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Toward a multifaceted platform for Humanitarian Demining

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1 ABSTRACT

The D-BOX project aims to increase deminers' confidence in technology developing a web-enabled platform which allows them to better utilize existing technologies and foster the development of the use of new ones. The idea behind D-BOX is to create an Information Management System which incorporates the process of Land Release, whereby the use of technologies is part of the process. The system will be flexible to adapt to local needs but at the same time it will be compliant with the IMAS.

In a complex domain like demining, single technologies are rarely effective. The new platform will foster functional tool chains to realize complex tasks, information merging and synergies amongst heterogeneous tools to increase the effectiveness of the tool combinations. In the paper we establish the requirements for the new platform and give examples of Functional Tool Chain(s) and of Synergies among tools being developed by D-BOX partners.

Key-Words: Humanitarian Demining, Mobile Robotic Systems, Modular Tool-Kit Solutions, Sensor for Detection, Information Fusion, Networked Information Management, Cultural Guidelines.

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2 INTRODUCTION

Humanitarian Demining is a safety critical domain. Like in other safety critical domains (aeronautics, air traffic management etc.), the end users only make use of tools which are fully reliable and fully safe.

Information Management is also problematic because the information is shared among different stakeholders, remotely located, that in most of the cases are not willing to share information due to confidential, strategic, commercial or simply cultural reasons.

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Despite these difficulties, Demining Stakeholders should remain open to innovation as new opportunities come from new sensing technologies, from Spatial, Aerial and Terrestrial assets, and new information technologies (Content Management, Mobile and Web). Most of these technologies promise to increase effectiveness of demining operations without impacting human safety.

The project D-BOX, co-financed by the European Commission in the Call Security 2011 (Grant Agreement 284996), has developed a functional prototype and an innovative concept for Information Management which links together, information, procedures and tools.

This paper is structured as follow: Section 3 has a double role to discuss the needs of the demining stakeholders for a new platform for information management and to introduce the D-BOX solution; Section 4, introduces the concept of functional tool chains by using examples from D-BOX; Section 5 introduces the concept of sensor data fusion; Section 6 draws the conclusions.

3 D-BOX Framework

End User learning time should be dedicated to information management issues and not on learning technicalities of an information management system.

When the User learns how to use D-BOX, he learns how to manage the land release process. The Information Management tool suggests which information is required for each step of the process and which tool can be used to gather the information. Then intuitive GIS features enable the user to overlay geographical, historical and new detection provided by the tools and to define the boundaries of the hazardous. At each step, it is possible to record the baseline of hazardous areas for reporting, lessons learned and training purposes (Figure 1).

Most of the data will be provided by tools that cover large areas and that provide information on indicators of the presence of hazards without entering physically on the area, as it is discussed in Section 4.

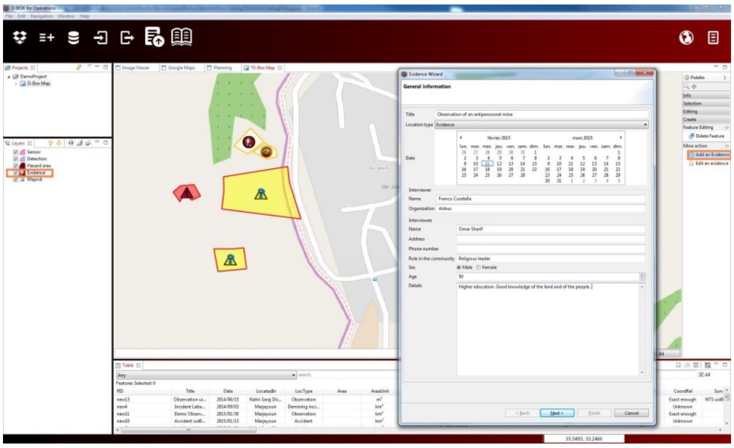


Figure 1 - Define the boundaries of a Hazardous Area with D-BOX for Operations. Baselines of Hazard Areas can be stored for reporting, lessons learned and staff training.

The places of demining span from international organizations, national offices, villages and remote regions in the countries affected by mine and ERW contamination.

Information Management has to manage the quality of the data and share the data between the correct actors.

The D-BOX architecture is composed of three main components; the first, D-BOX for Operations (Figure 1), is deployed on the user PC, provides GIS features and it is used to gather data from the source (humans or detection tool) no matter where the source is located; the second, D-BOX for Planning is a real knowledge management system and planning tool that enables collaborative decision making between stakeholders in the same organization (Figure 2); the third is the information sharing infrastructure that allows the different components to share information in a secure way. Information Sharing enables instances of D-BOX for Planning hosted by different organizations to exchange data.

