Development of the TIRAMISU Advanced Intelligence Decision Support System

Andrija Krtalić and Milan Bajić

ABSTRACT
The Advanced Intelligence Decision Support System (AIDSS) is the first mine action technology in humanitarian demining to combine remote sensing and data fusion methods with advanced surveillance and reconnaissance in a successful operational system. It aims to provide a reliable, efficient tool to support the process of making decisions about suspected hazardous areas, based on the methodology scientifically developed and validated in the FPS SMART project. The system was developed through Technology Project TP-006/0007-01, supported by the Ministry of Science, Education and Sports of the Republic of Croatia, and deployed in operations in several suspected hazardous areas in Croatia and Bosnia and Herzegovina in 2008 and 2016. It was upgraded in the TIRAMISU project, and its name changed to TIRAMISU Advanced Intelligence Decision Support System. Gaps identified by end-users and system operators were filled in. Among the main results were innovations for generating mine danger maps. In this paper, only the structure of the system and its potential application in non-technical surveys as part of humanitarian demining are shown.

Introduction
Croatia is facing the problem of mines left over from the Homeland War (1991–1995). About 10.5% of Croatia’s national territory (6000 square kilometres (sq km)) is considered potentially dangerous due to mines (Human Rights Watch, 1999). The Croatian Mine Action Centre reviewed, defined and marked all the suspected hazardous areas in Croatia between 1998 and 2004 (CROMAC, 2009). “A Suspected Hazardous Area (SHA) is an area where there is reasonable suspicion of mine/Explosive Remnants of War (ERW) contamination on the basis of indirect evidence of the presence of mines/ERW” (IMAS 04.10, 2003). However, SHAs were defined as larger than in reality in order to reduce the risk to local populations and due to insufficient information from deep within such areas. Since mine detection has not advanced much since World War II, and mechanical demining is entering the final stage of development, the need has arisen to develop new methods of reduction (CROMAC, 2010) and define better previously defined SHAs and risk assessments in humanitarian demining, which will result in resolving the mine problem more rapidly in affected countries. In 1998, intense scientific research and development activities were launched in Croatia, aimed at implementing airborne and satellite-borne remote sensing in non-technical survey operations (IMAS 04.10, 2003) to reduce SHAs as part of humanitarian demining campaigns.

Advanced Intelligence Decision Support System (AIDSS) technology was developed in the System for Multi-sensor Airborne Reconnaissance and Surveillance in Crisis Situations and Environmental Protection technology project (TP-006/0007-01) (Fiedler et al., 2008) based on methodology scientifically developed and validated in SMART. It is the first mine action technology in humanitarian demining (IMAS 04.10, 2003) to combine methods of remote sensing with advanced intelligence in a successful operational system in non-technical surveys (Bajić, 2010). The AIDSS is not a detector of mines. It is a set of tools and methods to be used by experienced operators and experts from Mine Action Centres in order to help area reduction from remote sensing data and expert knowledge. The system was upgraded and deployed in humanitarian demining campaigns between 2008 and 2010 in Croatia (ITF, 2010) and Bosnia and Herzegovina (ITF, 2011). Further progress was made within the Toolbox Implementation for Removal of Anti-Personnel Mines, Submunitions and UXO (Unexploded Ordnance) FP7 project (IMAS 04.10, 2003), (TIRAMISU, 2012–2015) and the name changed to T-AIDSS. The greatest contribution and value of these four projects (after SMART) are the integration of most of the tools developed and their implementation in non-technical survey processes in Croatia and Bosnia and Herzegovina.

This paper presents an overview of the development and structure of T-AIDSS as used in non-technical
surveys in Croatia and Bosnia and Herzegovina between 2008 and 2016. The system introduces the integration, implementation and on-going development and use of on-the-shelf tools for risk assessment and assistance in reducing SHAs by conducting non-technical surveys (Larsson et al., 2010; Yvinec et al., 2017), which can be easily adapted to different needs and terrain types. For this reason, accessible, lower-priced sensors are used from the visible, near, mid and long-wave infrared portions of the spectrum (multi-spectral and hyper-spectral). Due to experiences in working with radar sensors in the SMART and TIRAMISU programmes (high costs; complicated, long processing; unreliable results), radar technology was not included in T-AIDSS. The system can be used to collect data for an initial definition of an SHA or to redefine an existing one. Furthermore, T-AIDSS can be used as a complete system (data collection, capturing, screening, evaluation, pre-processing and processing of data), as well as an independent set of tools.

Background to airborne and satellite remote sensing in humanitarian demining

Military demands to detect mines using airborne systems are different from humanitarian demining demands. Military anti-mine campaigns focus on reducing human losses (but not on eliminating victims altogether). The definition of needs is realistic and actions may be undertaken which include collateral losses. On the other hand, the purpose of humanitarian demining is to reduce the impact of the presence of mines on local populations and to return cleared land to local communities (Lacroix, Herzog, Eriksson, & Weibel, 2013). The amount of time it takes to clear an area is less important than the safety of the clearance personnel and the reliability and accuracy of the humanitarian demining process. In humanitarian demining campaigns, safety is of the utmost importance, and casualties are unacceptable (Habib, 2007). Since this paper presents research exclusively linked to humanitarian demining and the development and use of T-AIDSS, it does not attempt to consider the military aspect.

