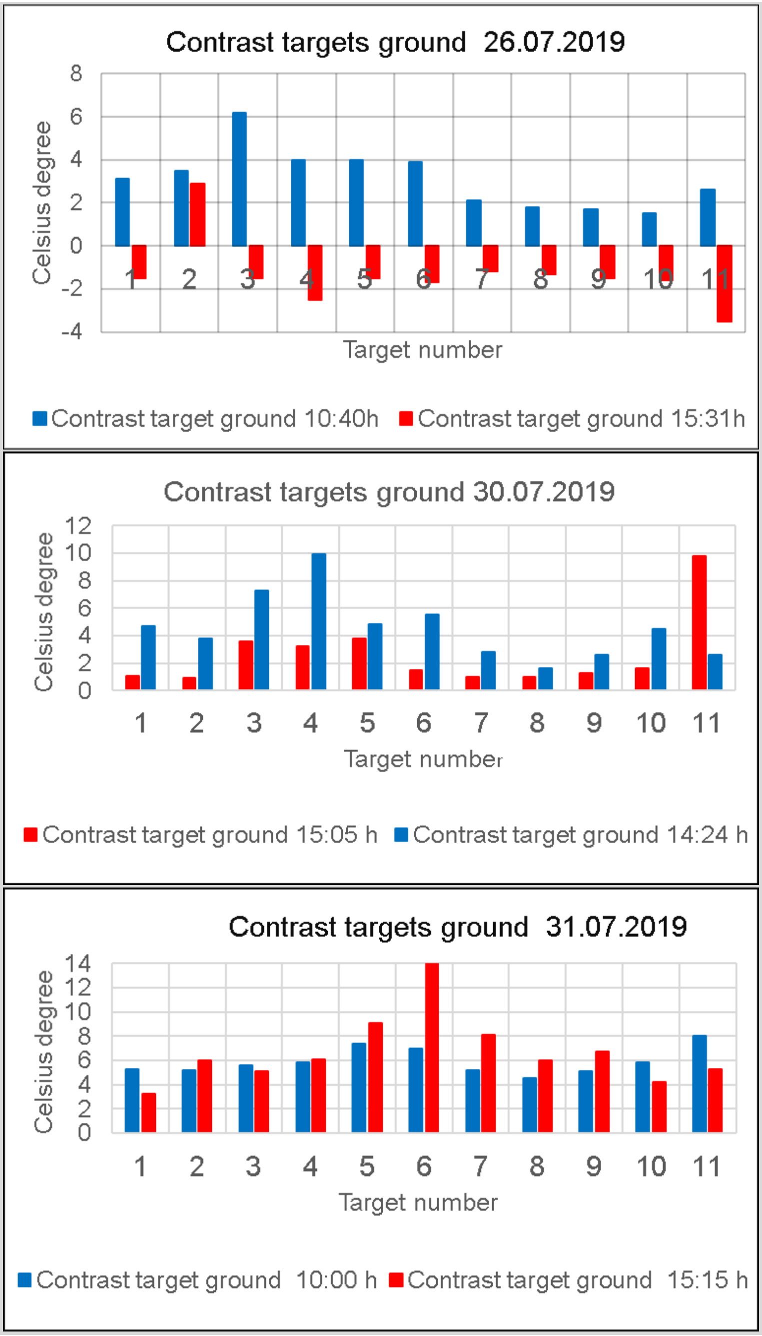


Figure 4.7 Targets used in measurements of the thermal contrast and diagrams of data for three days in Blagovac in July 2019.

A thermal contrast was measured in two periods of the day, earlier data are shown in blue, while the data obtained later are shown in red. The positive thermal contrasts happened in two of three testing days, the best data are obtained on 31.07.2019. On the first day, 26.07.2019, the thermal contrasts were negative in the later hours and this time is not usable for a successful thermal survey. The described measurements and analysis of the thermal contrast only show that for each thermal infrared survey mission, in each region, the knowing or at least a reliable estimation of the expected thermal conditions is a guarantee for success and the opposite.

4.1.3 Thermal contrast in Iraq

After the experience of the thermal surveys in Montenegro, where the thermal contrast was not positive, our expectation for Iraq contrasts was not optimistic, but two sources of data and information changed it: the information about Iraq climate [8] and contributions of Iraq NPA at the workshop [7].

General information about the climate of Iraq, [8]

> *„**Iraq** has a hot, dry climate characterized by long, hot, dry summers and short, cool winters. The climate is influenced by Iraq's location between the subtropical aridity of the Arabian desert areas and the subtropical humidity of the Persian Gulf. January is the coldest month, with temperatures from 5°C to 10°C, and August is the hottest month with temperatures rising up to 30°C and more.*
>
> *In most of the areas, summers are warm to hot with mostly sunshine, but high humidity on the southern coastal areas of the Persian Gulf. Daily Temperatures can be very hot; on some days **temperatures** can reach easily 45°C or more, especially in the Iraqi desert areas which causes a danger of heat exhaustion. Hot, dry desert winds can be very strong sometimes and can cause violent sandstorms.*
> *About 70 percent of the average **rainfall** in the country falls between November and March; June through August is often rainless. Rainfall varies from season to season and from year to year. Precipitation is sometimes concentrated in local, but violent storms, causing erosion and local flooding, especially in the winter months".*

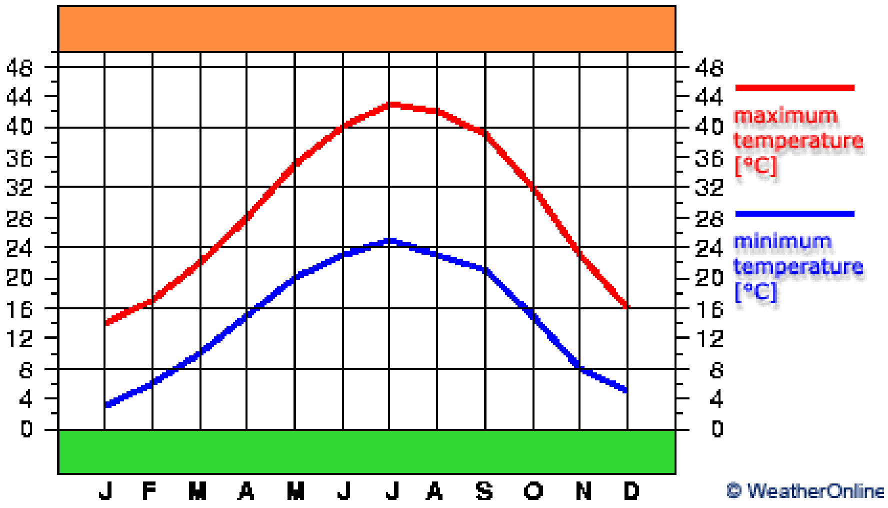


Figure 4.8 The temperature in Iraq, from January to December, minimum and maximum. (www.weatheronline.co.uk) .

Information and data provided by NPA Iraq

Regarding the expected contrast of the explosive objects (landmines, unexploded ordnance, improvised explosive devices, the cluster munition) in Iraq can be expected different situation, according to data and information provided by Mr. Mats Hektor (overview from a database, video from RPAS flight, images, presentation), [7], and Mr. Noe Falk Nielsen (images, report). They explain that in the arid terrain in Iraq, where NPA is active, the thermal contrast between the explosive targets and the ground is positive and that the positive thermal differences are large. Their comment explains this statement: the temperature can reach 50 ^{o}C and more. If you put the hand on the soil you can conclude that the soil is warm. But if you try the same on the landmine or the unexploded ordnance, you will conclude that it is extra hot and quickly remove the hand. Proposal for the name of this test: “Mats' hand test”.

5 Assessment of a spatial resolution for thermal infrared detection of a target on the ground surface

Several technical mathematical models enable us to quantify the reconnaissance (later we apply term survey) the targets on the ground surface by electro-optical sensors on aerial platforms. We are focused on the RPAS based reconnaissance of the landmines, unexploded ordnance, improvised explosive devices, cluster munition, explosive remnants of war, secondary indicators of the contamination with the explosive objects. Our aim and task are to support and advance reconnaissance via RPAS for thermal infrared, color visible sensors on NPA. While the considered reconnaissance in NPA is limited to the subjective photointerpretation, where the automatic processing and application of Machine Learning, Artificial Intelligence, Deep Learning technologies are not used yet, we selected basic well-proven, and simple Johnson's model. This model links probabilities of the reconnaissance (survey) with a spatial resolution of the imaging sensors (simplified version).

Johnson's model for assessment of the spatial resolution needed for the desired probability of detecting the target

Thermal infrared survey for the land release, for the detection of land mines, the unexploded ordnance, the improvised explosive devices, is limited to a subjective (manual) search of the objects in the thermal recordings. The survey functionalities are detection, classification, recognition, and identification.

Detection: The blob on the camera screen has a reasonable probability of being an object being sought.
Classification: Objects discerned with sufficient probability that belongs to different groups (classes).
Recognition: Object discerned with sufficient clarity that its specific class can be differentiated.
Identification: Object discerned with sufficient clarity to specify the type within the class

While the thermal survey shall provide reliable outcomes, we will introduce a quantitative model that can provide a needed level of probability. The survey of the UXO can be described by the probabilities of the following functions: detection, classification, recognition, and identification related to the spatial resolution and the search time, in Johnson's model [9], (Donohue 1991), and advanced [10] (Harney 2004). The main goal of our research and development is to provide a trade-off between needed very-high spatial resolution (linked to the critical dimensions of the smallest UXO) and desired coverage of a wide strip.

The Johnson's model (Donohue 1991) uses only the narrowest dimension of the target, while the advanced model (Harney 2004) is based on the geometric mean Lc of two orthogonal minimum dimensions, Lx and Ly,

$$Lc = (LxLy)^{1/2}. \qquad (5.1)$$

If the search time is not limited (here we could think of the search of the interpreter on the image), the probability P_∞ is determined [10, p. 427, 432] by

$$P_\infty = (N/N_{50})^E/[1+(N/N_{50})^E] \qquad (5.2)$$

where

$$E = 2.7+0.7(N/N_{50}), \quad (5.3)$$

N is the number of resolvable cycles across the target dimension, N_{50} is the number of cycles across the target for 50% probability of survey functions, given in Table 5.1.

Table 5.1 N_{50} for detection, classification, recognition, identification

Function of survey	N_{50}
50% Detection probability	1,5 resolution elements (0,75 cycles) per critical dimension
50% Classification probability	3,0 resolution elements (1,5 cycles) per critical dimension
50% Recognition probability	6,0 resolution elements (3,0 cycles) per critical dimension
50% Identification probability	12 resolution elements (6,0 cycles) per critical dimension

Example: Detection of mortar mine

Mortar mine has Lx=0,291 m, maximum of diameter is 0,06 m, equivalent Ly=0,014149 m and the critical dimension Lc = 0,11895 m, Fig. 5.1. Needed spatial thermal infrared resolution depends on the required probabilities of the survey: detection, classification, recognition, and identification, this is shown on the following diagrams, Fig. 5.2 and Fig. 5.3. However, in a complex environment with significant clutter, targets must not only be detected but must also be classified and identified. Using just the detection criteria, the false alarm rate will be too high to make the system viable. Therefore, we shall choose a system that is capable to provide the classification resolution for primary target detection.