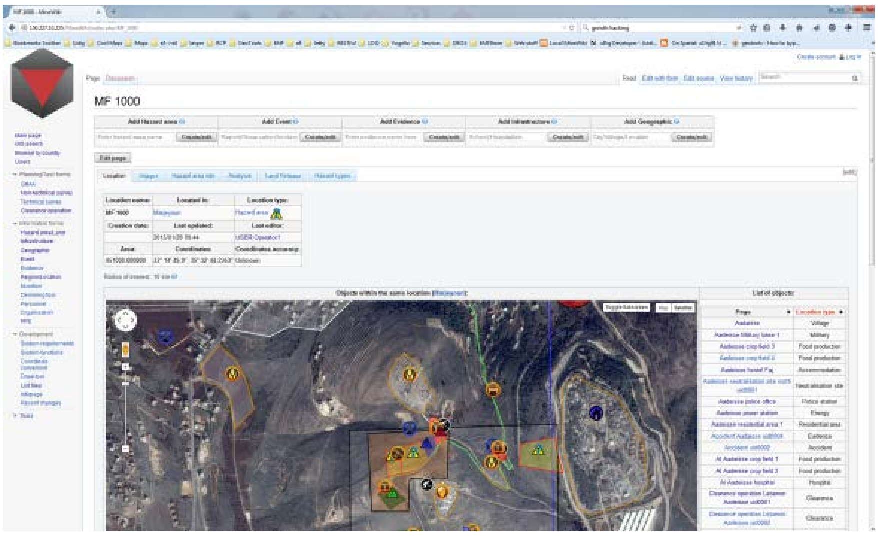


Figure 2 - D-BOX Planning Tool (knowledge management, collaborative decision making).

The objective of D-BOX is to create a value chain that includes all the stakeholders of Mine Actions irrespective of where they are located and the organization they belong to.

Data is collected from the operation field, elaborated, labelled with quality information and provided to the Mine Action Centre (MAC).

The Mine Action Centre verifies and confirms the information, defines the hazardous area and plans for the next step.

If required a report is sent to the international actors. The MAC can also share best practices and feedbacks with the GICHD. The mechanism is described in Figure 3.

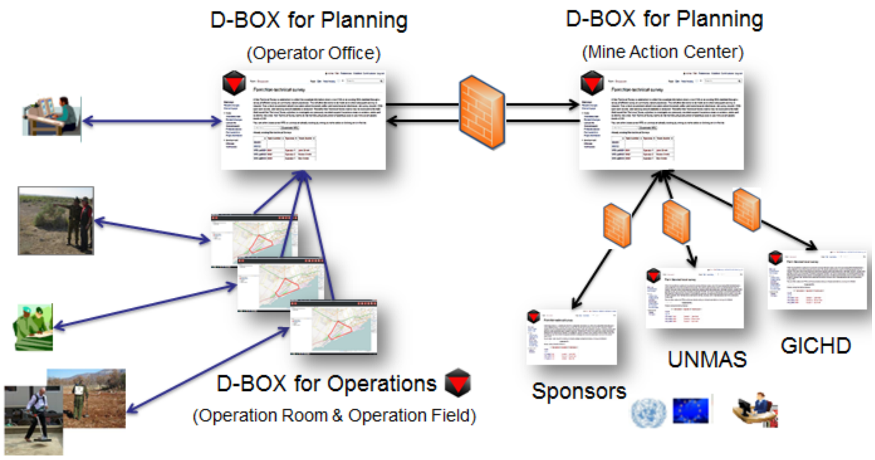


Figure 3 – A typical use case for D-BOX.

Several attempts have been made to create a global information management system for mine action. The SERWIS project, for instance, encountered the resistance of several Mine Action Programs concerned by the security of the data; they could not accept unrestrained public access to their full data base (c.f. [1]**).**

The D-BOX approach is different. D-BOX proposes the creation of a network of stakeholders that are willing to share data. Each stakeholder will select the actor(s) he wants to communicate with and the information he wants to share. The information is then exchanged in a secure way. Coordination is required on a bilateral base only.

4 D-BOX Tools

The approach proposed and adopted by D-BOX with respect to the detection tools is to arrange a functional chain of tools in a top-down fashion, where each tool supports a specific phase of the demining process (see fig. 4), starting from Long Range by satellites to close-in sub surface investigations. In particular, the following stages compose the tool of chain:

- **Long Range by satellite** aims at supporting the reduction of the scope of the investigation by exploiting Earth Observation techniques to exclude cleared area and focus on suspected area.

- **On Field Long Range** aims at acquiring detailed complementary information about the suspected area which cannot be retrieved by satellite imagery and/or which may be available by direct inspection of the investigation area (e.g.. shadowed by obstacles), by exploiting airborne platforms. In addition, airborne platform may become in the next future a sensor carrier for surface laid cluster munitions
- **Close-In Stand-Off** focuses on the suspected area(s), which has been confirmed by previous long range phases and aims essentially at close-in investigation by standoff methods, hence, without physically entering the minefield, in order to detect mines laid on the surface and swallowed or partially buried on the suspected areas, such as for instance cluster munitions. Essential tools at this stage are stand-off sensors such as thermal cameras, Man Made object detectors based on visible cameras. A detailed environmental mapping of the suspected area can be accomplished by means of unmanned ground vehicles (UGV) exploration tour equipped with high resolution terrestrial 3D mapping can be used for ground truth.
- **Close in Sub-Surface investigation** is the last stage of the tool of chain and focuses on the detection of the buried mines, by exploiting conventional commercial sensors such as Ground Penetrating Radar (GPR) and Metal Detector (MD). Indeed, one of the key points of the D-BOX approach is the compliance and the interfaceablity with respect to available technologies and currently used sensors. In addition, DBOX proposes enhancement of current technologies and novel sensing approaches which are beyond the state of the art. In particular, in DBOX the development of a prototype of an innovative autonomous multisensory system, based on the combination of a swarm of UGVs (provided with autonomous navigation capabilities) and sensor (MD, GPR, etc.) payload integration has been carried on.