One extremely complex problem in humanitarian demining which is difficult to resolve is how to detect mines and minefields and establish which parts of suspected areas are not in fact mined and could be returned to the local community and used as before. Initial operational demands (non-technical surveys based on airborne and satellite images) were to achieve a probability rate of 99.6% in detecting mines and minefields (the standard required by the United Nations Department of Human Affairs), (Blagden, 1993) with a reliability rate of 98.1% (ANGEL 1999; Antonič and Nicoud 1997). These unrealistic, unachievable demands were replaced by the aim of reducing SHAs by identifying non-mined sections (Blagden 1998; JRC 2000). In addition, the false assumption was made that the market would show a commercial interest in airborne systems for detecting mines. Instead, demining companies expressed interest in machinery for preparing the ground, removing vegetation and destroying mines. In Croatia, successful local production of these devices developed (Mikulić, 2009).

In the late 1990s and early in 2000, five projects were launched in Europe for the needs of humanitarian demining. One, the Advanced Global System to Eliminate Antipersonnel Landmines (ANGEL, 1999), was partially based on airborne and satellite remote research, while the other four were entirely so based: MineSeeker (Bishop and Partridge, 2000), Pilot Project on Airborne Mine-field Detection in Mozambique (van Genderen, 1999), Airborne Minefield Area Reduction (ARC, 2001–2004) and Space and Airborne Mined Area Reduction Tools (SMART, 2001–2004) After these projects, two more FP-7 projects were carried out, which also partially dealt with airborne and satellite remote research (TIRAMISU, 2012–2015) and D-Box (Esmiller et al., 2013). Various types of sensors were investigated in these projects. A wealth of experience was gained and the random aspect of selecting them was narrowed down while rebutting the frequently expressed claim, “the more data from different sensors, the greater the probability of success” (Habib 2007; CROMAC-CITDT 2008). New technologies need to prove their capabilities. But no single technology has the capability to detect and recognise a variety of mines under all circumstances (Habib, 2011). Most developed technologies and techniques are very slow, have low accuracy, are complex, large and/or expensive, and suffer from a high false alarm rate. Many are promising, but none has the sensitivity, size, weight, manufacturability and price range required for humanitarian demining (Habib, 2007; 2011). Experience in the projects implemented has shown that many countries with mine problems do not have adequate human and technological resources to handle expensive, complex technologies (such as radar). Because of that facts, developed T-AIDSS take into account the facts that many of the demining operators will have had minimal formal education and that the countries where the equipment are to be used will have poor technological infrastructure for servicing and maintenance, spare parts storage, operation and deployment/logistics.

A common limitation of these scientific-research and technological-developmental projects has been their focus on finding solutions, developing them and demonstrating functional models or airborne prototypes, without following these up in terms of production or introducing them into operational use. Airborne methods mostly focus on reducing existing SHAs (Eaton, 2003) and fall within the remit of
national demining centres. Any reduction in SHAs is contrary to the market interests of demining companies. As far as they are concerned, the greater the suspected area, the better. This means that the expectations of financiers (that the industry and economy would recognise their own interests in terms of producing and putting developed airborne systems into operational use) have not been met, sources of financing to ensure the implementation phase have not been forthcoming, and the scientific and technological development projects remain incomplete. The only project in which the reduction of SHAs was achieved based on data from additional demining using airborne and satellite-based remote research was SMART (Yvinec 2004, 2005; Yvinec et al. 2005).

An SHA occupies a certain surface area. In order to reduce or eliminate it, that surface area must be defined and positioned. Thus, the mine risk can be visualised (Schultz, Alegria, Cornelis, and Sahli 2016; Alegria, Zimanyi, Cornelis, and Sahli 2017; Lacroix et al. 2013) and experts given the opportunity to make decisions. One key issue in humanitarian demining is the choice of areas to clear. Using GIS, airborne and satellite data combined with GNSS in a non-technical survey, it is possible to georeference all existing and additionally gathered data in MIS (2013; Schultz et al. 2016; Mather 2000). GIS methods can be used to integrate the SHA history data (changing of defensive lines of battlefield during conflict years) to synthesise and interpret it (Nolan 2009; Heymans and Claassens 2015). In previous studies, remnants of war indicators defined as “visual signs that mines or ERW may be near” were extracted from satellite and airborne images and their spatial relationships examined as a basis for risk assessment (Schultz et al., 2016). Testing GIS methods in combination with geostatistical methods for modelling mine risks is on the rise for the purpose of integrating data on demining activities (Alegria et al., 2011); Chan, Alegria, Veratelli, Folegani, and Sahli 2012; Lacroix et al. 2013). GIS is integrated in humanitarian demining with different objectives. One is modelling the ability of a mine-impacted community to adapt to landmine contamination (Benini et al., 2002), producing risk maps that delineate high-risk areas requiring mine clearance prioritisation (Knezić and Mladineo 2005; Mladineo et al., 2014; Gisslen and Törne 2015). All activities and data gathered during demining are stored in GIS and used to support expert decision-making in Mine Action Centres. The decision support system (DSS) is based on a combination of GIS analysis and a multi-criteria method, in order to enable effective mine action management. GIS is a powerful tool for generating aggregated information used in multi-criteria analysis, as is the link between hierarchic decision levels in the DSS (Knezić and Mladineo 2005; Gisslen and Törne 2015). The DSS results pave the way for the production of thematic mine danger maps. Mine danger maps (Vanhuyssen et al. 2004; Bloch, Milisavljević, and Acheroy 2007) obtained using multisensory data fusion synthesise knowledge gathered from existing data (Bloch, 2007). They are synthetic documents designed to help end users in decision-making regarding area reduction, and constitute the final output of the system and the basis for proposing areas for reduction. The methodological concept was developed within the SMART project, and improved in the TIRAMISU project as part of research into T-AIDSS.