Figure 5.1 Mortar mine

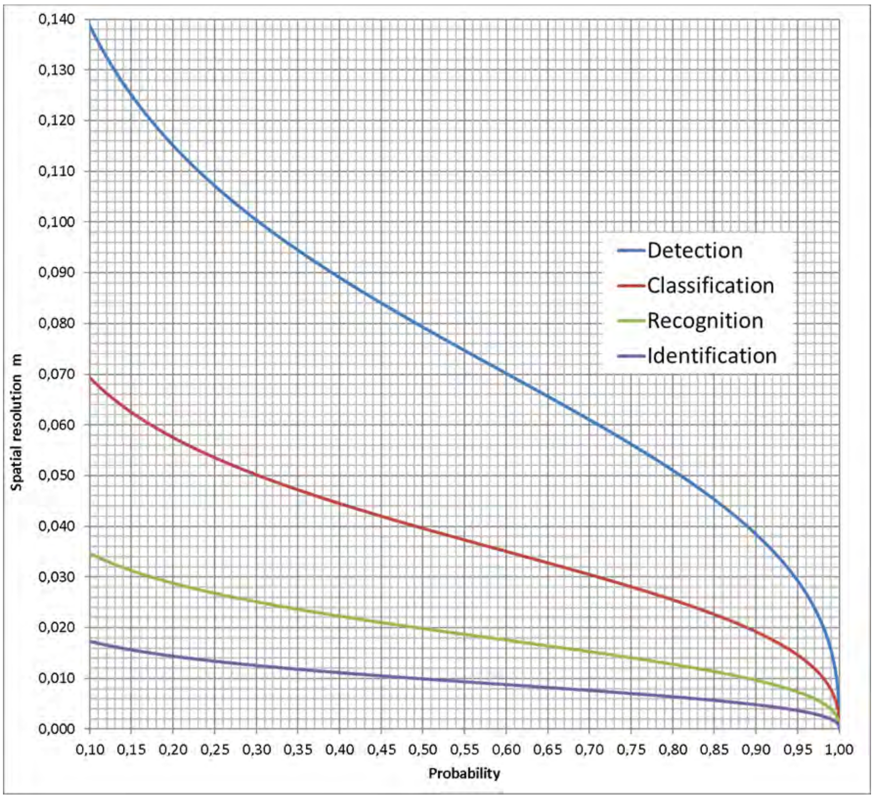


Figure 5.2 Spatial resolution of thermal infrared images needed for the selected probability of survey functionalities detection, classification, recognition, and the identification, for mortar mine

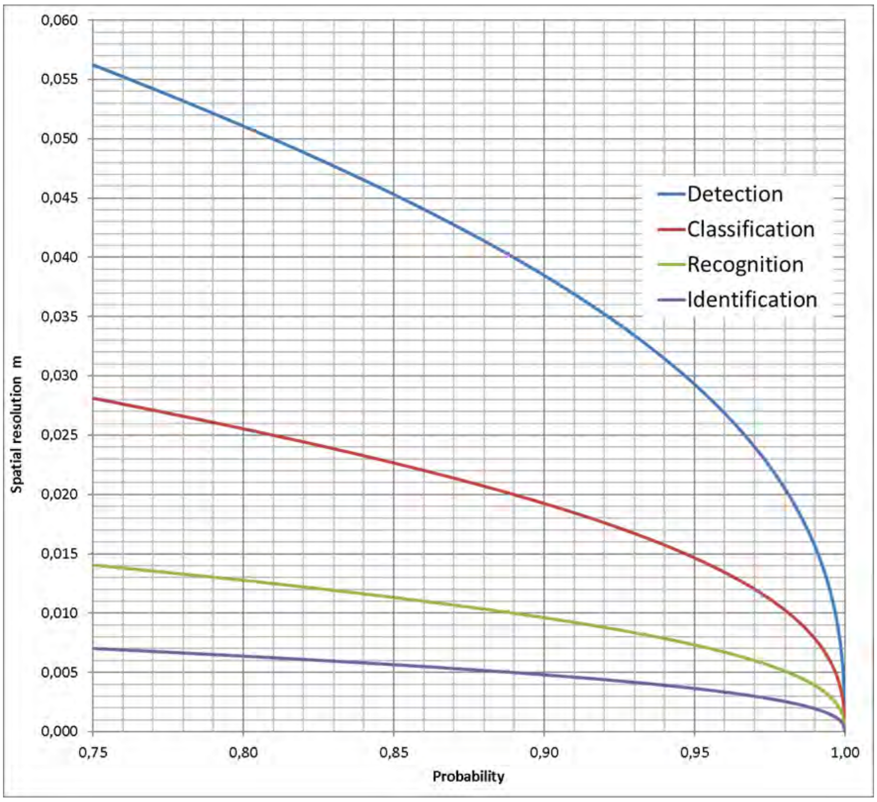
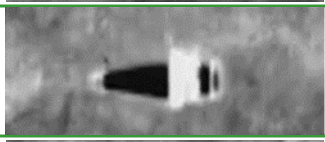
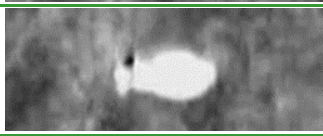
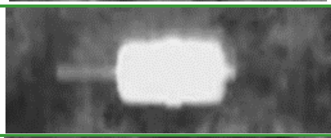
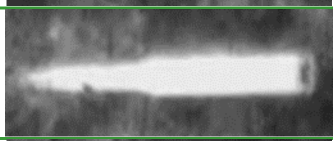
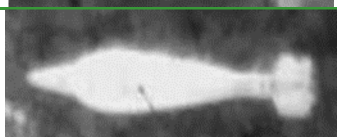


Figure 5.3 Spatial resolution of thermal infrared images needed for the selected probability of survey functionalities detection, classification, recognition, and the identification, for mortar mine, in probability range from 0,75 to 1,0.

6 Experimental analysis of the thermal survey of the landmines and the unexploded ordnance

Thermal infrared imaging of the selected landmines and unexploded ordnance

The subjective detection of landmines, unexploded ordnance in visible bands images and the video are natural and easy to be accepted by deminers – surveyors, while it is the opposite when thermal images and videos are considered. We decided to make a systematic experimental analysis of the thermal survey of landmines and UXO and use the collected data and experience for a new assessment of the thermal survey in the frame of NPA's standard operations procedures. The selected targets are shown in Fig. 6.1, their photography, thermal image and estimated critical dimensions Lc defined in relation (5.1).

Nr.	Photography	Thermal infrared	Target	Lc m
1			Mortar mine	0,11895
2			Fuse M125	0,08565
3			Tromblon mine TTM RP	0,09644
4			Hand grenade	0,07071
5			Landmine PMR Čapljinka	0,10015
6			Bullet 30,2 mm	0,11966
7			Landmine PMR 2A	0,09119
8			Mortar mine M82 mm	0,14533
9			Landmine PMR 3	0,09899

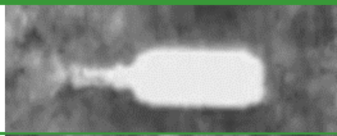
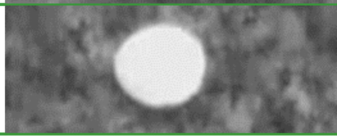
Nr.	Photography	Thermal infrared	Target	Lc m
10			Landmine PROM 1	0,10583
11			Landmine PMA 3	0,103

Figure 6.1 The critical dimension Lc of targets estimated following (5.1) starting from their physical dimensions. For targets 1, 8, and 11 the critical dimension Lc is assessed by taking into account a thermal image obtained from the lowest height of 2 m. Thermal images for each target at increased flight height are shown in Fig. 6.2.

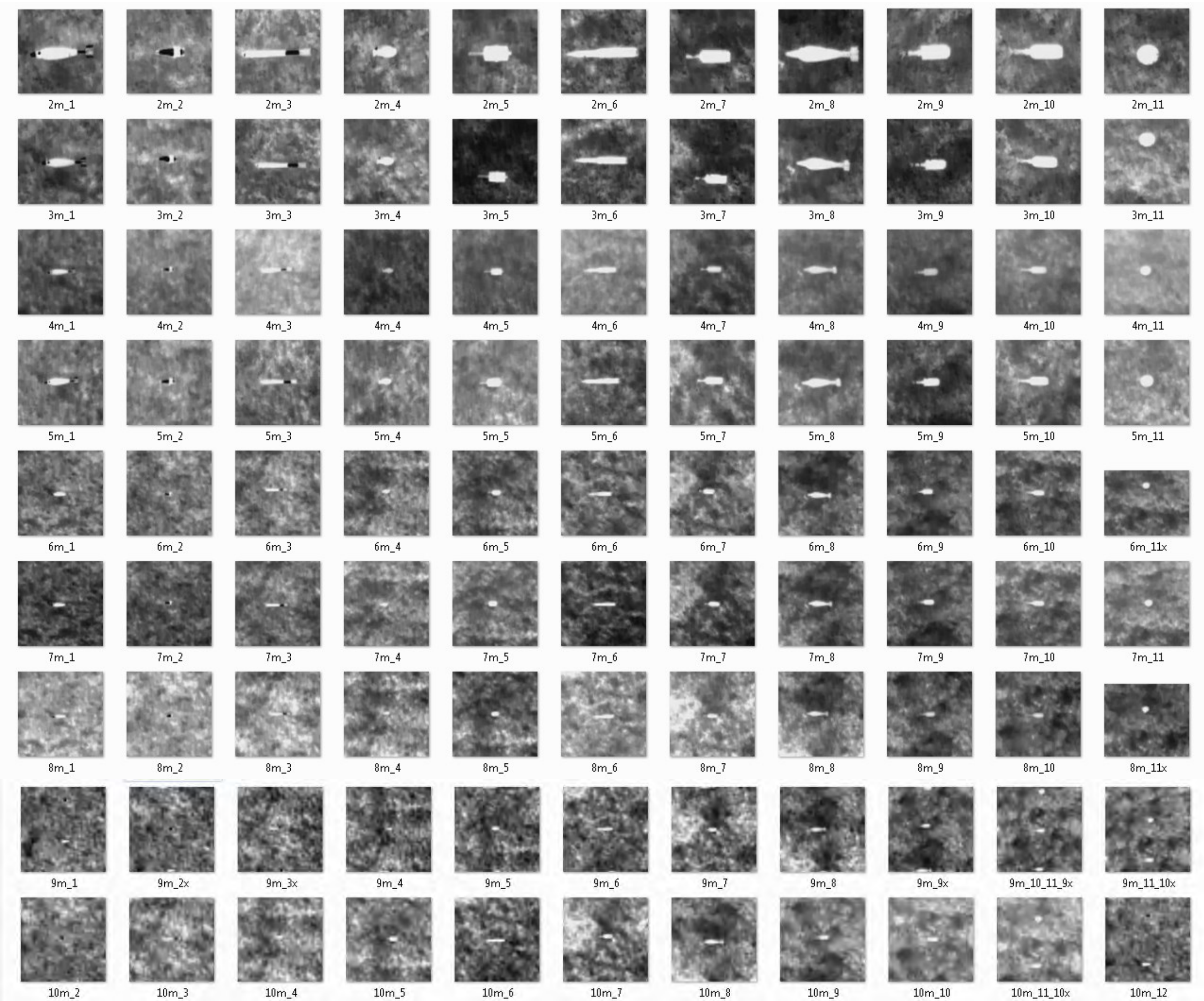
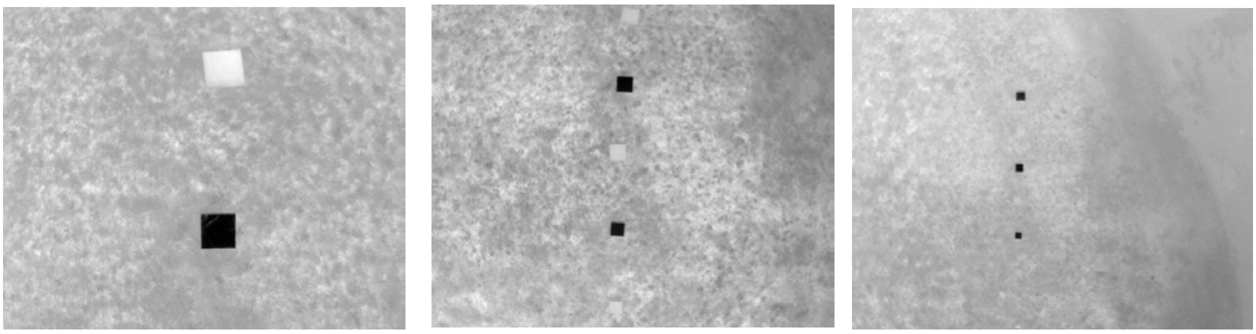


Figure 6.2 The thermal images for each target at increased flight height, from 2 m to 10 m, by step 1 m.