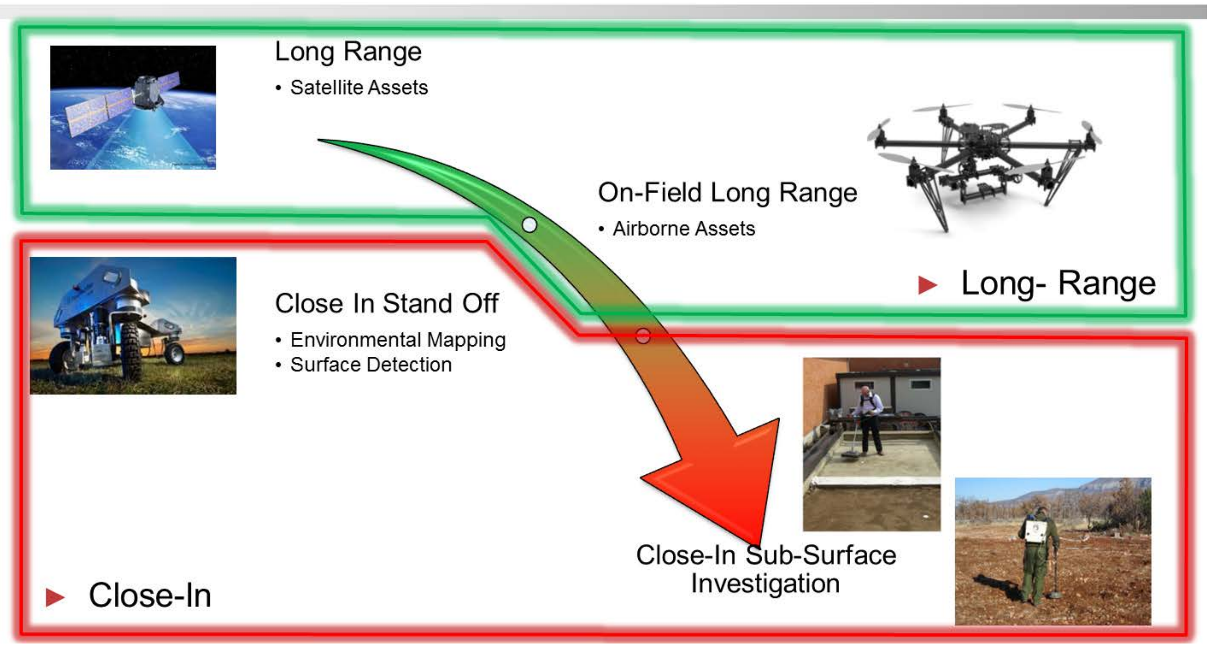


Figure 4 – Chain of Detection Tools

Information from different tools can be merged to improve the reliability of the detection (i.e. reduce the false alarm rate and improve the probability of detection), and in some specific cases sensor data can be applied. To use the above mentioned novel tools, the End User requires specific guidelines and procedures. D-BOX has also addressed these soft tools and, in particular, Error Correction Methodologies, Cultural Guidelines, Ethical Assessment.

4.1 Long Range Detection Tool

The Long Range Detection Tool aims at providing remote sensing mapping products, addressing the needs of the Mine Action (MA) community to optimize planning and preparation phases and to reduce the impact of demining activities, through long range detection techniques.

The use of Earth Observation (EO) is a promising technology, not yet fully exploited, in the framework of demining activities. In the last five years, the availability of radar images provided by the second generation of high resolution satellites such as COSMO-SkyMed (CSK) and TerraSAR-X, significantly increase the potential of EO based services.

Information obtained through space remote sensing, properly combined with ancillary information, can contribute meaningfully to several aspects of mine action planning, aimed to the reduction of land area for close-in analysis, through the detection of indirect indicators of mine presence.

With this respect, the tool developed within the D-BOX Project uses a methodology based on the combined use of different products obtained by the processing of COSMO-SkyMed data, such as a single image backscattering map or a Multi-Temporal with Interferometric Coherence image (MTC). MTC allows the generation of thematic maps and mine indicator layers supporting demining operations in their different operational phases (Planning, NTS, TS).