The T-AIDSS results also demonstrate how visualising mine danger can support decision-making in mine clearance. This happens less at the policy level (e.g. in determining national and international mine action priorities, assessing the humanitarian impact, or estimating the financial costs of reducing mine danger impacts (Knezić & Mladineo, 2005)), and more at the operational level. In Croatia, politics dictate priority areas for demining. However, visualisation of mine risks is a great help to experts planning operations in Mine Action Centres. They can send surveyors to areas within an SHA for which there are no data on mine contamination, in order to confirm or rebut T-AIDSS results. This means they can then suggest areas, which can be excluded from the SHA.

**TIRAMISU Advanced Intelligence Decision Support System**

AIDSS technology is based on information and knowledge in the mine information system (MIS) and geographic information system (GIS) of Mine Action Centres, and on new evidence from aerial and satellite images and a digital terrain model (DTM) (Figure 1). It is a complex system that consists of three modules:

- Module for analytical assessment of (MIS) data
- Module for data acquisition
- Module for data pre-processing and processing

The modules can be used together or individually (Figure 1). Input includes data from the MIS, expert knowledge, airborne and satellite data and contextual data. The main characteristics of T-AIDSS are its compatibility and operability with processes and main functions in Mine Action Centres (Bajić, Matić, Krtalić, Candjar, & Vuletić, 2011). Advanced intelligence technology uses new sources of information and data (airborne and space-borne multi-sensor images) and provides evidence of earlier situations in the SHA.

The results obtained by means of these modules (tools) should help experts to redefine and reduce SHAs. The system does not aim to solve the problem...
of SHA reduction, but to help analysts in interpretation tasks (Yvinec et al., 2005). Direct mine detection is not the main task, rather it detects indicators of mine presence (IMP) and absence (IMA), as introduced in (van Genderen & Maathuis, 1999) and (Maathuis, 2001) and defined in the SMART project research (Yvinec, 2004; Yvinec et al., 2005; Acheroy & Yvinec, 2008). IMPs are objects within the SHA that are assumed to be protected by mines (Table 2), whereas IMAs are objects (areas) within the SHA that are assumed not to contain mines (Table 2).

Reduction does not replace classic demining. It takes place in parallel, forestalling the expenditure of resources (equipment, people, money) on clearing areas which can be reliably determined not to contain mines. Mine clearance (IMAS 04.10, 2003) and reduction are complementary actions in the process of removing mine threats as quickly as possible and returning the entire SHA to the community for use (in Croatia (Bajić et al., 2009b)). T-AIDSS has been developed for the purpose of SHA reduction (Bajić, 2010).

T-AIDSS is the operational TIRAMISU solution for non-technical surveys proposed to Mine Action Centres worldwide, because it is adaptable to specific terrains and situations. It has been applied in six SHAs in the Republic of Croatia and three in Bosnia and Herzegovina. The results concern redefinition of SHAs, exclusion of suspected areas (SHA reduction) or inclusion (SHA enlargement) (Bajić et al., 2009b), (Bajić, 2011). Mine Action Centre experts select the areas where T-AIDSS technology should be applied.

T-AIDSS is a complex system and requires the close cooperation of all participants in individual phases. A detailed analysis of the data integrated in MIS is necessary to determine the confidence of all input data. Mine action experts provide data from the MIS, analyse its quality, and extract general and special requirements related to missing information and data on an SHA. Mine Action Centre experts use data on existing minefields in MIS for spatial positioning. If the data are insufficient to positioning mine, the experts issue special requirements for additional data collection (Figure 1). General requirements for additional data collection include the detection of indicators, but no material evidence of mines (mine records) (Figure 1). Aerial survey plans are based on general requirements.

Triage of images is carried out when data collection is complete. It includes the selection of images for further processing. Within the triage process, interpreters are looking for IMPs on the collected satellite and airborne images by naked eye or simpler image processing. Images in which IMPs have been detected are forwarded, georeferenced and processed (to extract the indicators more accurately). IMPs are spatially positioned based on these images. Processing and interpreting aerial and satellite images and other data must be performed by mine scene interpreters. The positions of IMPs and IMAs, and contextual data on the doctrine of war in a particular area, form the input data needed for multi-criteria data analysis and fusion (Figure 1). Mine danger maps visualise the results of data fusion. The next phase of the T-AIDSS technology process is the fusion of all available data. The final phase is the delivery of the products (positions of IMPs and IMAs and mine danger maps) to MACs, which are the only entities authorised to accept or reject proposals and to make changes to SHA documentation (Figure 1).
**Module for analytical assessment of MIS data**

The crucial document for the success of T-AIDSS application is the *Analytical assessment for the process of collecting additional data on a suspected hazardous area in humanitarian demining* (Matić, Laura, Tursić, & Krtalić, 2014) based on data and information available in the MIS of MACs. The experiences gathered during 20 years of humanitarian demining in Croatia has been compiled in the form of guidelines (suggestions) for the analytical assessment of data in MIS, and made available to users worldwide. The document provides guidelines for analytical assessment in Southeast Europe (the countries of the former Yugoslavia). However, the methodology can be adapted to other terrains and conditions of war, as long as the list of indicators is defined properly in collaboration with MAC experts. They can then use the guidelines to conduct analytical data assessment in their MIS, primarily to prepare T-AIDSS to determine the general and special requirements for collecting new, additional data, information and evidence on the earlier situation in an SHA (Bajić et al., 2011) in order to (re)define it. On the other hand, the guidelines can be used for a general analytical assessment of the data stored in the MIS to support SHA assessment, reduction, re-categorisation and inclusion. This publication is one of the more important results of the TIRAMISU project, written by experts whose suggestions and input have been incorporated in T-AIDSS methodology.