Operational calibration of thermal spatial resolution

The probability of a survey mission by a thermal camera onboard RPAS depends on the achieved spatial resolution of the collected images, which is defined by the application of the Johnson model. While numerous causes decrease obtained spatial thermal resolution, it is mandatory to check achieved spatial thermal resolution. For this task, we developed operational calibration by the use of polished aluminum markers. The aluminum square polished surface appears in the TIR image black and has a large contrast to other parts of the terrain. The use of such markers enables the operational calibration of the spatial TIR resolution. The markers that are painted black, appear in thermal images as white squares. This is a mandatory annex to SOP for the TIR survey. Application in testing in Blagovac in July 2019 approved its application, for example at Fig. 6.3.



a b c

Figure 6.3. a) h = 2m, markers 15x15 cm, b) h = 6 m, markers 15x15cm, 10x10 cm, c) h =10 m, markers 15x15 cm, 10x10 cm, 5x5 cm

Knowing the dimensions of the calibrating target, numbers of pixels in the horizontal axis (M=640), the vertical axis (N=512) one can calculate the dimension of the pixels of the considered survey. The measured spatial TIR resolution is always larger of theoretical value, due to several causes, e.g. the blurring of the images due to movement and the vibrations of the camera on RPAS, weather conditions, thermal conditions.

Probability of detection, classification for given spatial thermal resolution

The frequent and important question is how the spatial thermal resolution (ground sampling distance - GSD) of thermal recording (image or video) determines the probability of the survey via RPAS. The known fact is that a thermal scene in which are searched landmines, unexploded ordnance and improvised explosive devices is complex, besides the targets exist different elements of the environment. This happened in Bosnia and Herzegovina in the years 2018 and 2019 (exception tests in NPA test site Blagovac) and in Montenegro except in one region (Lovćen). Although the expectations are positive for Iraq, it is smart to consider not only the probability of detection but to take into account the probability of classification, for example in Fig. 6.4, Fig. 6.5. If the considered target has a known critical dimension for Johnson's model, it is possible to calculate the probabilities of detection and classification as the functions of the thermal spatial resolution.

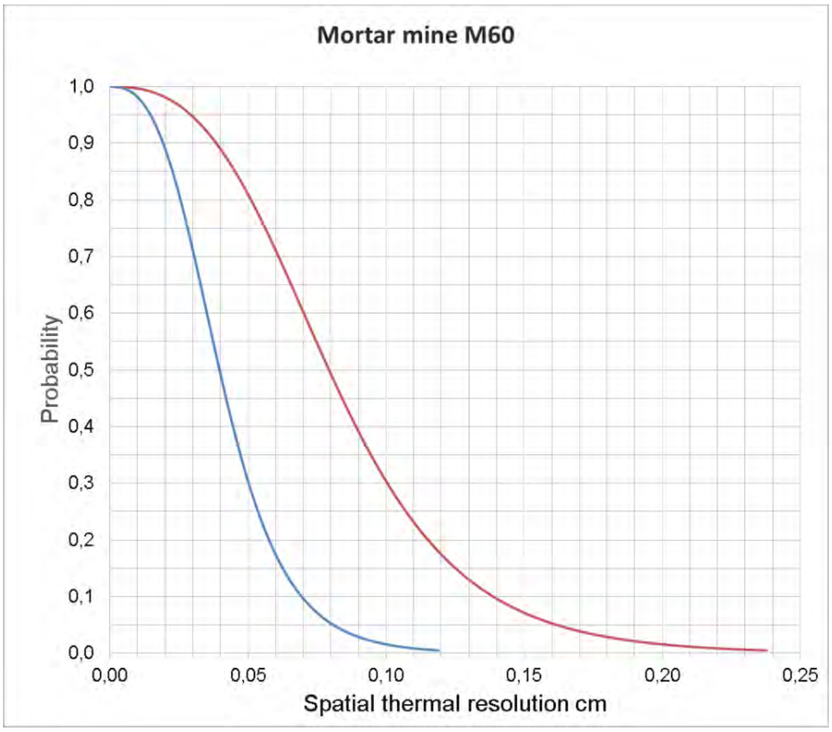


Figure 6.4 Probability of detection (red), classification (blue) of a mortar mine in a thermal infrared image

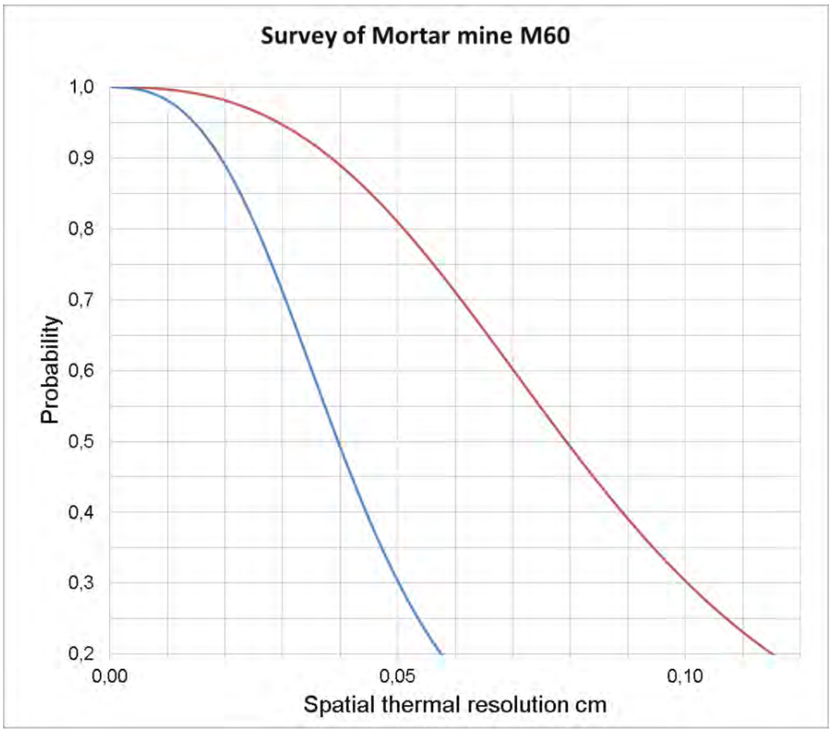


Figure 6.5 Probability > 0,2 of detection (red), classification (blue) of a mortar mine M60 in a thermal infrared image

7 Computer-Aided Photo Interpretation tools for RPAS based detection of landmines, unexploded ordnance, improvised explosive devices

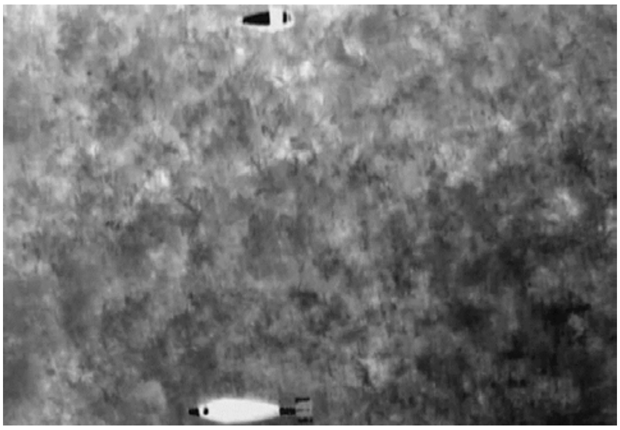
Till now (2019) the thermal infrared sensors on RPAS were not used in Iraq, [11], and we are limited on the experience described in our report.

The detection of targets in a thermal infrared survey from RPAS in NPA practice is performed:

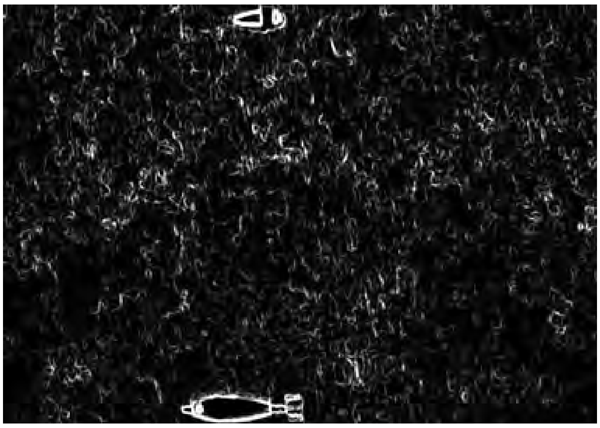
a) by manual search the targets on the collected images or the videos, which are collected by the automatically programmed survey flights;
b) by free RPAS flight, when the operator manually guides the RPAS while searching the suspected objects - targets.

In the first mode, the search can be supported by the set of software tools of Computer-Aided Photo Interpretation (CAPI) which can be developed in the user environment. For search targets in the video is needed real-time processing hardware which requires more skils.

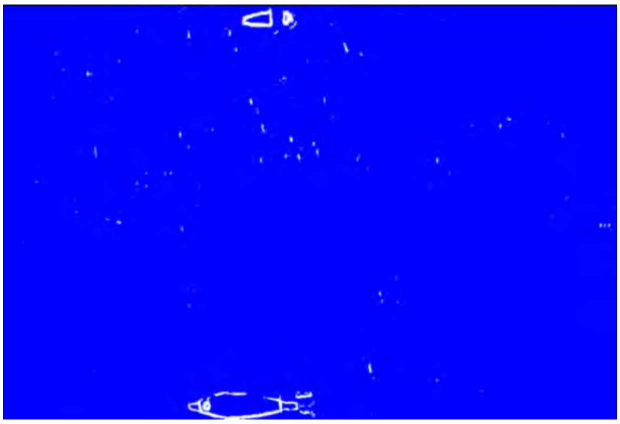
We developed the simplest tool example, shown in Fig. 7.1. This is a tool that enhances the edges of the target, can be used for a single image or for the sequence of thermal infrared images. Here we describe steps of processing of this example, while for the operational use this tool should and can easy transformed in the executive version.



a



b



c

Figure 7.1 Tool for the detection edges of targets in the thermal infrared image, and in the sequence of thermal images. a) Two targets in 720x480 pixels image, b) The enhanced edges of targets, c) The clutter suppressed.