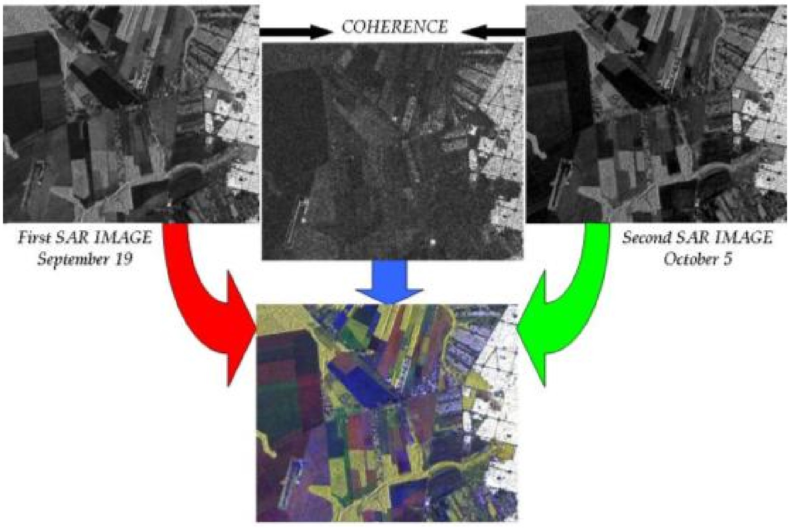


Figure 5 - Multi-Temporal with Coherence color composite methodology.

Starting from a single or multi-temporal series of COSMO-SkyMed SAR images and the aforementioned derived data as MTC, the following products are provided:

- Land Use Map
- Land Use Change Map

The scope of these maps is to provide and update the Earth observation-based layer, describing land cover and land use of areas of interest. In addition monitoring of territory evolutions and human activity through both amplitude and coherence change detection analysis.

Remote sensing and the derived products (Land Use and Land Use Change Maps) offer an economic advantage with respect to the "local" collection of information on large areas, supporting MA community during different hierarchical decision-making processes, starting from the definition of a Suspected Hazard Area, through prioritization of the intervention, to the post Land Release assessment.

Figure 6 - Example of land use map.

4.2 On-Field Long Range

On Field Long Range aims at acquiring detailed complementary information about the suspected which cannot be retrieved by satellite imagery and/or which may be available by direct inspection of the investigation area (e.g. not in line of sight or shadowed by obstacles) by exploiting airborne platforms.

An Unmanned Aerial Vehicle (UAV) adds the possibility of enhancing situation awareness within D-BOX by up-to-date high-resolution image data for environmental mapping. Unmanned Aerial Vehicles (UAV) are able to explore the hazardous area without safety risks. Another advantage is the ease of deployment when using small UAVs. Usually a single compact camera is mounted due to weight restrictions.

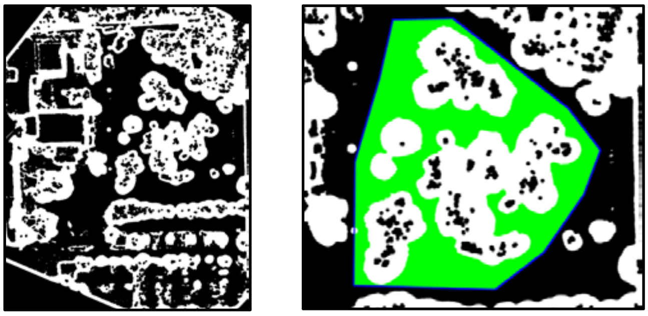
In order to cover a larger area, an UAV has and gather multiple images. These images can be merged into a combined representation by means of image processing methods, which are explained in the following. These representations allow further processing in order to assess relevant properties of the area.

Image mosaicking, where the images are stitched into a single high-resolution image is widely used. The resulting mosaic possesses a very high resolution of a few centimeters per pixel and provides a detailed view of the explored area (Figure 7) [2].

Figure 7: Image mosaic.

A geometric representation (3D point cloud and Digital Surface Map, DSM) can be acquired by photogrammetric methods like structure from motion and bundle adjustment.

Via discontinuity extraction from the DSM, the presence of buildings, obstacles, and bushes/trees can be displayed (Figure 8a). Possibly obstructive objects are shown in white while flat terrain is shown in black. Figure 8b shows a zoomed in view and an example of a referenced suspected hazard area from long range detection tools (blue line). Within this area an estimation of accessible areas (green) has been performed in order to give the operator a better insight to the area for planning and access.



(a) (b)

Figure 8: Extracted discontinuities and accessibility estimation.

The stitched image has a very high resolution but is not necessarily geometrically correct (it would be if the ground was totally flat). The orhtomosaic or 3D point cloud from the photogrammetric processing on the other hand is a geometrically correct representation, but does not have such a high resolution. So these two representations have opposite strengths/weaknesses and are both useful. The first for interpretation by a human, the second is more suited for algorithmic interpretation.

4.3 Close In Stand-Off

4.3.1 Platforms

An unmanned ground vehicle (UGV) equipped with sensors can be used for ground-based environmental mapping, detection of the minefield boundaries, and even for mapping of detected mines, if an appropriate sensor is attached.

As all sensor measurements are influenced by noise, no single sensor is sufficient for reliable and precise localization in all situations. Thus, the UGV used in D-BOX incorporates multiple sensors for simultaneous localization and mapping (SLAM) which are combined by means of multi-sensor fusion for better robustness and higher precision. The methods and algorithms are explained in more detail in [3].

