PARADIS: A Prototype for Assisting Rational Activities in Humanitarian Demining Using Images from Satellites

The PARADIS project aims to improve the planning of humanitarian demining campaigns with a software package working from the country scale to the field scale. A demining organization and an image interpretation team work together to put this system to use and benefit mine-affected areas.

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Introduction and Overview

The aim of the PARADIS project is to improve the planning of humanitarian demining (HD) campaigns using remote sensing data and Geographic Information System (GIS) techniques. In this context, a method and two software packages were built based on the needs expressed by the Bomb Disposal Unit of the Belgian Armed Forces. The main software package consists of management tools integrated in a common GIS platform, working from the country scale to the field scale. The planning method involves two main actors: a demining organization and an image interpretation team. A third actor is an image processing team for which the other software package was built. Applying image processing tools on satellite images and on scanned maps should speed up the extraction of objects of interest in an HD context. This aspect of the project is beyond the scope of this article.

The Belgian Armed Forces Bomb Disposal Unit, also known as SEDEE-DOVO, is responsible for rendering safe and destroying all munitions found in Belgium. Apart from giving direct support to Belgian units when deployed abroad, the unit also contributes directly to HD all over the world. At the moment, the unit has teams of technical advisors deployed in Laos and Cambodia.

Some basic knowledge in remote sensing can be found in the TELSAT guide.[4] Satellite sensors vary in spatial, spectral, temporal and radiometric resolution. In this document, we will often refer to the spatial resolution. Spatial resolution is related to the resolving power to distinguish image details. In remote sensing, it is common to specify the spatial resolution as the size each pixel represents in the real world. For example, the SPOT satellite has a spatial resolution in the panchromatic mode of 10 m, meaning that the image is composed of pixels with a ground diameter of 10 m. Also, a sensor may be active or passive. Optical sensors are passive, as they measure the reflected sun-radiance and radiance emitted by the observed objects. Radar sensors are active, as they emit a beam of electronic radiation and detect the wave that is reflected by objects.

GIS and Remote Sensing for HD

We made a review of existing GIS tools for HD in *A Geographical Information System for Humanitarian Demining*[1] when proposing the design of PARADIS. The review included the project undertaken at James Madison University (JMU); the Information Management System for Mine Action (IMSMA), developed by the Geneva International Center for Humanitarian Demining (GICHD); Minedemon, developed at ITC; the Digital Mine Documentation System Prototype, developed by the Business for Industry Concerns (IABG); "FOCUS HD," a Mapping Information system designed by Landair International Ltd.; and the integrative approach proposed by the Defense Evaluation and Research Agency. These projects are described in more details in *Demining Technologies*, a publication from International Exhibition, Workshops and Training Courses.[2] Also, some studies aimed at using remote sensing data in order to detect mine fields, as for example, the "airborne mine field detection[5]" project.[3]

From the latter review, we conclude the following:

- The use of airborne or satellite images to help the detection of hidden mines and general mine fields has not yet been demonstrated.
- None of the GIS tools is oriented by the tasks assigned to deminers during a mission.
- IMSMA is becoming the UN standard for collecting and managing mine field data. However, the tools provided were mainly developed to analyze spatial distributions and to centralize information about suspected areas and mine fields.

Therefore, we decided to build a tool based on IMSMA and ArcView in order to plan the humanitarian campaign, following the tasks of deminers during a demining mission.

Design of PARADIS

Identification of Spatial Data Needs

In order to identify the spatial data needs of deminers during an HD campaign, a collective work was started. As a starting point, a table of the user needs established by Paddy Blagden, technical director of the GICHD, was used and expanded during meetings with the Belgian deminers.