Processing steps

- This tool uses sequence images of 720x480 pixels, extracted from thermal infrared video "Video.MP4" by use of the software Avidemux.exe (available free), [12].
- Select on Video.MP4 the usable part, between start time A and stop time B, and save it as "Video_AB.MP4".
- Extract images 720x480 pixels from Video_AB.MP4, save them in *TIF format. Using software ImageJ.exe (free) organize them in STACK sequence by ImageJ.exe, [13], save it in "Video_AB_stack.tif"
- Watch Video_AB_stack.tif and try to perceive targets. Note detection times. If the visual detection was reliable, note results and finish the interpretation. If NOT, continue.
- Process Video_AB_stack.tif by ImageJ.exe ImageJ/Process/Filters/Variance/Radius 0.1 pixels/Image/Adjust/Threshold/Default & Over/Under & Dark background/select uper slider and lower slider to enhance target and suppress the background clutter.
- Apply this process on a whole stack and save new stack "Video_AB_stack_enhanced_borders.tif" with enhancing borders of targets.
- Watch "Video_AB_stack_enhanced_borders.tif" and try to perceive targets. Note detection times.
- If visual detection in "Video_AB_stack_enhanced_borders.tif" was reliable, note results and finish interpretation. If NOT, change parameters of UAV flight and TIR images and TIR video collecting. Repeat the whole process.

Resume

The described tool was tested on a simple thermal infrared scene. For the proposed dual sensor, which integrates thermal infrared and visible color images, should be developed a new hardware solution.

There are several software systems from the Remote Sensing domain, that are very effective, free for use, tested in years by hundreds of university students, but also used in many scientific and in technology development projects. The evolutionary development of CAPI software tools can start and be based on some of them, e.g. on ImageJ.exe [13], MultiSpec.exe [14].

The program of education for RPAS based surveys should include training for development and continuous advancement of CAPI tools by operators of survey missions.

8 Technologies that can provide a positive impact on Land Release and detection of landmines, unexploded ordnance, and improvised explosive devices

Several advanced sensor technologies, usable from RPAS, that can provide a positive impact on land release and detection of the landmines, the unexploded ordnance, the cluster munition, and the improvised explosive devices are presented at the NPA workshop, Fig. 8.1

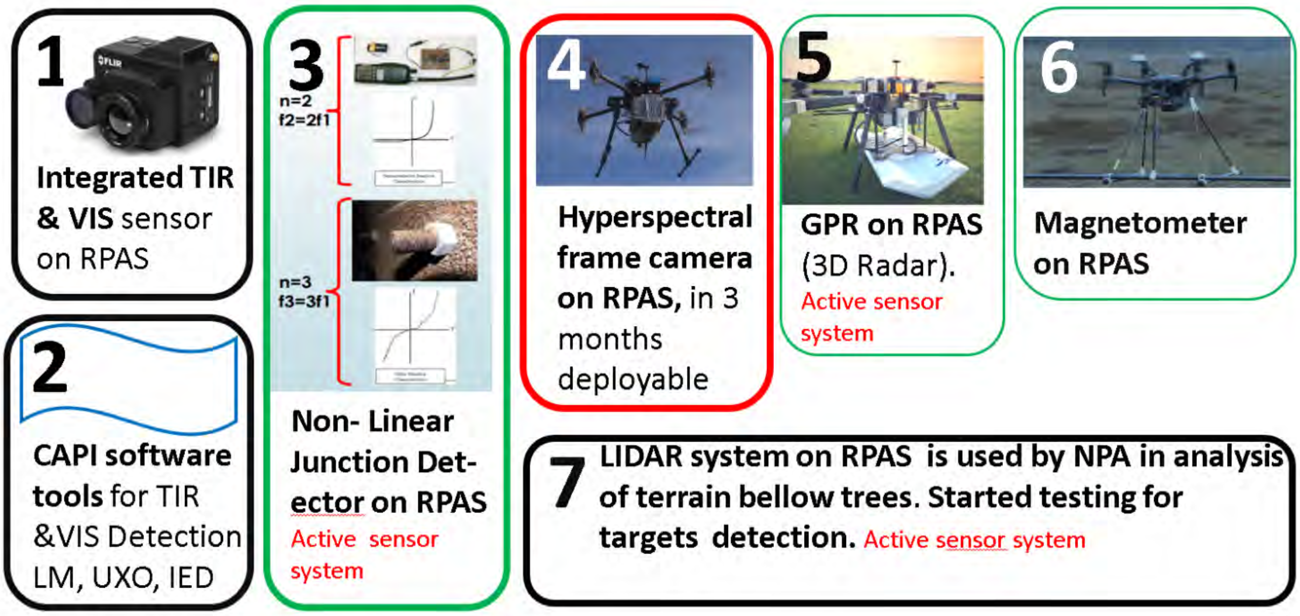


Figure 8.1 The sensors that are in use in NPA and the sensors recommended for future implementation in NPA survey technology.

We divided the considered technologies into the following categories:

- Technologies that are in use in NPA, that are tested in Bosnia and Herzegovina and Montenegro (1, 2, 7) and with small effort can become fully effective in Iraq.
- The hyperspectral survey technology (4) can provide the most usable recordings in Iraq of the targets on the ground surface. After purchasing the equipment, in three months the hyperspectral survey from RPAS can be deployed into operations. Testing and training can be done in NPA Bosnia. Note that in the FP7 project TIRAMISU we did it in only one month.
- The Non-Linear Junction Detector (NLJD) 3 is an active sensor that detects parts of improvised explosive devices, exist the manual and the ground vehicle-based versions. We propose NPA to support the potential development of NLJD for use from RPAS, by expertise in an operational statement of the need (SoN), by testing, evaluating for operations.
- The ground-penetrating radar (GPR) 5 is also an active sensor, that can detect targets (landmines, unexploded ordnance, improvised explosive devices, cluster munition) in-ground and not only at the ground surface. Although research and development in several projects are underway, we propose NPA to support the potential development of GPR for use from RPAS, by expertise in an operational statement of the need (SoN), by testing, evaluation for operations.

- The magnetometer on the RPAS system is a fully automatic system that can do a survey of the ferromagnetic targets in the ground and provide maps of the detection. NPA in Iraq applies manual magnetometers with satisfactory efficiency, this sensor could be considered for regions where it is a hazardous risk for a manual survey.

Dual sensor for RPAS

The thermal infrared survey of landmines and UXO in Montenegro and Bosnia and Herzegovina verified the strong dependence on the thermal contrast. The consequence is that the success of a thermal survey mission by RPAS is often uncertain while the use of dual-sensor (thermal infrared camera and visible color camera integrated into one unit) can overcome this problem, [20]. The dual sensor system for RPAS provides synchronized two images, thermal infrared image and visible color image (high spatial resolution) that are available in several combinations: separate, parallel, or overlapped, Fig. 8.1.

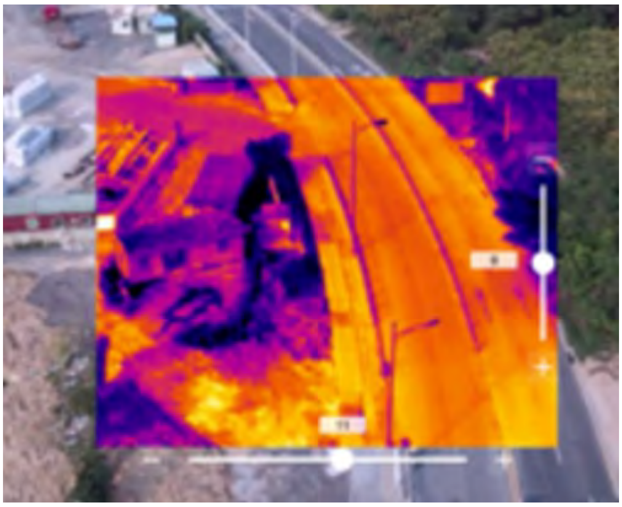


Figure 8.1. The overlapped thermal image in its color pallet and the visible color image in the background, [20, p.7].

Note that the fusion of the images is done inside of dual sensor, the operator selects a version that is suitable for survey tasks. If applied on an RPAS in the survey of the explosive targets on the ground surface, the operator can start a search of the targets from higher height watching the visible color images. Once when potential targets seem to be perceived, the height of RPAS can be decreased until the reliable thermal infrared and visible color images are recorded.

Computer-Aided Photo interpretation CAPI development for the thermal infrared survey of the explosive targets

The detection of targets in a thermal infrared survey from RPAS for land release, for the detection of targets on the ground surface, in NPA is performed in two modes:

- by manual search the targets on the collected images or the videos,
- by free RPAS flight, when the operator manually guides the RPAS looking for suspected objects,
- similar modes of the search are applied in Bosnia and Herzegovina, [6].

In the first mode, the search can be supported by the set of software of Computer-Aided Photo Interpretation (CAPI) tools. The development of CAPI tools we started during the testing in 2019 and should continue. The thermal scene in Iraq is simpler if compared to a thermal scene in Bosnia and Herzegovina and Montenegro, Fig. 9.2, Fig. 9.4, Fig. 9.6, Fig.9.7, Fig. 9.8. Therefore we could expect that more CAPI tools will be applicable in Iraq.

Non-Linear Junction Detector for RPAS

The NLJD, [21], [22], [23], is the harmonic radar that transmits electromagnetic waves at frequency f (~ 900 MHz) and receives the response of the passive electronics, electronic components, electric components, at doubled frequency 2f (~ 1800 MHz). Also, the corroded contacts of two metal surfaces respond at the tripled frequency (~2700 Mhz). There are the NLJD for manual use that showed the following detection performances, Fig.8.2 and Tab. 8.1.

The European Denese Agency developed from 2016 to 2019, tested and demonstrated in October 2019 several technology demonstrators of the systems aimed for detection of the improvised explosive devices (IED) and among them a vehicle-based NLJD system for forward-looking and detection IEDs on the dirty road, road, motorway, and aside of them. We propose NPA to support the potential development of NLJD for use from RPAS, by expertise in an operational statement of the need (SoN), by testing, evaluating for operations in Iraq.