The analytical preparation for additional data collection in a SHA consists of an in-depth, comprehensive analysis and interpretation of all previously collected data stored in the MIS. The analytical preparation is the basic stage in technical and non-technical SHA surveys. The primary goals are spatial positioning and contextual interpretation of all data stored in the MIS. This forms a strong analytical basis for identifying general and special requirements for collecting missing data. The analytical preparation and its results (general and special requirements) are essential prerequisites for high quality T-AIDSS in humanitarian demining.

In order to understand the process better and implement it more efficiently, the tasks of additional data collection may be divided into three groups:

- Individual analysis of existing data, entering the data in the MIS, reliability assessment of positions shown on maps (part of the MIS containing geographical and geodetic bases used for entering end positioning data in the MIS) and defining requirements for data collection in the field
- Integrating existing data in organisation system of defensive and offensive unit activities, improving results shown on maps and defining requirements for data collection in the field
- Analytical assessment of the initial SHA state, with a list of requirements for collecting additional data on the terrain.

In order to complete the analytical preparation tasks, suitable maps are needed so that geospatial data can be marked as accurately as possible. Additional MIS information is created through the analytical assessment of existing information. In order to enter (store) the data obtained, adequate overviews in the form of vectors and tables must be created. In other words, the positions of all material or contextual data on minefield boundaries (obtained by the analytical assessment of existing information) must be determined as precisely and as accurately as possible on maps and positioned in MIS, depicted as points, lines or polygons. The analytical assessment of existing information for additional data collection is a process in which experts (in warfare and mining activities) analyse all existing data, present it as precisely as possible on GIS maps, and store it in MIS. They must identify connections through integration according to the chronological order of military activities, and create an analytical assessment of the condition of the SHA. At the same time, expert assessment of existing information can identify missing data that should be collected. Thus, analytical assessment is the basis for additional data collection on mine contamination in specific areas. This means that the mine action system at any given moment can provide relevant data for planning and organising efficient humanitarian demining activities.

The results will greatly depend on expert military knowledge and the skills and affinities of analytic team researchers. The achievements of T-AIDSS in comparison to the initial version of AIDSS are as follows. General guidelines for conducting the analytical assessment (Matić et al., 2014) to define SHAs and general and specific requirements for additional data collection (with T-AIDSS) for better SHA re-definition were defined, written and published within this T-AIDSS module. A simplified version of T-AIDSS was also developed (without airborne multi-sensor acquisition and satellite images, Figure 11–1) for use in MACs to support MSA assessment, reduction, re-categorisation and inclusion, with only IMPs and IMAs derived from MIS data and MAC standard operational procedures. In the simplified version, an analytical assessment of existing data in the MIS (with only indicators of mine presence and mine absence derived from MIS data) and multi-criteria analysis for producing thematic SHA maps were carried out for Canak, Dinara-Peruča and Svlaja SHAs in Croatia. Figure 11(a) presents the difference between thematic presentations produced with MIS data only and those produced with data
collected in T-AIDSS. It shows the overlap and difference in regarding T-AIDSS and MIS results for the area of danger inside and outside Čanak SHA (red – results with MIS data, green – overlap of T-AIDSS and MIS data, orange – difference between T-AIDSS and MIS results, purple polygon – Čanak SHA).

Module for data acquisition
This module is used for additional data collection from deep inside an SHA. The requirements (general and specific) for additional data collection are the result of work done in the module for analytical assessment of MIS. The concept of the aerial data acquisition system and standard operating procedures for surveying are exclusively related to T-AIDSS sensors and equipment. The T-AIDSS module for data acquisition for a non-technical survey of an SHA consists of matrix cameras (to collect information from the visible part of the spectrum, 0.4 up to long-wave infrared 14 µm), a hyperspectral linear scanner (to collect information in the visible and near infrared part of the spectrum, 0.43–0.9 µm), an independent power supply system, navigation devices (Inertial Measurement Unit (IMU), Global Positioning System (GPS) devices), and a central control system.

The initial module for data acquisition with a single sensor pod was designed and used on two helicopters (Mi-8 (Figure 2(a)) and Bell-206). The module for T-AIDSS aerial data acquisition was upgraded, installed, tested and used on the following platforms: Mi-8, Bell-206 and Gazelle (Figure 2(b)) helicopters, UAV X8 MK (Figure 2(c)) and UAV 8 ZERO RPAS and blimp (Figure 2(d)) in a variety of combinations of sensors in Croatia and Bosnia and Herzegovina within the TIRAMISU project.

This module can ensure the stability and reliability of (aerial) data acquisition for non-technical surveys of SHAs on each platform. The subsystems (system configurations are different for different platforms) for (aerial) data acquisition are examined and should operate stably, without cancellation, on each platform. The technical stability and robustness of the system were confirmed by testing and evaluation (based on the behaviour of the system during data collection in the test areas) on different platforms and missions between June 2012 and the end of the TIRAMISU project in Croatia, and in Mine Action operations in Bosnia and Herzegovina in 2014 (Krtalić, 2016).