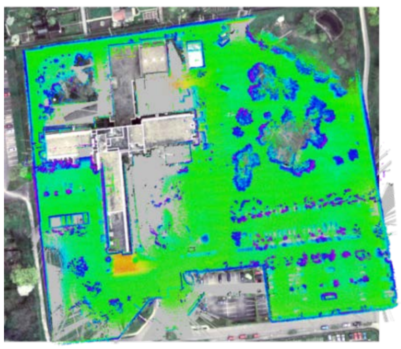


Figure 9: 3D map over satellite image.

3D Light Detection and Ranging (LiDAR) is the main sensor used for 3D mapping. Since a GPS is incorporated in the fusion process, implicitly geo-referenced maps are generated (Figure 9). The figure shows the 3D map over a satellite image of the area. The elevation of the 3D map is color coded from red (deep) to purple (high).

4.3.2 Sensors

LiDAR – A LIDAR is an active sensor that measures distance to hard surfaces. There are several technologies available, one of which uses a narrow beam pulsed laser to measure the range by measuring the time of flight for the laser pulse from the laser to the target and back. By scanning the laser beam in a pattern a 3-dimensional point cloud (x, y, and z coordinates) of objects and surroundings is produced. With each point the reflected intensity is recorded. The range can be up to 300 m with 5 mm accuracy in all three dimensions. By collecting data sets from different views, and merging the point clouds, shadowing effects and drop-outs can be avoided.

The 3-D point cloud can be rotated and viewed from different aspect angels, hence revealing useful 3-D features to the deminer. Various algorithms can also be applied to detect objects behind vegetation and camouflage if multiple echo extraction is used. In a forested area, the trees can be "removed" to reveal the topography of the ground, i.e. to detect craters or trenches.

3-D LIDAR can be used to generate a 3-D map of the hazardous area, and to serve as an aid in documentation of the demining efforts.

Thermal Camera – With a passive optical camera in the long-wave infra-red (LWIR) spectral region (8-12 µm) the emitted and reflected infrared radiation in a scene can be measured. This means that objects lying on the ground can be detected as anomalies in the image. Buried objects can cause an anomaly on the ground surface, depending on differences in the thermal inertia between the object and the ground. Here, the contrast can vary with the time of day. Recording during a diurnal cycle may improve detection; in addition, differences in soil structure and vegetation above buried mines can be detected.

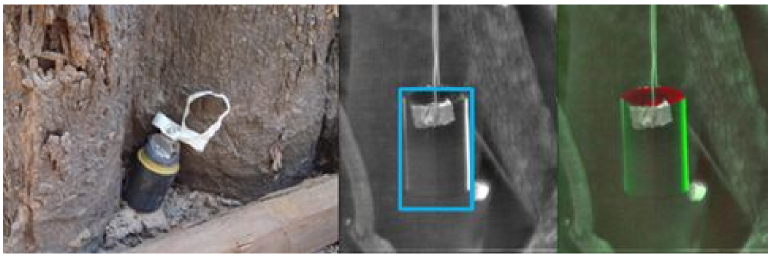


Figure 10 - Photograph of cluster munition bomblet scenario, ManMade Object detection camera automatic detection in reproduced scene, Image improved for visual confirmation of ManMade object.

ManMade Object Detector – The ManMade Object detector (Figure 10) is a novel camera design using different channels in visual light. The camera image provides the operator high contrast between man-made objects, e.g. plastic, rubber, casings and the natural vegetation in the background. Detection software is under development for automatic detection of cluster munition containers and bomblets.

Multi-camera user interface A user interface is designed for a ruggedized tablet PC that presents the images from multiple camera's (e.g. LWIR and ManMade Object detector), and allows an operator in the field to do a visual confirmation of automatic detections.

4.4 Close In Sub-Surface

4.4.1 Conventional Commercial Sensors

As mentioned above, the D-BOX is open to interface commercial off-the-shelf detection tools, which are typically used in demining activities, such as hand-held MD. Indeed, by means of a proper portable interface the data coming from the hand-held sensor can be automatically recorded and geo-referenced, in order to be easily integrated into D-BOX and merged with data provided by the other tools.

4.4.1 Beyond the State of the Art Sensors

Different novel sensor concepts and technologies have been proposed with the D-BOX.

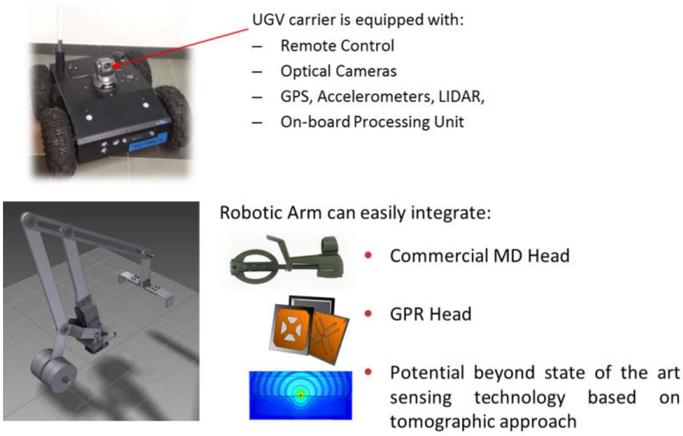


Figure 11: Distributed Sensor Network carrier.