A demining mission involves the following tasks:

- Collecting general data at mission

Table 1: INFORMATION NEEDS FOR PLANNING HD CAMPAIGNS

Info	Detail	Remark	Source	Ideal - Realistic Scale
1. Mission announcement		Desk work1 week up to 6 months		
Global topographical data	Relief (altitude and slope)		DCW, road maps, WEB	1:°250,000 – 1:1,000,000
	Hydrographic network	Permanent	DCW, WEB	1:°250,000 – 1:1,000,000
	Inhabited areas location and toponymy		DCW, road maps, WEB	1:°250,000 – 1:1,000,000
	Administrative limits		DCW, road maps, WEB	1:°250,000 – 1:1,000,000
	Roads		DCW, road maps, WEB	1:°250,000 – 1:1,000,000
Local topographical data	Practicable roads and bridges		TC, VHRSI, HRSI, AP, (RP)	1:°50,000
	Hydrographic network	Permanent and temporary	TC, VHRSI, HRSI, AP	1:°50,000
	Inhabited areas location and toponymy		TC, RP	1:°50,000
	Land use	Towns, villages, cultivated areas, cultivable areas, forests, swamp, etc.	TC, VHRSI, HRSI, AP	1:°50,000
	Areas liable to flooding		TC, VHRSI?, HRSI°?, AP?, RP°1:°50,000	
	Important infrastructures	Dam, high tension line, industries, hospitals, schools, etc.	TC, VHRSI, AP, RP	1:°50,000
	Military buildings		TC, VHRSI, AP, RP	1:°50,000
Climate	Precipitation and wet/dry seasons		Meteorological data	1:°250,000 –1:1,000,000
Conflicts	Which were the parties (guerrilla or military)?		Non-geographic	Press, RP
	Where were the areas of conflicts/fighting?		Press, RP	1:°250,000
	Which were the ammunitions used?		Geographic: DB ammunitions per country	RP
	How are the ammunitions placed (Pattern)?		Non-geographic	RP
	Changes related to conflicts	Land use and roads	HRSI	1:°50,000
Refugees (IDPs)	Where do they come from?		UNHCR, RP	1:°250,000 –1:1,000,000
	Where are they?		UNHCR, RP	1:°250,000 –1:1,000,000
	How many?	Evaluation from surface covered by camps	UNHCR, NGO refugees intervening person, AP, HRSI	1:°50,000 – 1:°10,000
	Where do they have to go?	Relocation	Government, UNHCR, HRSI, TC	1:°250,000 and 1:°50,000 – 1:1,000,000°?

DCW: Digital Chart of the World
TC = topographic maps
AP = aerial photographs
VHRSI= very high-resolution satellite images
HRSI = high-resolution satellite images
DB= database
RP = resource person

Info	Detail	Remark	Source	Ideal - Realistic Scale
Cultivable areas			AP, VHRSI, HRSI	1:°50,000
Economy	Which economical activities are still working? Where are they?		RP, TC, Atlas	1:°250,000 –1:1,000,000
	Which economical activities should be settle up? Where are they?		RP, government, donors	1:°250,000 –1:1,000,000
Government	Which attitude towards demining?		Government, RP	
	Where are the areas the most important for the economical reconstruction of the country?		Government, RP, donors, Atlas, etc.	1:°250,000 –1:1,000,00
Injured/Dead	Mine accident description and localization	Localization per village or per district	BD IRCRI (Croix-Rouge International) and hospitals	1:°250,000
Demining	Which organizations	Geographic (per province)	WEB, embassies, Organizations	
	(International, national, NGO, etc.)?			
	What do they do?		Organizations	
	How (material, training, etc.)?		Organizations	
	Field staff and management		Organizations	
	Where are they working?		Organizations, UNDP	1:°250,000
	Where are the cleared areas?		Organizations, UNDP, (BD?)	1:°250,000
Level 1	Organization responsible of Level 1? Method to make Level 1?°	See also Phase 2		
2. Field Survey			On the field Duration: a few months	
Level 1	See phase 1: If Level 1 exists, the information below will be obtained from the organization that made it.	Available maps? DB? Reliability?		1:°250,000
	Collateral Information	Government, population, hospitals, NGO, UNDP, BD, maps	DB?°	
	Overview of mine field location	Information origin and reliability		
	Suspected areas			1:10,000, 1:50,000
	Marking		Map, mark in the field	
Mine fields	Localization and extent		Government, population, hospitals, NGO, UN, sketch	1:°50,000
	Who put it there and how (Pattern)?		Government, population	
	Types of mines	Link to mine DB	Government, population, NGO, UN	
	Important potentially mined buildings	Precise localization and nature: Hospitals, industries, military buildings, schools, villages, trenches, etc.		1:°250,000
Communications roads		Verify practicability	Population	1:°250,000
Level 2 already done and cleared areas		Geographic	Government, NGO, UN	1: 5000
3. Planning		Desk work Duration: 1 week		