Module for data pre-processing and processing
The module for pre-processing and processing airborne and satellite imagery consists of a series of sub-modules:

- Pre-processing (parametric geocoding of hyperspectral and multi-spectral images, conducting atmospheric correction on hyper-spectral images, establishing coverage of the field with images, determining the quality of images)
- Triage (viewing and selecting images for further processing),
- Processing and interpreting images (subjectively and computer-assisted identification and extraction of indicators), data fusion (various thematic maps, multi-criteria analysis).

These sub-modules ensure the smooth flow of data preparation and processing for interpretation and analysis.

Figure 2. Platform for AIDSS aerial data acquisition module on: (a) Mi-8 helicopter (green ellipse), (b) Gazelle helicopter, (c) UAV X8 MK, (d) blimp (green polygon).
Pre-processing and triage

The first phase of pre-processing collected images with T-AIDSS is geotagging (linking the centre of the aerial colour image taken by the camera with the nadir position of the platform on the map at the moment when the image was captured). Triage of the images was carried out afterwards. It included selection for further processing. This step is very important because it reduces the quantity of data to be processed and the time required. In cooperation with an expert from the regional office responsible for the pertinent SHA, interpreters estimate the usability of the images taken. They perform a subjective analysis using all types of data and information. Their subjective interpretation is supported by computerised enhancement techniques to achieve higher probability and potential confidence in detection. The interpretation report defines images that contain IMPs or IMAs (Figure 3). These are geocoded and their image quality measures calculated (Bajić et al., 2011). This can be done manually (by registering one image on top of another) and automatically by using parametrically specialised software (AgriSoft). The mosaic orthophoto depiction of the destroyed ammunition warehouse in Padjene, was produced in the TIRAMISU project. It served as the basic document to produce a better plan for inspecting the destroyed warehouse and its surroundings.

The National Imagery Interpretability Rating Scale (NIIRS), (NCAP, 2018) is used by imagery analysts to define the quality of aerial imagery. The scale uses a number (0 to 9) to indicate the level of detail seen in an image, and therefore how much information it can be expected to yield. NIIRS levels were calculated for 25 Nikon D90 images (Table 1). The value levels ranged from 6.9 to 8.2 (7 and 8 respectively). At level 7, it was possible to identify individual railway sleepers, individual stairs on a flight of steps, and tree-stumps and rocks in forest clearings and meadows. At level 8, it was possible to identify truck grilles and/or license plates, individual water lilies in a pond, wind-screen wipers on a vehicle, and individual lambs (NCAP, 2018).

Image processing and interpretation

Geocoded aerial images are the main source for positioning detected IMPs or IMAs in a national or global coordinate system for use by mine scene interpreters. These experts perform the interactive interpretation of all selected images of the region of interest, searching for evidence of IMPs and IMAs. Interactive methods of semi-automatic

Figure 3. A large number of trenches and shelters for soldiers and tanks detected on the aerial image for the SHA in the municipality of Gospić, Croatia (Bajić et al., 2011).

Table 1. Summary evaluation data for a semi-automatic methodology to interpret digital multi-sensor images to detect and extract unexploded ordnance.

| Image number | Acquisition date | Acquisition time | Latitude (DD) | Longitude (DD) | Height above ground [m] | Ground Sample Distance [cm] | Image Quality Measure (IQM) | Commission Error for Corroded Objects [%] | Omission Error for Corroded Objects [%] | Overall Accuracy [%] |
|--------------|-----------------|-----------------|---------------|----------------|------------------------|-----------------------------|-------------------------------|-------------------------------------|-------------------------------------|---------------------|
| 1308         | 2012-06-15      | 10:04:24        | 44.072925     | 16.13118       | 290                    | 3.19                       | 0.0395                        | 6.7                                 | 30.16                              | 99.3000             |
| 1865         | 2012-06-13      | 17:36:35        | 44.074978     | 16.13629       | 123                    | 1.35                       | 0.0854                        | 7.0                                 | 6.17                               | 99.7528             |
| 1375         | 2012-06-13      | 16:56:00        | 44.073906     | 16.13731       | 95                     | 1.04                       | 0.5133                        | 8.2                                 | 79.24                              | 99.3908             |
interpretation of digital images of SHAs assist the interpreter, rather than replacing him. Experience has shown that in this task, the human eye cannot be replaced by automatic digital image processing methods. No special algorithms have been developed for this, but on-the-shelf software and image processing methods are used (pixel and object based), appropriate to the scene and indicators (Principal Component Analysis, different spatial filtering for line or area extraction, contrast change, etc.) (van Kempen, Katartzis, Pizurica, Cornelis, and Sahli 1999; Katartzis, Vanhamel, Chan, and Sahli 2004; Sahli, Busto, Chan, Katartzis, and Vanhamel 2004; Lacroix and Vanhuyse 2014; Vanhuyse et al., 2014). This is a major difference in contrast to other research. The results of automatic processing are interpreted and treated manually, if necessary, improving their confidence rating in the eyes of the (human) interpreter. Only then can data fusion be performed.

Computer assisted digital photo interpretation for extracting UXO based on object-oriented analysis is carried out in the interactive interpretation of images. This methodology (Racetin & Krtalić, 2014) requires one image or partial image with ground truth data to be used as a training set. Conclusions and regularities found on it can then be applied to other images of similar scenes. This methodology is sensor-independent and can easily be applied to different objects of interest. The method consists of the following procedures (Figure 4): pre-treatment and transformation of images; segmentation; statistical analysis of segment parameters – setting isolated parameters; application of common methods of image processing according to isolated parameters, and combining the results of image processing to enhance objects.