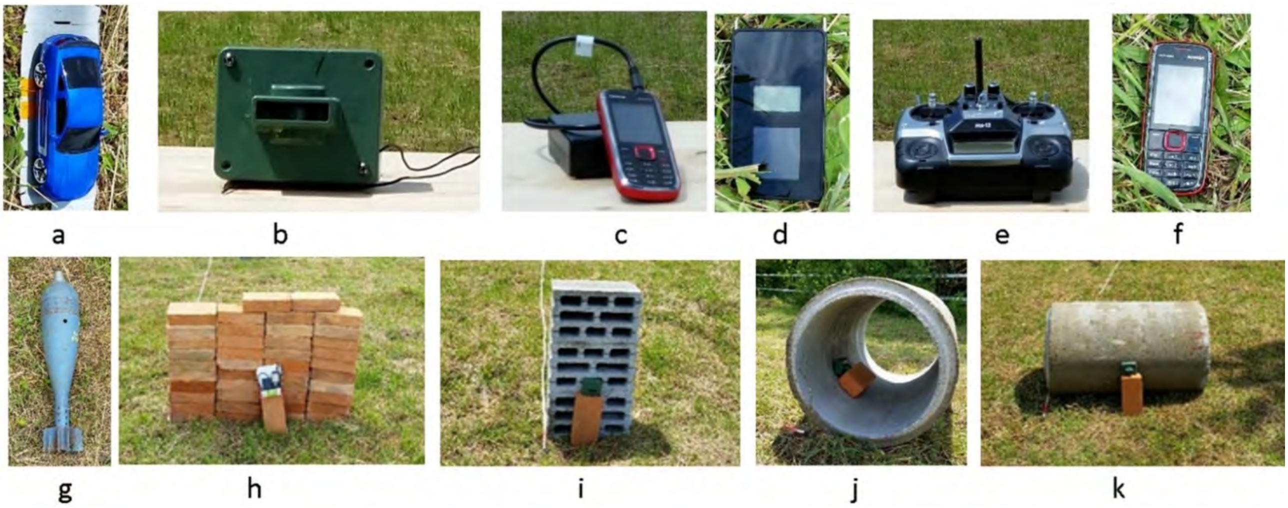


Figure 8.2 The targets detected by a manual NLJD, a – g. Targets behind or inside of the obstacles, h – k.

Table 8.1 The detection distance from a manual NLJD to the target

Targets	Soil	Height of target 1.2 m	Target on the ground	The target behind the obstacle
Toy Car	dry	11,5 – 18,5 m	11 - 14 m	
IR sensor	dry	20 - 30 m	11 – 23,5m	
Nokia1616+electric switch	dry	14 - 22m	12,5 - 17 m	4 – 11,5 m
Meteo station	wet	12 m -13,5 m	9 m	8 m
Remote Control unit	wet	18.3 - 20 m	16,5 - 17 m	
Nokia5130c	wet	10,5m - 11m	7 m	
Mortar shell 120 mm	dry	-	2 - 3 m	
$\lambda/2$ dipole, diode	dry	76 m	21 m	

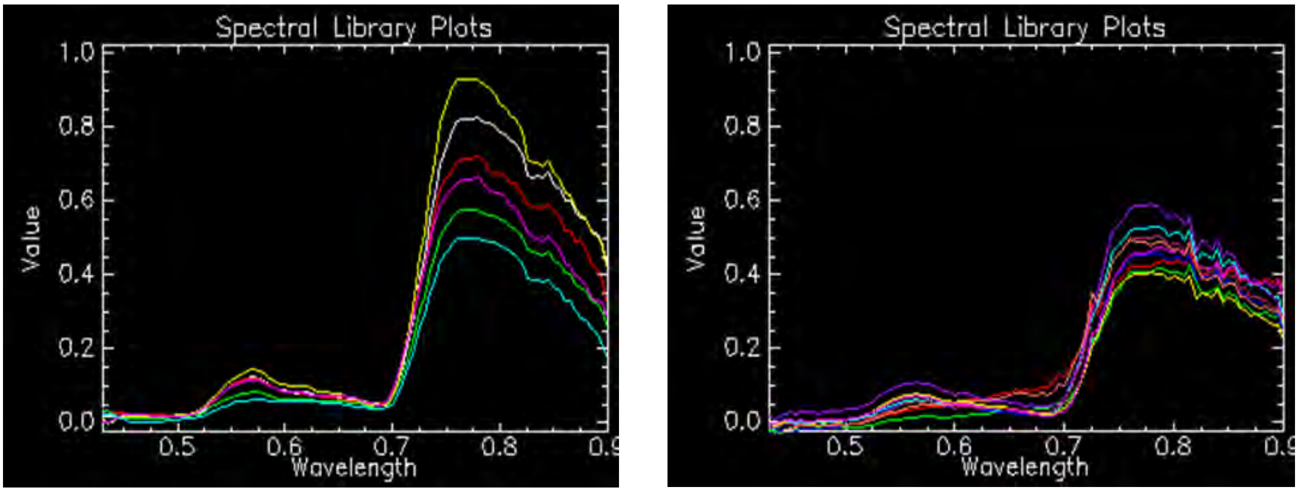
8.4 Hyperspectral frame sensor for RPAS

The hyperspectral sensors for RPAS are available in several versions, [24], the simplest for quick implementation is the hyperspectral snapshot (frame) camera, Fig.8.3. This camera provides images of 1000x1000 pixels for separated 125 wavelengths in the visible wavelengths and the near-infrared wavelengths (450- 950 nm).

a b c

Figure 8.3 a) The hyperspectral frame camera on the RPAS. b) The example of the ground scene marked areas for the analysis of the spectra. c) Reflectance spectra of the selected areas in b), [24].

The radiance spectra of the grass inside of the minefield differs from the spectra outside it, Fig.8.4. Hyperspectral features ("fingerprint") of the unexploded and exploded ordnance enable their detection by processing the collected hyperspectral recordings from RPAS. Fig. 8.5 shows the spectra of the aerial bomb RBK, of the soil surface, of the grass.



a b

Figure 8.4 a) Spectra of the grass in the minefield, b) spectra of the grass outside of the minefield, [24]

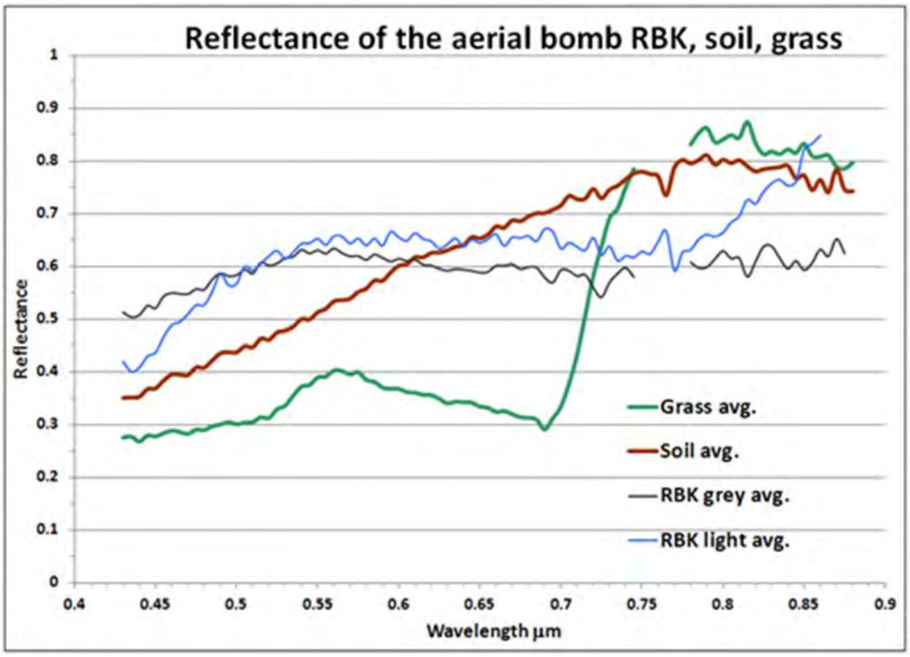


Figure 8.5 Reflectance spectra of the aerial RBK bomb, of the grass and the soil surface, [24].

8.5 GPR for RPAS

The main weakness of passive sensors on RPAS is their ability to detect explosive objects only if they are on the ground surface. The ground-penetrating radars (GPR) are available for survey the landmines, unexploded ordnance, and the improvised explosive devices in the ground, from the ground vehicle, although there are several research and development projects of the GPR on the RPAS, Fig. 8.6.

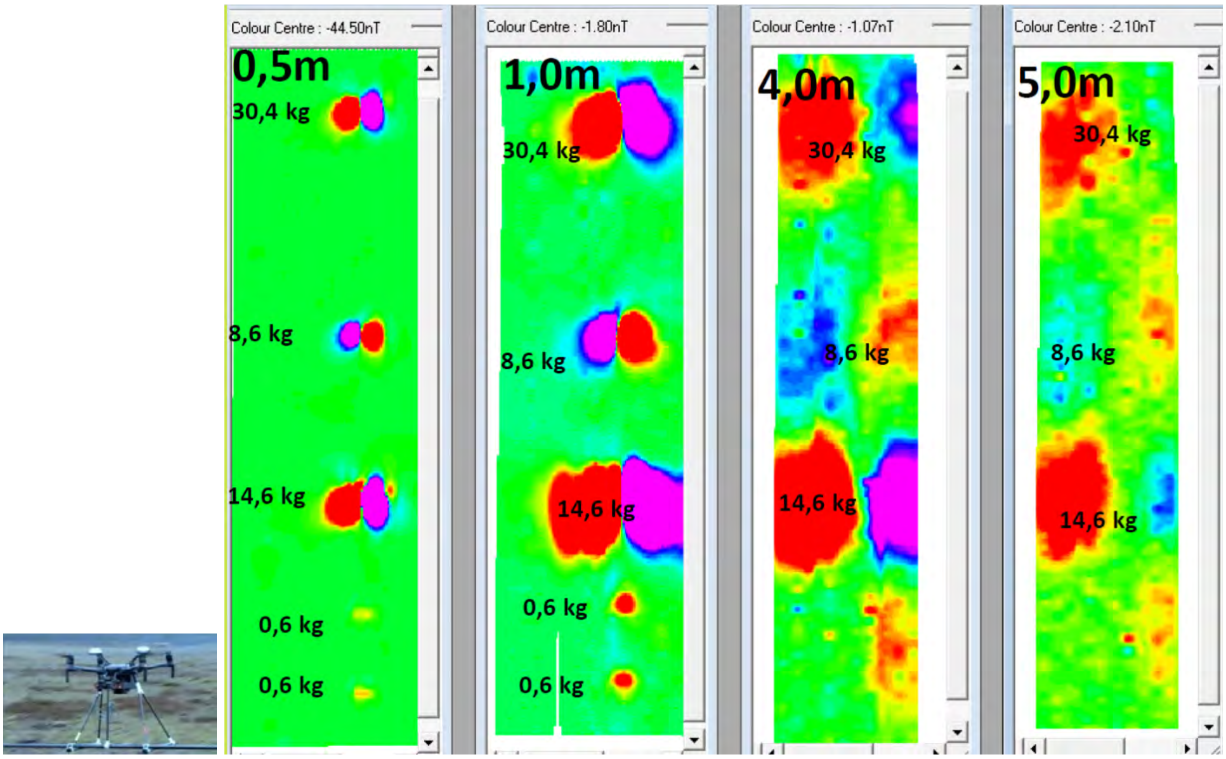
The GPR Mk IV Norwegian technology is ideal for IEDD applications. A high resolution 75 mm, effective scan width 1,575 m, weight 28 kg. An increased depth penetration, and an open software interface. Available in ground vehicle version. For aerial application, the RPAS shall carry a payload > 40-50 kg. Needs Artificial Intelligence training to IED scene. Very ambitious. We propose NPA to support the potential development of GPR for use from RPAS, by expertise in an operational statement of the need (SoN), by testing, evaluating for operations.

a b c

Figure 8.6 a) GPR developed at FERI, University of Maribor, Slovenia, [25]. b) Antenna a key part of GPR produced by Norwegian company (3-D RADAR), [26]. c) One concept of the GPR for use from industrial RPAS, [no-name photo on the Internet].