Info	Detail	Remark	Source	Ideal - Realistic Scale
Priorities	Which one?	Economical, agricultural, population social	Government, local authorities, donors demining organization	1:°250,000
	Who is setting them?	Government, UN, local chiefs, demining organizations		
	Which are the constraints? Easy/difficult areas to clear	Seasons, roads	Demining organization, Phase 1 results	1:°250,000
	Which means are available for demining (dogs, manual, robot, etc.)?			
Task scheduling	Map production: areas to clear first, explicit constraints (seasons, etc.) (ex symbols)			
4. Level 2: Demining		Work fieldDuration: <5 years		
	Which detailed map available?		Cartographic inventory, national geographic institute, etc.	
	Precise mine field localization and extent	Areas to clear	Work field: from mine field corners, draw automatic sketch of mine field border	1:°10,000
	Nature of area to clear		AP, work on the field	1:°10,00
	Types of removed mines	Geographic (per mine field)	Work on the field	
	Existence of traps	Geographic (per mine field)	Work on the field	
	Clearing methods and techniques (manual, automatic, dogs, etc.)	Geographic (per mine field)	Demining organization	
	Personnel	Number of deminers and management	Demining organization	
	Working pace of the clearing	Depends on surface type, season, munitions, traps	Automatic computation	1:°10,000
	Productivity	Number of cleared m^2/deminer/month	Automatic computation	1:°10,000
	Security	Deminer accidents	Work on the field	
	Localization of cleared areas + Precision			1:°10,000
Planning update	Based on the surface cleared compared to the surface initially estimated. New map production			
			Syntheses of demining results	1:°250,000
5. Level 3		Work on the field Duration: indeterminate		
	Which method is used to control the demining quality?	Non-geographic	Organization responsible for controlling	
	What is the quality of the demining?	Geographic (per mine field)	Work on the field	

Info	Detail	Remark	Source	Ideal - Realistic Scale
	Accidents over the cleared areas	Geographic (per mine field)		
6. End of Mission				
Conformity to mission objectives	Is the use of the cleared areas in accordance with the declared use?		VHRSI, HRSI	1:°50,000 – 1:°10,000

Table 2 Tasks for the PARADIS interface

1. Mission announcement (Global Scale ˜ 1: 1,000,000)

A. Visualizing a regional topographical mapping existing at global scale, scanned and geo-referenced topographic map or existing vectorial DB.
B. Overlaying and mapping existing geo-referenced UXO – suspected mine field – number of accident DB of Level 1 (if exists)
C. Visualizing the extension of all types of geographic data
D. Printing and reporting

2. Field survey (Regional Scale ˜ 1: 50,000)

A. Visualizing space map, conducting a preliminary interpretation and overlaying topographical mapping
B. Introducing GPS reference points measurements into the system and correcting the geo-referencing of the satellite imagery
C. Overlaying geo-referenced UXO – suspected mine field selected into the Level 1 DB, if exists; if not, filling a form in IMSMA
D. Creating a map of the past conflicts (legend to be defined) and visualizing on map of the IMSMA information about conflicts
E. Computing the number of UXO-suspected mine field per administrative area
F. Modifying topographical data according to ground survey and the satellite image interpretation: adding, modifying or deleting vectors; adding, modifying or deleting attributes of vectors
G. Getting feedback on image interpretation to SGR/IM
H. Printing and reporting

3.1. Planning for each clearance team (Regional Scale ˜ 1: 50,000)

A. Visualizing the priorities (selecting or setting locations and adding an attributes to set the priorities) or setting the priorities according to UN or the country taking into account future refugees or displaced people resettlement
B. Visualizing the constraints: flooding, accessibility, etc.
C. Getting a user decision on the team localization
D. Logistic facilities for teams (distance to water, electricity, roads, etc.)
E. Computing the estimated time to clear a mine field according to the estimated size (from the DB or from the ground?) of suspected mine field, the demining means (number of detectors), time to clear a square meter (parameter to be fixed by the user according to the vegetation cover, the duration of a working day, the mine density)
F. Printing and reporting