The methodology is based on a combination of pixel and object-based image analysis, where lessons and rules learned in a test dataset are then applied to other images of the same scene, but in different locations. Computer-assisted image processing based on pixel analysis was carried out to extract UXOs from images of the exploded ammunition depot in Padjene. Method validation was performed on 25 aerial Nikon D90 matrix RGB images of the depot. A randomly selected spatial subset of 500 × 500 pixels for each image was taken (Figure 5(a)) as a validation sample. As ground truth was not feasible, the images were interpreted visually and classified manually. The objects were vectorised using object-based image analysis (Figures 5(b), 6(a,b)) to reduce human error in manual vectorisation (Racetin & Krtalić, 2016). An accuracy estimation was made with the confusion matrix. The following average values for quality measures were achieved for the 25 analysed images:

- Commission Error for Corroded Objects: 18.54%,
- Omission Error for Corroded Objects: 5.57%,
- Overall Accuracy: 99.52%,
- Kappa Coefficient: 0.84.

**Indicators**

A list of indicators was established for each region of interest, depending on type, number found, and configuration of the terrain (see, e.g. the list of IMPs and IMAs in the municipality of Gospić, Croatia (Table 2) (Bajić et al., 2009a)). Experts in doctrines of war, mining in a particular area, and remote sensing participated in compiling the list.

All the indicators found in T-AIDSS application were vectorised manually (files were created for each type of indicator found on the scene and entered in the national or global coordinate system) (Figure 7) and their attributes were stored in attribute tables. Thus, the indicators were located in space and their existence demonstrated with certain confidence. This was the basic difference between IMP extracted in this way and in MIS. Another difference was that each interpreter also determined the subjective confidence of each indicator found. If the interpreter was

| Indicator of mine presence | Risk start from (m) | Maximum risk from (m) | Maximum risk to (m) | No risk from (m) | Order of importance |
|---------------------------|--------------------|-----------------------|---------------------|-----------------|--------------------|
| Mine accident             | 0                  | 0                     | 100                 | 200             | 1                  |
| Reconstructed position of minefield | 0 | 0 | 100 | 200 | 2 |
| Orientation point from minefield record | 0 | 0 | 100 | 200 | 3 |
| Trench                    | 0                  | 0                     | 50                  | 100             | 4                  |
| Bunker                    | 0                  | 0                     | 50                  | 100             | 5                  |
| Drywall                   | 0                  | 0                     | 50                  | 100             | 6                  |
| Shelters for people and artillery | 0 | 0 | 40 | 200 | 7 |
| Natural objects arranged for firing | 0 | 0 | 50 | 400 | 8 |
| Bridges and bridge crosses| 0                  | 0                     | 0                   | 100             | 9                  |
| Shallow draughts          | 0                  | 0                     | 0                   | 150             | 10                 |
| Ruined house on the first line of defence | 0 | 0 | 50 | 200 | 11 |

Table 2. List of indicators of mine presence and absence graded by importance and control points of membership functions for the production of danger maps for the flat terrain in the municipality of Gospić, Croatia (Bajić et al. (2009a)).#.
sure that the object seen on the image was a bunker, a confidence rating of 100% was recorded. If any suspicious anomaly in the shape of the bunker was found, the interpreter recorded a confidence level of 25%. Between these extremes, confidence level of 50% or 75% were applied, depending on the interpreter’s assessment. Humanitarian demining is a very dangerous business, and no information from the field should be ignored, no matter how insignificant it may seem. The quality of the interpreters’ work depends on the quality and resolution of images and processing, their knowledge of war doctrine, and in particular, their experience. The aim of data processing is to prepare all data for classification and data fusion, followed by the production of thematic images.

Figure 4. Methodology for semi-automatic interpretation of digital multi-sensor images (Racetin & Krtalić, 2014).

Figure 5. (a) Aerial Nikon D90 image (1865.jpg) of exploded ammunition depot; red rectangle – spatial subset used for validation purposes, (b) segmented image – spatial subset used for ground truth definition (Racetin & Krtalić, 2016).

Figure 6. (a) Ground truth data created by visual interpretation and manual classification, (b) Result of implemented methodology on the spatial subset; red – corroded objects, blue – not corroded (Racetin & Krtalić, 2016).
Multi-criteria analysis and confidence of results

The T-AIDSSs sub-module Decision Support System (T-DSS) was designed for analysing and processing all accessible compatible data, information and expert knowledge about a mined scene. The basic concept of T-DSS in humanitarian demining and its interaction with the environment is shown in Figure 8. After collecting all accessible data on a particular scene, it must be placed in a comparable relationship to obtain final results (thematic images). T-DSS is a methodological tool for processing multi-spectral and hyper-spectral data, contextual data and expert knowledge. The final results are images that show the impacts of all indicators on the scene.

The biggest problem in processing in this system is uncertainty. Therefore processing is conducted according to the principles and logic of fuzzy sets (fuzzy logic (Ross, 2017)) and the analytic hierarchy process (APH) (Saaty & Vargas, 2001) of multi-criteria analysis. The APH method compares indicators in pairs directly, and for this reason, this particular multi-criteria analysis method was selected. The determination of relationships is performed by an expert in humanitarian demining. Thus, expert knowledge of calculating indicator weights is introduced directly. Different indicators on different types of terrain do not necessarily have the same importance and weight. Neither is the same indicators found on all types of terrain, which results in varying numbers in individual SHAs. Experts in humanitarian demining determine the importance of each individual indicator based on their knowledge of explosive devices (chemistry, military engineering) used on certain terrains, or military doctrines in specific geographic areas, and on their prior experience in demining projects.