Among them it is a multi-sensorial autonomous system, called the Distributed Sensor Network (DSN), which is based on a swarm of UGVs, provided with autonomous navigation capabilities, communication systems, and able to integrate on board heterogeneous detection sensors, such as a MD or a GPR or other possible, conventional and beyond the state of the art, detection system, by means of a proper electro-mechanical, moving, robotic arm (Figure 11). This prototype is able to autonomously explore the suspected area, without risks for the operator and leveraging on the multi-sensor payload. Different mission logics can be implemented by the swarm, according to the specific demining scenario at hand. The architecture of the system is flexible and customizable on the basis of the specific requirements of the mission.

4.5 Procedural (Soft) Tools

D-BOX contains several tools that are procedures, protocols and guides of various types. Two examples are described below.

4.5.1 Cultural Guidelines

Demining takes place in countries where there has been armed conflict or terrorist action. The contractors and NGOs employed to do it are usually from other countries with different cultures. The Cultural Guidelines provide a Tool to help demining managers assess and accommodate the cultural sensitivities of the people living in the affected area, thereby promoting the goodwill between the local community and the contractor that is vital for successful and efficient demining.

It is not feasible to embrace in a single set of Guidelines the religious and cultural requirements of all communities of the world. Instead, the Guidelines are intended to promote an awareness of cultural issues among demining contractors and to incorporate human development goals. The Guidelines are intended for use whatever the extent and effectiveness of national governance.

The following cultural topics are considered in the guidelines: Religion, Gender, Corruption, and Access to Land, Recreation and Social Life, Environment, detection technologies, Land Handover, Dress Code, employment and restoration.

Fifty-five guidelines emerged from the development process.

4.5.2 Aide Memoire

The function of an Aide Mémoire is to remind people to do things they know they must do, and know how to do, but (because they are human) they might forget to do. In the context of D-BOX, the purpose is to help demining employees to remember important points during a demining project. It should also limit any possible negative perceptions of the project or of the deminers within the local community and beyond. The Aide Mémoire Tool includes information from the Cultural Guidelines, the ethics assessment process and the human error reduction methodology

Each statement in the Aide Memoire:

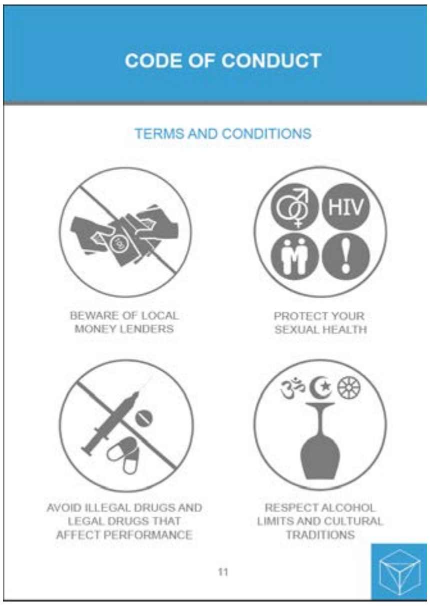


Figure 12: Example page from D-BOX Aide Mémoire

- Is simply expressed, to accommodate the users' varying levels of education and familiarity with English. This reinforces the need for clarity of icons and of language.
- Starts with a positive verb – e.g. "Photograph only with permission" rather than "Don't take photographs".
- Is expressed in the active voice – e.g. "Respect accommodation boundaries" rather than "Accommodation boundaries should be respected".

It was decided to create an icon for each statement in the Aide Mémoire, because:

- Complex ideas can be conveyed with a single image.
- Concepts presented simultaneously as pictures and texts are more easily recalled.
- Icons bridge the language gap.

Figure 10 shows an example of the finished artwork.

4.6 Quantitative mine risk assessment

The Quantitative Mine Risk Analysis (QMRA) software tool supports users in estimating and analyzing the effects of intentional and unintentional explosions in individual demining scenarios. The graphical user interface of the desktop application (see Figure 13 on the left) provides functionalities which allow users to model the demining scenario to be analyzed in a virtual 3D environment. Objects such as explosive hazard sources (i.e. landmines and sub munitions), buildings and protective measures can be easily placed inside the 3D environment by using 'drag-and-drop'. Based on the generated scenario model the QMRA tool performs an automated calculation of explosion effects following the step-by-step risk analysis approach illustrated in Figure 11 on the right. Calculation results of each analysis step are displayed in the 3D visualization. In the hazard analysis, the QMRA tool calculates direct explosion effects such as the blast overpressure as well as fragment trajectories and densities. Based on this, the tool determines in the damage analysis effects on buildings and people in the form of probabilities for different types and severities of damage. Individual and collective risks for people are calculated by multiplying the injury probability with the event frequency of a possible explosion and the fractional exposure of the people to the hazard sources. To support the user in assessing the resulting risk values the QMRA tool provides existing thresholds for tolerated and accepted risks.