8.6 Magnetometer on RPAS

This system is fully operational, presented at the Mine Action Symposium in April 2019 in Slano, Croatia, [27], and demonstrated in Allentsteig Austria in May 2019, Fig. 8.7.



a b

Figure 8.7 a) Magnetometer on RPAS. b) Results of testing in Allentsteig, Austria. The precision of locating UXO depends on the strengths of the magnetic field in nT (top of each sub-image), which is dependent on the mass of UXO and its distance to a magnetometer.

8.7 LIDAR on RPAS

The LIDAR system on RPAS is used by NPA Bosnia, Fig. 8.8, in an analysis of the terrain. The examples are shown Fig.3.9b, Fig.3.10, Fig.3.13, Fig.3.14, Fig.3.15, Fig. 3.16, and Fig.3.17. LIDAR is an active sensor system that can be used for detection of the IEDs buried in the road, motorway and for detection remnants of the military objects on the former battle area (remnants of trenches, bunkers, shelters).

Figure 8.8 a) LIDAR on RPAS operational in NPA Bosnia. [NPA Bosnia and Herzegovina].

Proposal to NPA: start development of the detection of IED by Lidar in a dirty road, road, motorway and the detection of the remnants of the military objects.

8.8 Proposals to NPA

1. Purchase a dual sensor (thermal infrared and high-resolution color visible) and train the NPA operators for use in all available modes.
2. Apply the producer's technical instructions and strictly follow procedures of matching the survey of the targets and the environment defined in this report.
3. Modify the procedures of the images and the video acquisition with this new sensor. Test the available software tools for computer-aided photointerpretation (CAPI) and develop the additional tools for new survey potential, enabled by a new mode provided by the dual sensor.
4. Continue the more systematic testing of the survey by LIDAR on RPAS for the detection of the remnants of military objects at the former battle areas, and the detection of the landmines and, the unexploded ordnance. Advance the former survey procedure.
5. Consider initiatives regarding the hyperspectral frame camera, the non-linear junction detector, and the ground-penetrating radar on RPAS, for future activities of NPA.

9 Iraq terrain, explosive threats features, basic statistics

Drone Use in Iraq, Mats Hektor presentation at the workshop

Section 9.1 is a copy of the text from the presentation made by Mr. Mats Hektor, (2019), "Lessons learned from the use of RPAS in Iraq". NPA Workshop, Podgorica, Montenegro, 16-17 October 2019. It is estimated that this original contribution sends a clear message about the current status of RPAS practice in Iraq. Our goal is to accept messages from this presentation, and additional explanation and data, and information provided by Mr. Mats.

"*Drone Use*

Currently only used in North and Central Iraq (Improvised mines). The drones are used to assess ground signs from an aerial view. Confirming of direct and indirect evidence where needed. We have used them only to help us indicate where the EO is quicker which therefore makes our surveys more efficient and also helps us clear only the areas we need too.

Drone Positive Points

Currently, the DJI Phantom 4 Pro has an excellent camera, and being able to maneuver in and around suspected objects is a great tool. Able to record footage in HD and play it back in slow time gaining an accurate appreciation of the ground. The drones are relatively easy to fly and only take a few hours of instruction allowing all person to become avid pilots in days. The drones can get access to areas we can't without physical intervention. Drone can be utilized to view technical procedures which are normally a 1man risk. The Iraqi Army has established a drone curriculum which is currently being taught just outside Baghdad airport at a cost and the duration of 1 month.

Drone Negative Points

The drones are costly in Iraq $2K Plus (DJI Phantom 4 pro). The DJI Geofencing software doesn't allow them to be flown in most areas of Iraq.

The crack which opens geofencing can have negative impacts on the drone's functionality if not installed correctly. When crashed, drones are not easily repaired. Over familiarity or too much confidence can cause issues with pilots crashing drones. Drones are still a taboo subject in Iraq and many local authorities have yet to sign off on their use even though this has come through at the ministerial level. Currently, we have 2 crashed drones which we are having difficulty in fixing as nobody in Baghdad has the experience and logistical companies refuse to transport them

Drone Future Hope/Expectations*.*

We would like to have a drone which is capable of flying into buildings prior to any physical technical intervention. We hope that the Iraq people and authorities warm to them more so and they become easier to obtain and therefore easier to maintain and to fix when required.

What we want to test Drone for NTS and TS function on?

- ☐ *Improvised Mines*
- ☐ *Iran-Iraq conflict Mine Fields*
- ☐ *Cluster Munitions."*

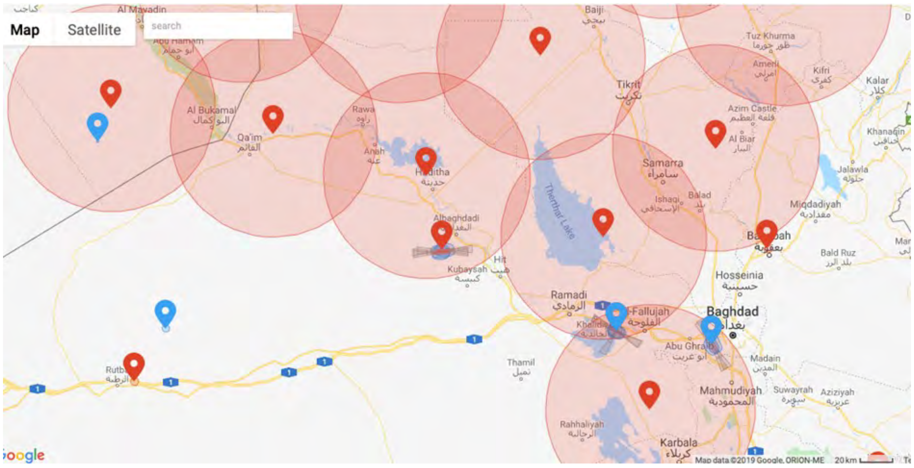


Figure 9.1 The DJI Geofencing software doesn't allow them to be flown in most areas of Iraq. [Mats Hektor, NPA South Iraq].

Basic statistics of explosive contamination in Iraq

The magnitude of the explosive contamination in Iraq can be conceived by looking at the basic statistical data in Tab. 9.1, provided by Mr. Mats Hektor.

Table 9.1 The basic statistical data of the contaminated areas in Iraq

Description	Confrontation Area km^2	MineFields Area km^2	Cluster Munition Area km^2	Improvised Explosive Devices Area km^2	Explosive Remnants of War Area km^2
Total Area	617,403745	1011,087129	197,092910	656,435802829	617,403745
Average	2,212094	3,611025	0,576295	1,783792942	1,400008
Stand. Dev.	12,148978	15,523160	1,984441	12,168209000	12,854667
Median	0,054439	0,025025	0,051962	0,042324979	0,036018
Maximum	121,020153	165,267193	24,562926	206,537197000	254,253159

The sum of cluster munition and the improvised explosive devices area is 84.42 % if the minefields area is defined as 100 %. The consequence is that the technology of the survey with thermal infrared and color visible sensors on the RPAS should be matched to these types of targets. There are no data that specify unexploded ordnance, probably they could be partially included in the category Explosive Remnants of War.

Representative views of the contaminated areas in Iraq

Mr. Hektor Mats and Mr. Noe Falk Nielsen from NPA provided a set of valuable images that enable us to understand the terrain in Iraq and the appearance of types of the area contaminated by different kinds of explosive objects. Figures 9.2, Fig. 9.3, Fig. 9.4, and Fig. 9.5 present elements of the minefields.

Figure 9.2 The ground signs of a typical Iraq contaminated area. Note the lack of vegetation. [Mats Hektor, NPA South Iraq].

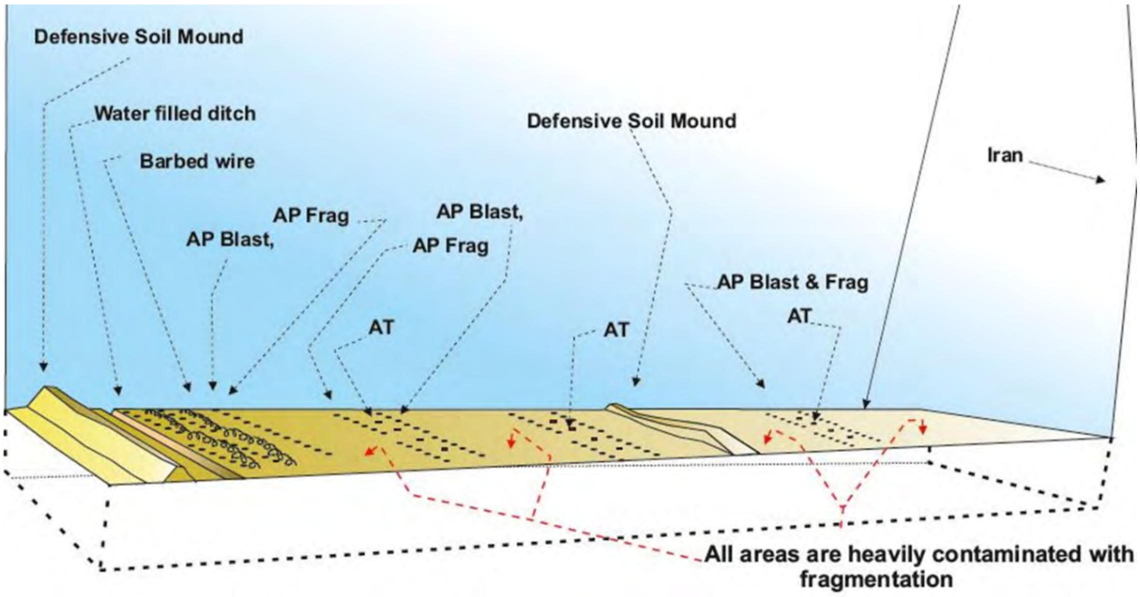


Figure 9.3 Scheme of the minefields between Iraq and Iran. The region of the Non-Technical and Technical Survey in South Iraq. Note the remnants of barbed wire on the left side of this figure and in Fig. 9.4. [Mats Hektor, NPA South Iraq].

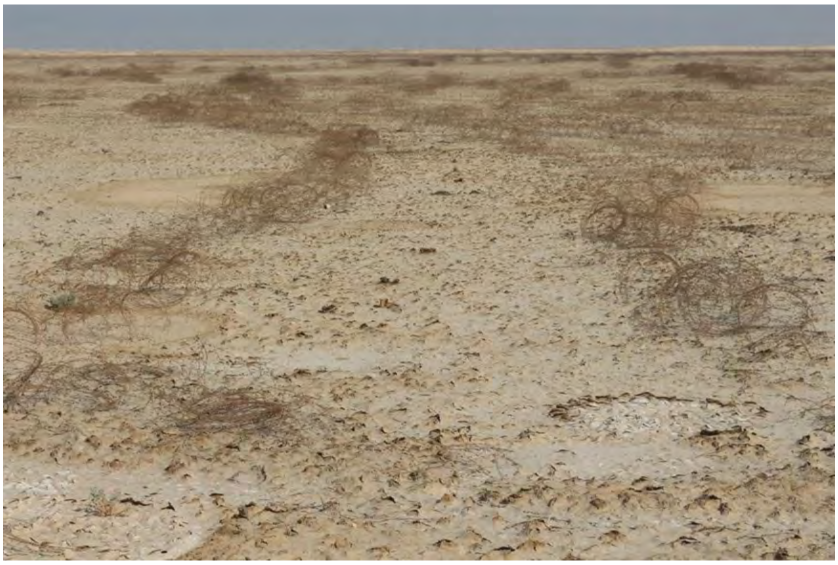


Figure 9.4 The remnants of barbed wire in the minefields at the border region between Iraq and Iran. [Mats Hektor, NPA South Iraq].