3.2. Planning for each roving team (Regional Scale ˜ 1: 50,000)

A. Mapping some DB attributes of UXO or suspected mine field (i.e., size)
B. Comparing the villages of the IMSMA DB to the ones on the space map
C. Encoding progressively the number of UXO found in each village
D. Visualizing the updated map of the number of UXO found in each village
E. Printing and reporting

4. Clearance: drawing the mine field (Field – team scale ˜ 1:°5,000)

A. Overlaying the detailed topographic map or the space map and its interpretation
B. Overlaying geo-referenced UXO – suspected mine field selected into a DB
C. Filling/creating/modifying a follow up form of clearance activities with information such as precise location (GPS points, reference of map, reference of image or photo), descriptive information of the mine problem coming from the Level 1 DB (injured person, etc.), vegetation cover
D. Drawing and/or updating a sketch of the mine field on a spacemap (if available)
E. Printing and reporting

5. Clearance: follow up of each section (Field – section scale 1: 500)

A. Overlaying of a grid (size and orientation of the grid defined by the user) on the sketch
B. Printing the sketch with the grid
C. Encoding the number and the type of mine or UXO found in each cell of the grid
D. Filling the grid each week according to the cleared area
E. Printing and reporting

6. Updating the planning from the mine field to the region (1: 5000 to 1: 50,000 to 1: 1,000,000)

A. Computing the cleared area and the area to be cleared and updating the estimated time required to clear the area according to the demining means (number of detectors) and the time needed to clear a square meter (parameter to be fixed by the user according to the vegetation cover, the duration of a working day, the mine density).
B. Following up with indicators (to be determined) to be visualized and computed at several geographic scales (grouping and generalization procedures) for a feedback to the headquarters
C. Printing and reporting

Remarks:

It seems necessary to maintain an attribute related to the scale at which any information was collected.

The follow-up of a mine field through time should be possible.

announcement.

• Performing a Field Survey to roughly locate mine fields (Level One Survey).

• Planning campaigns.

• Going back to the field to obtain precise mine field and UXO locations (Level Two Survey).

• Clearing the mine fields and removing UXO.

• Evaluating the quality of the work (Level Three Survey).

Table 1 lists the required information at each step of the mission, its possible sources and the appropriate scale. A short version of this table has been presented at the JRC, in ISPRA, at the workshop "Towards Harmonized Information Systems for Mine Action in South Eastern Europe[6]," and published later in *A Geographical Information System for Humanitarian Demining*.[1]

PARADIS Interface

We have identified the tasks to be performed in the interface according to the routines of a mission and the identified data needs previously described. A software package working at four scales embedded in an ArcView platform that is compatible with IMSMA and the Belgian EOD Champassak database has been produced.

The global scale or Country Scale (1:1,000,000) may contain the Digital Chart of the World (DCW), topographic maps, meteorological data and maps of refugees. At this scale, the user should be able to combine information such as administrative limits, roads, relief, hydrographic networks, inhabited areas and local names, climate zones, soil types, refugees, airports, mine clearance center locations and responsibility areas.

The Region Scale (1: 250,000 to 1: 50,000) may contain satellite images (SPOT, Landsat TM, ERS and RADARSAT), topographic maps and information from field surveys. Based on this data, the user should see practical roads and bridges, village extensions, hydrographic networks, hospitals, military buildings, accident localization, campaign schedules, mine field locations and land cover. This overlay information comes from image interpretation and from the IMSMA database. At this scale, the demining staff has tools to plan its campaigns and organize its teams according to priorities, regional constraints and logistic facilities.

The Field Scale (1: 10,000 to 1: 1,500) may contain aerial photos, very high-resolution satellite images (IKONOS), statistics and sketches. Highly accurate maps of the suspected areas and cleared mine fields could be available as overlay. An Advancement Scale (1:500) is added in order to produce a detailed description of each mine field.