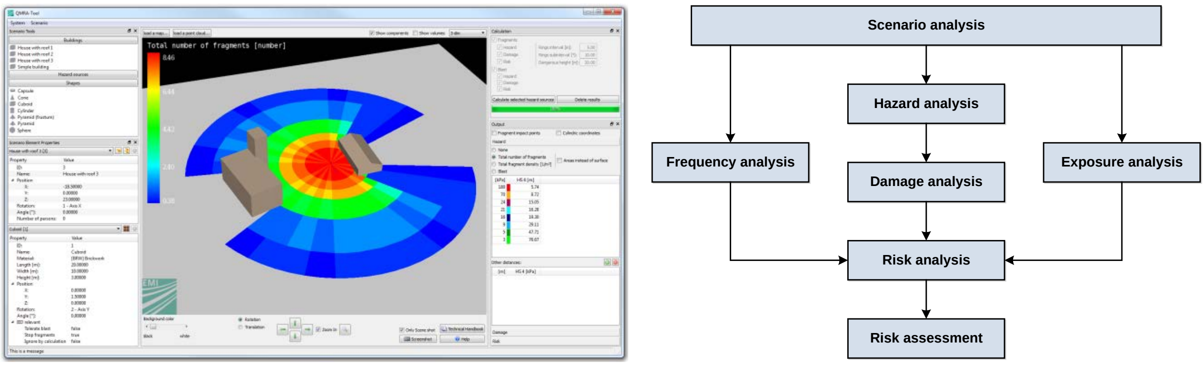


Figure 13: Graphical user interface with 3D visualization (left) and risk assessment procedure (right) of the Quantitative Mine Risk Analysis tool.

The output of other D-BOX tools can be used to facilitate the scenario modelling. On the one hand the QMRA tool provides an interface for the import of 2D pictures which show the top view of the demining scenario. Satellite images and maps, for instance, can support the exact positioning of objects, such as buildings, inside the virtual 3D environment (see Figure 14 on the left). Furthermore the QMRA tool allows the import of 3D point clouds which are generated by sensors like 3D LiDAR (see Figure 14 on the right). Beside the exact location of objects point clouds provide additional valuable information such as the height of objects.

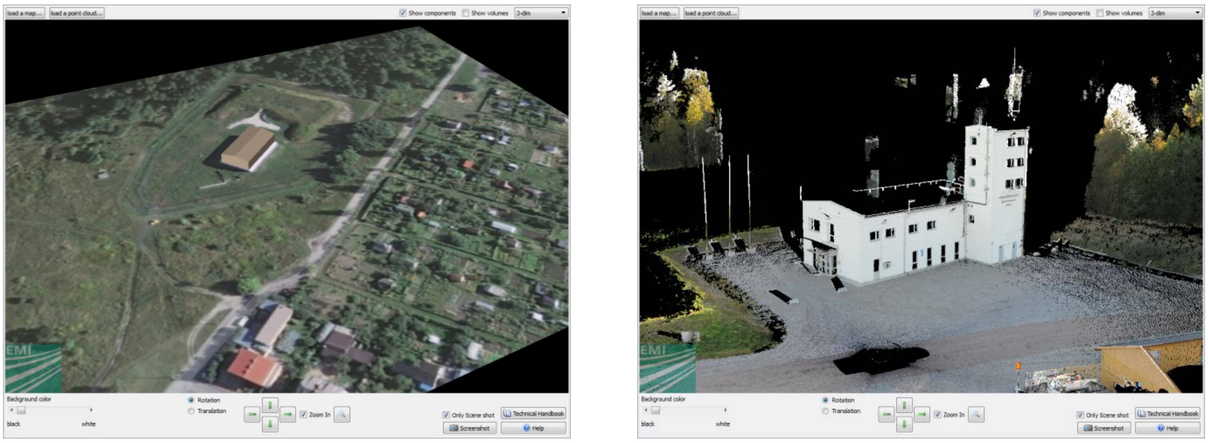


Figure 14: Import of satellite images (left) and 3D point clouds (right) into the Quantitative Mine Risk Analysis tool to facilitate the scenario modelling process.

The QMRA tool can be used for different purposes and in different demining phases. Basically it is an easy to use software tool to determine and visually display danger areas of possible explosions in individual demining scenarios. For instance, it can be applied during the process of clearance to check whether a building might be damaged by an explosion (see Figure 15) and whether additional protective measures have to be applied to reduce the possible damage. Furthermore, the tool can be used for educational purposes.

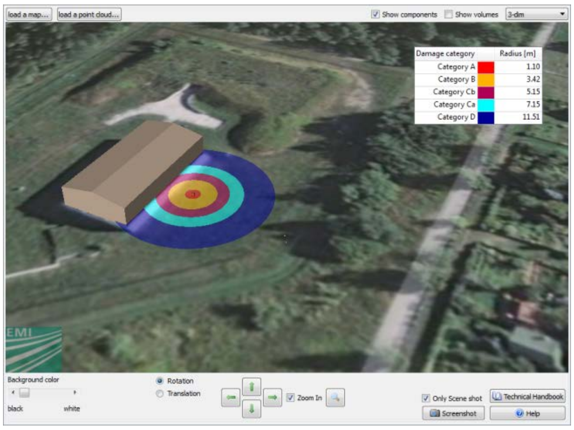


Figure 15: Expected building damage displayed in the 3D visualization of the Quantitative Mine Risk Analysis tool.