Figure 9.5 Identification of a mine row in the right part of the image. [Mats Hektor, NPA South Iraq].

The images Fig. 9.6, Fig. 9.7, and Fig. 9.8 are very useful, while they show the remnants of the ordnance and the cluster munition on the ground surface. It seems that the scene for the thermal and the visible color survey via RPAS in Iraq could be significantly simpler if compared to the scene in Montenegro and in Bosnia and Herzegovina, where vegetation (indeed trees, bushes, high grass) made this task mostly impossible or possible with low chances for reliable detection.

The demands for survey inside of remnants of the demolished house can be conceived, Fig. 9.9, but there is a very high hazardous risk inside of the house due to improvised explosive devices. The survey with imaging sensors is feasible, there are available very small RPAS that could be used but they should be additionally modified against the crashes. The second issue is the detection of the remains of the improvised explosive devices, for this task could be used Non-Linear Junction Detectors that we considered as a promising technology for considered cases. Note that in Syria Russian military forces used the NLJD.

Figure 9.6 The view of the cluster munition remnants. [Mats Hektor, NPA South Iraq].

Figure 9.7 The remnants of the exploded ordnance. [Mats Hektor, NPA South Iraq].

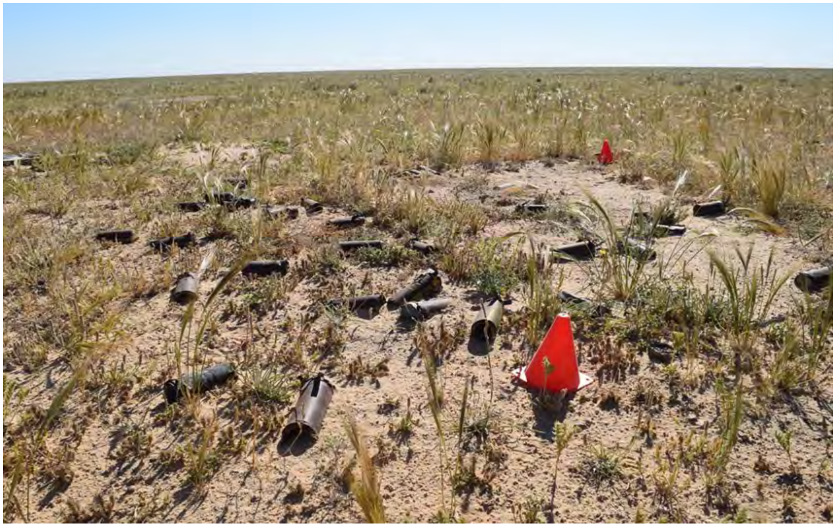


Figure 9.8 Non-Technical and Technical Survey of the cluster munition in South Iraq. [Mats Hektor, NPA South Iraq].

Figure 9.9 Building overview. NPA needs tools for the survey inside of the ruined house. [Mats Hektor, NPA South Iraq].

The dominant types of explosive objects used in Iraq are the improvised landmines, combined with parallel plate switches, Fig. 9.10. The main charge of the improvised landmine is shown in Fig.9.11. It can be expected that the improvised landmines and their main charges on the ground surface will be detected by the thermal infrared and visible color survey from RPAS. The parallel plate switches are covered by the soil and the chances for direct detection via thermal infrared and color visible survey are negligible. The technology that can detect differences of the soil surface around the buried parallel plate, or of soil surface that was used to cover the parallel plate exist, this is a hyperspectral technology. A chapter on promising technologies is discussed hyperspectral technology and its potentials for the needs of a survey in Iraq.

Figure 9.10 Improvised landmine ("Cooking Pot Mine) and parallel plate switches. [Mats Hektor, NPA South Iraq].

Figure 9.11 The image of the main charge of the improvised landmine. [Mats Hektor, NPA South Iraq].

Overview of the contamination in Iraq by 1 October 2018

The systematic overview in 2018 of the contamination in Iraq was done by Mine Action Review in "Clearing the mines 2018, a report by Mine Action Review for the seventeenth meeting of states parties to the anti-personnel mine ban convention" [15]. The complexity of the situation in Iraq is elaborated in ten pages, while the introduction announces what one can expect:

> *"Iraq is the world's most contaminated country by the extent of mined area. Legacy mined areas include contamination resulting from the 1980–88 war with Iran, the 1991 Gulf War, and the 2003 invasion by the United States (US)-led coalition account for most known contamination, including barrier minefields along its borders with Iran and Saudi Arabia. In addition, occupation of large areas by Islamic State after 2014 added extensive contamination with mines of an improvised nature and other explosive devices. A high proportion of these explosive devices emplaced are antipersonnel mines prohibited under the APMBC."*

10 Education and training for objective interpretation of recordings collected by color, thermal infrared, and Lidar sensors from RPAS

The current practice of the interpretation of the images and video collected in the NPA survey from RPAS for the needs of the Land Release, for Non-Technical and Technical Surveys, for detection of the landmines and the unexploded ordnance is manual (subjective) with low reliability of the positive outcomes. Opposite to the interpretation of the results of the RPAS based surveys, the production of the outcomes of RPAS recordings is at the high professional level, due to excellent software support for mission planning, conduction the flight, production image, mosaics, digital surface models. NPA operators do this all in a short time after the flights. There are different levels of training, knowledge, skills, and competencies in data collection and processing using RPAS, but the largest weakness is lack of education, training, and experience for the interpretation of the collected images, videos following the needs of survey goals. A more systematic training approach is needed to increase team capability to process data collected by RPAS to improve the quality of assessment of explosive threats in different environmental conditions. The program of education for RPAS based surveys should include training for the development and continuous advancement of CAPI tools by operators of survey missions. There are references for such activity, Fig. 10.1.

Figure 10.1 Training 10 surveyors of Bosnia and Herzegovina MAC and regional offices, 2 of NPA Bosnia and Hercegovina, 2 of Croatian MAC, 2015.

Training is composed of three parts: (1) on-the-job survey training of RPAS teams, (2) training by the RPAS flight and on a simulator, and (3) a 10-day seminar on the aerial survey for mine action use in cases of natural emergency and disaster. The nine-day workshop and training were completed from 18 to 27 February 2015 in Vogosca, Bosnia, and Herzegovina, [28].

11 Annexes

Review of NPA SOP for the survey via RPAS

The NPA SOP for a survey from RPAS provides the general frame for the surveys aimed for the Land Release, for Non-Technical and Technical Surveys, as well as for the survey aimed for the detection of the landmines, unexploded ordnance, improvised explosive devices, and the cluster munition.

There are specific requirements regarding the thermal surveys from RPAS, they are investigated and developed in the NPA project of testing thermal detection of explosive targets from RPAS. The outcome of the collaborative testing resulted in "A new technical procedure for a thermal infrared survey from RPAS", presented in section 11.2. These technical procedures are initial version, developed at the results and the experience collected in Montenegro in 2019 and Bosnia and Herzegovina in 2018 and 2019, by use of separated thermal infrared camera onboard of RPAS. The next phase of testing in Iraq should be used a dual sensor in one unit (thermal infrared and visible color) on RPAS. For this phase should be done evolutionary development of the advanced technical procedure for the survey in Iraq.

A new technical procedure for a thermal infrared survey from RPAS

Assessment TIR spatial resolution for considered targets

Consider and divide targets into groups by the amounts of their surfaces which should be visible from the TIR camera on RPAS. Define the relative importance of the targets and provide the following process for the targets that have the smallest dimensions. Determine needed TIR spatial resolution for the desired probability of detection, or identification using Johnson's criteria for each kind of the target, or estimate it by the simple rule of thumb, that requires 600 pixels at the area of a target. Do this for each group of targets. Select allowable flight heights for each group of targets.

Difference between TIR image and TIR video

TIR camera will acquire the thermal image of the rectangular area that has dimensions AxB, A=1,25xB if oriented at nadir to a ground surface. The ground sampling distance is a and b, Tab. 11.1 and Fig. 11.1. In used TIR camera image has 640x512 pixels, ratio A/B = 1,25, TIR video has 720x480 pixels, ratio A/B = 1,50.

Table 11.1 TIR image, the dependence of A, B, and a,b on the height of RPAS flight.

Height	A	a	B	b
m	m	cm	m	cm
2	2,418	0,378	1,934	0,378
3	3,627	0,567	2,901	0,567
4	4,836	0,756	3,868	0,756
5	6,044	0,944	4,836	0,944
6	7,253	1,133	5,803	1,133
7	8,462	1,322	6,770	1,322

Height	A	a	B	b
m	m	cm	m	cm
8	9,671	1,511	7,737	1,511
9	10,880	1,700	8,704	1,700
10	12,089	1,889	9,671	1,889
11	13,298	2,078	10,638	2,078
12	14,507	2,267	11,605	2,267
13	15,716	2,456	12,572	2,456
14	16,924	2,644	13,540	2,644
15	18,133	2,833	14,507	2,833
16	19,342	3,022	15,474	3,022
17	20,551	3,211	16,441	3,211
18	21,760	3,400	17,408	3,400
19	22,969	3,589	18,375	3,589
20	24,178	3,778	19,342	3,778

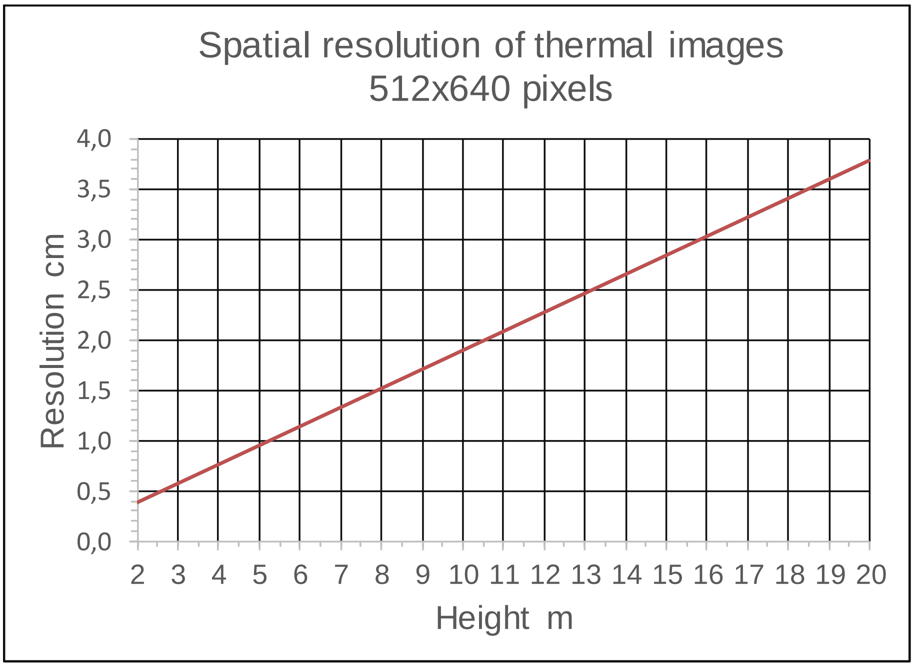


Figure 11.1 Diagram shows a relation between flight height and the spatial resolution of the thermal infrared images

A training terrain area for matching TIR survey to a new environment

The TIR survey must be matched to each new environment and for this process, a small training area shall be prepared. It should be of the nearly same or very similar ground surface (soil, vegetation) to the areas where the TIR survey will be done via RPAS. Targets shall be distributed in a training area.