The system was fed with data for test sites in Laos and Mozambique (see section entitled Test Sites). The design of the prototype was presented at the ISPRS 2000 conference in Amsterdam.[1] A double-face summary illustrating the system for the Laos and Mozambique test sites is available at the SIC website.[6] Table 2 describes all the functions to be implemented in the interface and their working scale.

Organization of a Campaign

The general planning method proposed involves a demining organization and an image interpretation team. Additionally, an image processing team may ease the work of the interpretation team.

In the PARADIS project, the SEDEE-DOVO played the role of the team of deminers. During the designing phase of the project, the interpretation team was distributed between the scientific partners of the project: the IGEAT and the SIC. However, as the method should be performed in routine, an operational partner had to be found inside the Belgian Defense itself. The General Intelligence and Security Service, Section Imagery (SGR-IM) assumed this task. This role could be given to a well-chosen subcontractor in the case of non-Belgian missions.

Extracting information from satellite images and scanned maps could be tedious work if a lot of images must be analyzed or if images are large: semi-automatic feature extraction could be a precious help for image interpreters. This work is not mandatory, but it should speed up the interpreters' work.

The procedure of data collection goes as follows; it is summarized in Figure 1. At the mission announcement, the demining team contacts the interpretation team (SGR/IM) in order to identify the regions and the best season for acquiring satellite data over the areas of interest, and to purchase them. This team is also responsible for collecting maps and performing the georeferencing of the satellite images. The images are then sent to the image processing team (SIC) for automatic analysis: extraction of the hydrographic and road networks, identification of water areas and classification of the images. This information should be used to facilitate the image analysis which aim is to produce the vectorial overlays made of roads, inhabited and cultivated areas, infrastructures, etc., again performed by the interpretation team. The latter team will also produce colour composite images using all bands, and black and white images displaying the panchromatic data. Meanwhile, the deminer team (SEDEE-DOVO) fills the IMSMA database with the field survey. When all this data has been collected, it is introduced in the prototype described in the "PARADIS Interface."

Test Sites

The first test site chosen was in Mozambique because of the co-lateral data already available from the "airborne mine detection" project mentioned above. In order to show the adaptability of the method in a different context, another test site was chosen in Laos, where the Belgian deminers are active. All missions involved data collection, data interpretation and ground survey, as well as work with local deminers, specifically Norwegian People's Aid (NPA) in Mozambique and UXO Lao in Laos.

Mozambique

The test sites were located in the province of Tete close to Songo and Mameme. A first mission on the sites was conducted in order to obtain all the missing information, establish contacts with NPA and elaborate a working method with them, and test the use of high-resolution images for demining activities and check their interpretation. A second mission there aimed at presenting final results to NPA and confirming the use of very high-resolution data.

For the first mission, LANDSAT TM (resolution 30 m), SPOT multi-spectral (resolution 20 m) and panchromatic (resolution 10 m), RADARSAT (resolution 13 m) and LANDSAT MSS images (resolution 80 m) were available and processed. For the second one, IKONOS panchromatic data (resolution 1 m) was acquired.

High-resolution satellite images (resolution between 10 and 30 m) were used to extract information about roads, railways, villages and crops. Thanks to a sequence of images, it was possible to observe an increase of inhabited areas, crops and even tracks in the Songo area. On the RADARSAT image, we could only see roads and rivers, while the LANDSAT MSS images were of too low resolution for our purpose. It should be emphasized that the advantage of radar images is to provide information despite the clouds; thus, they are useful in very cloudy areas where maps do not exist.

Laos

For the test sites in Laos, in the Champassak province, we purchased SPOT multispectral data (resolution 20 m) thanks to the "Secrétariat pour la Coopération au Développement." UXO LAO lent IKONOS panchromatic data (resolution 1 m) in order to assess the use of high-resolution images for HD activities.

Assessment

The assessment concerned the method, the use of remote sensing data of various resolutions and the validity of its interpretation, the completeness and the appropriateness of the table of needs, the tools provided in the PARADIS interface and the use of image processing tools. We will not speak about the latter as its interest is more for image interpreters than for deminers.