Contextual information and expert knowledge form a fuzzy set (Ross, 1995). Data are used which connect physical objects in the field with their impact.
on the environment. Since the set is ruled by fuzzy logic, there are no clear boundaries between the members of the set (where the hazard begins, culminates, decreases or is absent). A fuzzy set is characterised by the possibility of grading the affiliation of information to a specific class, from 0 (does not belong to any specific class) to 1 (complete affiliation to a specific class). The expert determines the zone of influence on the environment (on the assumption that mines present) (Wolff, Vanhuysse, & Willekens, 2004) for each indicator (Table 2). For each zone of influence, the expert determines the control points. Membership function are used to create connections in the fuzzy set (Ross, 2017) and then used to describe the appearance and value of the impact of an individual IMP on its environment and neighbouring indicators (Figure 9). The type and shape of the membership function depends on the type of IMP and its impact on the environment. For IMPs such as trenches, bunkers and various shelters, the trapezoidal shape of membership functions is used (Figure 9). The experts estimate the parameters of membership function (control points) based on information, data, acquired knowledge, experience in mine clearance and the weapons used in the conflict (Table 2). Physical objects on the ground can be linked with their impact on the environment based on the contextual data. Membership functions are used to link impact of indicators on the environment and each other and describe the influence of each indicator of mine presence on its surroundings and neighbouring indicators. Control points define the shape of membership functions (Table 2). Mines are laid in front of fortifications (bunkers, trenches, shelters) to protect equipment and the people using it. The people behind the fortifications must also protect the mines, so must have a clear view of the minefields, which should be within range of the fire cover. The first point marks the location where the membership function begins to rise above 0. The second point indicates where it reaches 1 (maximum danger). The third point indicates where it begins to drop below 1 again, while the fourth point marks where it returns to 0. An example is given in Table 3 and Figure 9. The maximum risk starts at 50 m and ends at 250 m from the trench. Beyond 250 m, the risk is reduced and is eliminated at 300 m. The shape of membership function depends on the type of terrain and vegetation cover.

**Data fusion and mine danger maps**

The thematic images that display the interaction between all input data are made on the basis of data processing. Before input data and information processing, it is necessary to analyse the data and information and define characteristics (imperfections, redundancy and complementarities (Yvinec et al, 2005)) and levels (low – mostly original data, high – pre-processed data (Yvinec et al., 2005)). Decision-makers then plan further action on the basis of processing the results of all input data. (Bajić et al., 2011).

The primary aim of data fusion is to combine all results derived in the DSS and from expert knowledge. The second aim is to produce thematic images with impacts of indicators on the scene, and impacts between indicators based on the fusion results. The goal of data fusion is to produce thematic maps of the influence, interaction and reliability of these results by combining all the results of data processing and formalising expert knowledge in other words, mine danger maps (Vanhuysse et al, 2004).

Thematic mine danger maps (Wolff et al., 2004) are synthetic documents designed to help end-users in decision-making regarding SHA reduction. They combine all the available MIS data and results yielded by T-AIDSS methodology, with added expert knowledge on the size of the area of influence of each indicator. Data fusion is performed if there is more than one result for a given indicator. Two types of danger map have been defined: a discrete mine danger map (Figure 10(a)) and a continuous mine danger map (Figure 10(b)) (Wolff et al., 2004). The discrete mine danger map covers a complete scene and mainly features the areas of influence of all detected indicators. It combines the results of output by detectors and classifiers, with added expert knowledge on the size of the area of influence of each indicator.

A continuous mine danger map covers a complete scene and features more elements than a discrete danger map. It introduces more nuances and requires

| Indicator of mine presence (IMP) | Risk starts from (m) | Maximum risk from (m) | Maximum risk to (m) | No risk from (m) |
|---------------------------------|---------------------|----------------------|---------------------|-----------------|
| Trenches                        | 0                   | 50                   | 250                 | 300             |

![Figure 9](image-url)  
**Figure 9.** Trapezoidal membership function for linking a trench’s zone of influence with control points.
additional expert knowledge (indicator ranking of importance), on the basis of which membership functions are determined to show the effects of individual indicators on the environment and each other. A scale of danger is also shown and can be read directly from the map. The greater the surface area marked in red, the greater the risk of mine presence. On the other hand, a thematic map of IMA (Figure 11(b)) shows selected areas which are used in some way and for which it is assumed that there are no mines. T-AIDSS proposes the exclusion of such areas from SHAs.

Mine danger maps are the main products of T-AIDSS along with IMP positions. A discrete mine danger map is a visualisation of danger that may be caused by all detected IMPs, regardless of their weight. A continuous mine danger map is a visualisation of danger that may be caused by all detected IMPs with their weight included. It can be used by the experts in MACs to plan further humanitarian demining projects. Based on the

Figure 10. (a) Discrete mine danger map of Čanak SHA (Croatia). Red filed polygons represent the zone of influence of IMPs. (b) Continuous mine danger map of Čanak (Croatia) SHA. The redder filed polygons represent a higher risk of mine presence.