Estimation of the daily changes of TIR contrast between targets and a ground surface

Measure the temperature behavior of samples of targets, on test terrain, that is the same or similar to the terrain of the surveyed area. Do this continuously during the mission to provide a reliable and critical experience. Estimate periods when thermal contrast between samples of targets and ground environment have maximum.

Operational calibration of TIR spatial resolution

Make calibrating markers, aluminum squares, with polished surfaces. The dimension of markers shall be 5 % to 20 % of A, the wider dimension of the area which will be surveyed by a TIR camera on the RPAS. On thermal images, these targets will appear very dark – black, Fig. 11.2.

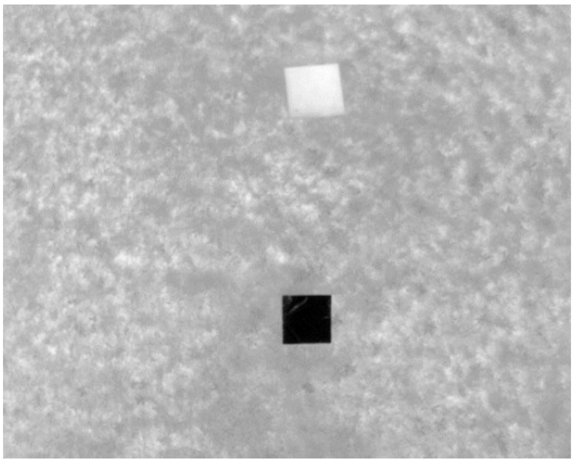


Figure 11.2 The calibrating targets in a thermal infrared image: the polished aluminum target appears black, while the black-painted cardboard plate appears white.

Assessment of a TIR behavior of the targets and the environment in the training area

Distribute target samples, calibrating markers on a training terrain surface. Collect

(a) TIR images (640x512 pixels) with ordinary overlapping, at flight heights from 2 m to selected maximum (recommended not more of 10 m), with height steps 1 m.
(b) Collect TIR video (720x480 pixels) at flight heights from 2 m to selected maximum (recommended nor more of 10 m), with height steps 1 m.

For smaller targets use RPAS flight speed < = 1 m/s. Let the time T when a target appears in the Field of View of the TIR camera be more than 5 sec. Calculate realized spatial resolution, using images of applied markers, of known dimensions. Consider collected (a) TIR images and (b) TIR video and conclude which combinations (height, speed, markers) are suitable for detecting targets in the planned survey.

Survey with selected height, speed, markers

Do the survey and analyze (a) the TIR images, (b) the TIR video. If (a) TIR images provide reliable detection of the considered targets, if visual detection was reliable, note results and finish interpretation. If NOT, continue with (b) TIR video. Use software Avidemux.exe and extract usable part of the video,

video_AB.MP4 between time borders A and B. Watch video_AB.MP4 and try to perceive targets. Note detection times. If visual detection was reliable, note results and finish interpretation. If NOT decrease the height of flight and repeat the process.

Workshop in Podgorica, Montenegro, 16-17 October 2019, overview and conclusions

Norwegian People's AID organized in Podgorica, Montenegro, 16-17 October 2019 "The workshop on lessons learned from the use of unmanned area vehicles for the identification and assessment of explosive devices threats". The objective of the workshop was validation of results of testing in Bosnia and Herzegovina and Montenegro and developed standard operating procedures of use of UAS (or RPAS, or drone or UAV) for identification and assessment of threat caused by explosive devices and an indication of needs and challenges for the next phase of the trial on the UAS use in Iraq.

Workshop conclusions

1. Trials in Bosnia and Herzegovina and Montenegro were focused on testing the usability of UAS with thermal and color cameras to detect explosive devices.
2. Application of UAS survey techniques in Bosnia and Herzegovina, Montenegro, and Iraq confirmed that the use of UAS (survey team, hardware, and software for data collecting and analyzing) has a wide application in land release and assessment of various explosive threats.
3. During the first and the second stage of a trial draft of SOP Module 11.3. RPAS – Data Collection and Assessment Using Unmanned Aerial Vehicles were verified in several different environments and situations.
   3.1. Draft of SOP should be transformed to NPA global generic SOP on Unmanned Aerial System (UAS) with additional guidelines for data processing and analysis of recorded results.
   3.2. Global generic SOP on UAS should be shared with NPA programs.
4. During the second stage of a trial, NPA BiH Information Management developed an application for planning, data collection, and reporting mobile in ESRI Survey123 which enabled advanced data processing and analysis in ArcGIS. Data are in a user-friendly form applicable for analysis in other software, as well. During the trial period, these existing forms must be used by all trial implementers (BiH, Iraq)
5. There are different levels of training, knowledge, skills, and competencies in data collection and processing using UAS.
   5.1. It will require a more systematic training approach to increase team capability to process data collected by UAS to improve the quality of assessment of explosive threats in different environmental conditions.
   5.2. NPA should develop a training package for drone operators and separate training packages for data analysis and interpretation.
6. The background of the initial proposal is from the European experience, therefore additional efforts are done to match proposals for detection technology to a situation in Iraq. During the workshop, we started communication and changed and improved several initial proposals.
7. Seven technologies for the detection landmines, UXO, improvised explosive devices (IED), and interpretation approaches aimed to support Land Release and IED Disposal are critically

considered (Integrated TIR & VIS sensor on RPAS; CAPI software for TIR&VIS Detection LM, UXO, IED; Non- Linear Junction Detector on RPAS - Active sensor; Hyperspectral frame camera on RPAS; GPR on RPAS (3D Radar) - Active sensor; Magnetometer on RPAS; Lidar system o RPAS - Active sensor system).

8. The NPA is approved ready for more complex testing of RPAS based thermal, color, and Lidar sensors and deployment of RPASs in operational conditions. The Lidar system on RPAS is already used by the NPA BH team in the analysis of terrain below trees. NPA BH has a team that is qualified to plan and conduct future RPAS testing.

9. The workshop supported proposals for the following detection technologies:

   9.1. Purchase dual sensor system (color sensor and thermal sensor) installed in one unit, which delivers overlapped color and thermal image, that is usable just after landing the RPAS. Do this for the Iraq mission.

   9.2. Purchase a hyperspectral camera and RPAS, integrate camera on RPAS, train NPA surveyor, in three months after purchase.

   9.3. Use the Lidar system on DJI RPAS for the detection of IED. The system is fully operational in NPA, and the only needed is the development of Lidar detection of IED.

   9.4. Ground-penetrating radar (GPR) on RPAS. Initiate communication with Norwegian company 3D RADAR to establish cooperation aimed to integrate GPR on the industrial RPAS (large payload). Assess the possibility to apply for grants from Norway Innovations.

   9.5. Consider possibilities for donors' support for the development of Non-Linear Junction Detector on RPAS. NPA can be a leading partner that defines needs, applications, provides operational validation in Iraq.

   9.6. NPA in Oslo has several software systems for remote sensing, which shall be available to NPA field teams.

10. It is necessary to provide software licenses for the implementation of the second stage of the trial in NPA Iraq timely.

   10.1 During the first stage of a trial, data processing and analysis of recorded results were limited due to a lack of coordination within the NPA structure to provide needed software licenses timely. Such a problem was solved during the second stage of the trial in Bosnia and Herzegovina and Montenegro.
   10.2 NPA HO should fix licenses for Pix4D including annual maintenance

11. Planning of the third stage of the trial in Iraq should secure continuity with findings and developments and lessons learned through the previous stage of a trial, including adjusting SOP to Iraq national regulations, country context, and nature of contamination.

12. Training of staff of NPA Iraq should be focused more on processing, analyzing, and interpretation of recorded data than on flying skills. There is a need for training of Ops management for planning purposes.

13. The nature of the contamination in Iraq (IED mixture with landmines) and the security situation will require more effort in the planning and execution of the trial.

14. The scientific/ expert support in the planning and implementation of the third phase of the RPAS trial in Iraq should be more intensive.

11.4 Workshop presentations

- Darvin Lisica. "Introduction to a workshop program, trial stages and methodology"
- Milan Bajić, Saša Džinić, Braco Pandurević. "Analysis of the recent and current experience of RPAS survey based on thermal and color sensors, aimed for detection of the explosive devices in Bosnia and Herzegovina and Montenegro", [17].
- Braco Pandurević, Darvin Lisica. "Introduction to the draft of the SOP Module 11.3 RPAS – Data Collection and Assessment Using Unmanned Aerial Vehicles"
- Franjo Damiš, Braco Pandurević, Saša Džinić. "Application of Survey 123 in data collection and recording with RPASs"
- Milan Bajić, Saša Džinić. "Testing of a thermal camera on board of RPAS and matching its usage for detection explosive devices on the ground surface"
- Franjo Damiš, Saša Džinić, Braco Pandurević, Darvin Lisica. "Designing a 3D model of ammunition storage area (ASA) with RPAS for the purpose of the risk assessment for populated places in the vicinity of the ASA"
- Milan Bajić. "New technologies based on RPAS which provide a strong impact on the detection of the improvised explosive devices, unexploded ordnance, and the landmines"
- Darvin Lisica. "Evaluation on use of RPASs in the general assessment of suspected-hazardous areas in Bosnia and Herzegovina"
- Mats Hektor. "Lessons learned from the use of RPAS in Iraq"
- Qasim Hashimi and Mats Hektor. "Panel discussion on further RPAS testing - needs and challenges for the next phase of a trial in Iraq"
- Qasim Hashimi, Milovan Joksimović, Darvin Lisica, Jonas Zachrisson, Mats Hektor. "Workshop conclusions"

11.5Acronyms

CAPI	Computer-Aided Photo Interpretation
DRONES	Internet jargon, civilian
FOV	Field of view
GPR	Ground-penetrating radar
IED	Improvised Explosive Device
IEDD	Improvised Explosive Device Disposal
LIDAR	Light Detecting and Ranging
LM	Landmine
LR	Land Release
LWIR	Long Wave Infra-Red, 7,5-14,5 μm
NLJD	Non-Linear Junction Detector
NTS	Non-Technical Survey
TIR	Thermal Infrared
TS	Technical Survey
RPAS	Remotely Piloted Aircraft System, International & National Aviation Agencies

UAV	Unmanned Aerial Vehicle, Internet jargon, civilian
UAS	Unmanned Aerial System
UXO	Unexploded Ordnance
VHR VIS	Very High-Resolution Visible
VIS color	Visible wavelengths, 400 – 700 nm, blue, green, red

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