Method

In order to assess the method at the end of the project, we simulated a campaign in Laos, following the scheme of Figure 1. SGR-IM found SPOT and IKONOS images in the archives and purchased the SPOT data. Image Processing tools were applied to the images and sent back to the interpreters. SPOT and IKONOS images were interpreted according to the legends defined by the team. The time schedule was satisfied, and the products (space maps, overlays, documentation) were up to the end-user expectation. The interface was fed with information from Level One and Level Two Surveys for which IMSMA forms were used.

Use of Remote Sensing Data

For the first mission in Mozambique, the visual interpretation performed by our scientist was useful for non-experts; however, some errors occurred, so we recommend a check on the field and feedback to the interpreters.

For the mission in Laos, the image interpretation of the IKONOS panchromatic image was good for punctual and linear elements such as houses, trees, roads, rivers, etc. The land cover interpretation seemed more difficult to use due to the complexity of the land use in that region (e.g., the mixture of coffee plants and bushes). In fact, the land cover interpretation seemed useless, since the local population—both deminers and villagers—could read and work with the raw image. Indeed, when asked to delineate an area selected on the image on the field (and conversely, to draw on the image a "cleared area" on the field) deminers had no hesitation. Local people also preferred the raw image because the interpreted layers hid the reality of the image.

Thus, with a limited budget, panchromatic images (resolution 1 m) should be preferred to multi-spectral data (resolution 4 m) because field details are probably more useful than the spectral information (i.e., the "color").

The survey and the roving teams might also use the IKONOS panchromatic images, for example, in order to locate the UXO on the image instead of drawing schematic maps or leading the team to the right place.

The assessment is different for the SPOT image. Due to its lower resolution and maybe to the chosen color composition, the raw image is much more difficult to read. Thus, the visual interpretation was very helpful for the deminers. They could use it as a map, associating each color or symbol with an object or an affectation. A villager had almost no difficulties reading the interpreted image; he could guide us along paths while showing his position on the document. Similar observations were obtained from the last mission in Mozambique.

Both types of satellite images need to be properly geo-referenced if they are used as reference maps to locate mine fields or UXO. If topographic maps exist, the user has to identify points in the image and give their correspondent on the map. However, the map may not be precise enough to geometrically correct the satellite images. Therefore, a set of ground control points collected on the field with a GPS should be used for the geometric correction.

In conclusion, very high-resolution satellite images (resolution 1 m) are useful for the work in mine fields since they do not require an interpretation. On the other hand, high-resolution images (resolution of 10 m to 30 m) are useful as regional maps for planning the teams' work. However, they require an interpretation by an expert, and this interpretation could be sufficient for deminers.

PARADIS Interface

The PARADIS interface was not finished in time, so only part of it could be tested. However, its philosophy has been explained to other end-users, and much appreciated. The presentations made to various people have sparked great interest and encouragement. Deminers showed their willingness to use it later, because (among other things) it simplifies the representation of the clearance areas, and it optimizes—both in easiness and speed—the encoding of data in IMSMA.

Furthermore, we noted that specific tools (such as clearing the grid, automatically integrating GPS measurements and shifting the scanned maps) might improve the deminers' work both for the everyday job and for the planning process at the office.

Conclusions and Further Work

As a general conclusion, we may say that PARADIS was a successful project, thanks to a motivated multi-disciplinary team and the motivated and cooperative end-users.

The following is a list of conclusions from this project:

• The project has demonstrated the benefits of using remote sensing data in HD. The study of image sequence in high-resolution images provides relevant information and can be used as a substitute for topographic maps. High-resolution images require interpretation by an expert, and this interpretation seems sufficient for deminers. Very high-resolution images are useful for the fieldwork and do not require any interpretation.

• The team has set up an operational method involving two main actors: a demining team and an image interpretation team. The method has been elaborated and evaluated thanks to field missions in Mozambique and Laos.

• An interface answering the user needs has been produced.

• Various Image Processing methods have been designed and tested. Their use as tools for image interpreters has been evaluated.

These conclusions should be validated by other field missions. Moreover, the table of spatial data needs could be enhanced by defining the precision of the location (implicit in the scale) and the relevant attributes (e.g., for a road, its width) as well as their translation in terms of graphical differences (i.e., defining a symbology dedicated to demining activities) for each object. Last but not least, the interface should be finalized and distributed as a complementary tool to the existing ones. ■

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