Figure 11. (a) Intersection and differences in statements related to T-AIDSS and MIS results about the area of danger within and outside of SHA Čanak (red – MIS results, green – intersection of T-AIDSS and MIS data, orange – difference between T-AIDSS and MIS results, purple polygon – SHA Čanak). (b) All IMAs found and extracted by T-AIDSS for Čanak SHA, Croatia (purple polygon); the discrete map of IMAs for this region. Green polygons represent surfaces covered of IMAs.
information on these maps, priority areas for demining can be selected. Surveyors can be sent to inspect areas with no danger information (either in MIS or T-AIDSS results) to check whether there is any real mine danger. If there is none, the process of SHA reduction can be launched. These maps can be used to prepare deminers for entry into an SHA.

Internal cost benefit analysis

The blind tests performed on three SHAs in Croatia (=33 sq km) in the SMART project showed that this method had a reduction rate of 26% and an error rate of 0.1% (Yvinec, 2005). For three areas processed (the municipalities of Gospić, Bilje and Drniš =115 sq km) as part of the Deployment of the Advanced Intelligence Decision Support System for Mine Suspected Area Reduction project, cost benefit analyses were carried out (Bajić & Krtalić, 2010; Bajić 2010). The outcome of applying AIDSS to SHA reduction was a proposal in 2010 for a reduction of 10.99 sq km (Gospić: 5.23 sq km, Bilje: 5.68 sq km, Drniš: 0.08 sq km – 10.5% of the total area of interest). The data were used in general surveys conducted by the Croatian Mine Action Centre in 2011, when the SHA was reduced by 70,355.31 square meters (sq m) (27,665.26 sq m by demining and 42,690.05 sq m by reduction) (CROMAC, 2012). A cost benefit analysis was performed mainly for the user of the results achieved by the project (Bajić & Krtalić, 2009). The cost of the project was USD 244,512.47 while the cost of demining borne by the Croatian Mine Action Centre was USD 16,434,098.56 (2009). The calculated cost did not include performing the proposed reduction on the part of the Croatian Mine Action Centre. The estimated time needed to carry out the proposed reduction was between one and three months (2009). This information was presented in (Bajić, Laura, & Turšić, 2012) and by Davor Laura (Head of Sector for Operations at the Croatian Mine Action Centre) at the Humanitarian Demining 2012 international symposium held in Šibenik, Croatia.

Conclusion

T-AIDSS is an integrated system and operational solution for non-technical survey proposed to Mine Action Centres worldwide because it is adaptable to specific terrains and situations. It can be used as a complete system (data collection, capturing, screening, evaluation, pre-processing and processing of data), as well as an independent set of tools (e.g. the part that relates to the support in decision-making referring to MIS data, without additional data collection). A simplified version of T-AIDSS has been developed, introduced (without airborne multi-sensor acquisition and satellite images) and used in three SHAs in Croatia (Čanak, Dinara-Peruča and Svilaja). It can be modified (according to local specifics) and used in Mine Action Centres to support SHA assessment, reduction, re-categorisation and inclusion, with only the indicators showing mines and mine absence derived from MIS data and Mine Action Centre Standard Operation Procedures. This version of the system can only be used if MIS is available in a country.

Guidelines for conducting an analytical assessment of MIS data (to define general and special requirements for additional data collection to define SHAs better) have been defined, described in detail, implemented and made available to the humanitarian community.

The system for T-AIDSS aerial data acquisition has been upgraded (industrial controller, power supply), installed, tested and used on several platforms (Mi-8, Bell-206 and Gazelle helicopters, UAV X8 MK and UAV 8 ZERO RPAS and blimp), with new sensors and acquisition units in a variety of new combinations. The robustness of the system has also been improved and tested.

Semi-automatic interpretation of images was developed and implemented to detect UXO at the Padjene destroyed munitions depot in Croatia. For some types of UXO and ERW, promising results have been achieved. Further research in this field continue to improve the results.

The cost benefit analysis, though performed on a small sample and restricted number of areas, demonstrated the potential of T-AIDSS for use in non-technical survey activities within humanitarian demining.

The main limitation of T-AIDSS technology is that it depends on trees being bare and mountains free of snow at the time of aerial image and data collection. Forested mountainous terrains are mostly accessible in spring. The problem is of course greater in evergreen forests, but it could be solved by introducing Lidar into the Module for data acquisition. In addition, the efficient use of the system requires the prior existence of MIS, experienced mine scene interpreters and experts in warfare doctrine in certain geographic areas. They optimise resources and provide high-quality input data (lists of IMPs and IMAs, specific requirements for additional data collection, positions and confidence of IMPs and IMAs). This kind of system is suitable for collecting and processing images of relatively small areas, due to the large quantity of image data that must be processed.

Acknowledgements

The following people (listed in alphabetical order) participated in activities for the projects mentioned: Milan Bajić, Anna Brook, Igor Buneta, Zlatko Ćandjar, Teodor Fiedler,
Dubravko Gajski, Mateo Gasparović, Hrvoje Gold, Marijan Grgić, Cedomil Gros, Tamara Ivelja, Tihomir Kičinbašić, Marko Krajinović, Andrija Krtalić, Davor Laura, Cedo Matić, Ivan Medved, Josipa Nikolac, Nikola Pavković, Marija Pejaković, Zeljko Prčić, Ivan Racetin, Silvio Šemaljški, Tajmin Tadić, Roman Tursić, Luka Valožić, Dejan Vuletić, and pilots and technicians of the Croatian Air Force.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**Funding**

This work was supported by European Community’s Seventh Framework Programme (FP7-SECURITY Specific Programme “Cooperation.: Security), under grant agreement No. [284747] (“TIRAMISU project.”)

**ORCID**

Andrija Krtalić [http://orcid.org/0000-0002-9441-0179](http://orcid.org/0000-0002-9441-0179)

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