4.7 Ethical Review of D-BOX Tools

This is part of the D-BOX soft tools. D-BOX tool development process benefits by a thoroughly ethical advice and evaluation. As part of this process, *D-BOX Ethics Impact Evaluation of Tools Template* aims to inform and advice the tool developers of ethical issues relating to the design of the tools for future use in the field of operation. The methodological approach understands 'ethics' in a broader sense, as referring to *making decisions responsibly* based on *value sensitive design*. *Value sensitive design* evaluates and informs the development of technologies or procedures by taking into account human values [4]. A *value sensitive design* analysis will take into account the *technological characteristics of the de-mining technologies* and the impact on the core set of values proposed by the ECHR. In the context of de-mining technologies, the most important human rights that have to be considered are respect for private life and data protection (under the value of freedom), environmental protection (under the value of solidarity), and respect of health and safety. In terms of privacy, the robotic technologies used for environmental surveillance (UAVs, UGVs and sensor platforms) face issue strictly related to the large amount of the data collected, where also recognizable people are involved.

The Template is supplemented by the *D-BOX Ethical Impact Risk Assessment Form*, a practical tool that summarizes the ethics evaluation effort.

5 Multi-Sensor Data Fusion

The whole landmine detection task is divided into two sub-tasks - long-range image fusion task and close-range landmine detection task as shown in Figure 16. Sensors, such as satellite Synthetic Aperture Radar (SAR) imagers, will be used for mined area reduction. Data from close range sub-surface sensors, such as Ground Penetrating Radar (GPR), metal detectors and infra-red (IR) cameras will then be fused to identify mines in the reduced mine-suspect area.

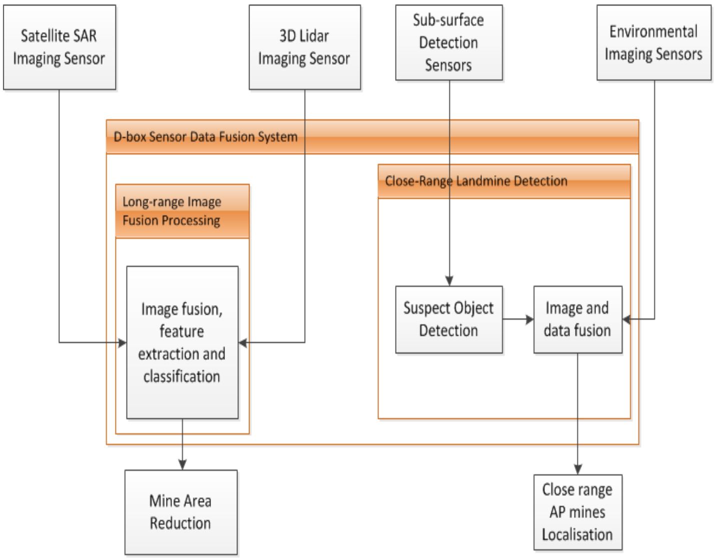


Figure 16 - Proposed D-BOX sensor data-fusion concept.

The long-range image fusion process reduces the mine suspect area through identification of key environmental indicators or geographical landmarks like rivers, roads, forests, landmine area marks, small towns, etc. Sensor data, such as satellite Synthetic Aperture Radar (SAR) and optical multispectral (MS) images as well as 3-D images e.g. 3-D Lidar, could be used as the input for that task.

First indicators of landmines could be recognized in 3-D images through feature extraction and classification algorithms.

Then 3-D images could be fused with satellite SAR and MS images to achieve reduction of the landmine area.

For the close–range landmine detection work sub-surface detection sensors could be used, such as Ground Penetrating Radar, Metal Detector and Thermal Infrared Camera as well as surface imaging sensors, providing information about the environment, e.g. man-made object detection camera, UAV mounted camera, etc.

Suspect object target recognition will be achieved by fusing the sub-surface detection sensors input at a feature level. Metal detectors are based on Electromagnetic induction (EMI) technology and are the dominant sensors in the nowadays demining practice. An induced magnetic field is measured over a target by using a time-varying magnetic field over the respective target. This technology is good for detecting buried mines in non-metallic soils, but it generates a very high rate of false alarms. Data fusion with other sensors, e.g. GPR and IR cameras, will help to discriminate between mines and other objects in order to reduce the false alarm rate of EMI sensors. GPR detects discontinuities in the ground including landmines with little or no metal content (high detection rates) but there could be also a high rate of false detections due to being quite sensitive to the type of soil and its condition, surface cover and terrain [7].

The suspect target recognition output could be fused with environmental data at a decision level to reach a final decision on the location of the landmine in the minefield. The fusion result will be superimposed on a GIS MAP to be used by the deminers for mine clearance.

6 Conclusions

Detection tools will be incorporated into the D-BOX system providing the means to transform the raw data into useful information for the End User. D-BOX will initially integrate existing tools (such as Metal Detectors) and some new tools with demonstrated capability to improve the situational awareness of the user and reduce errors. As soon as new technologies become available they will be plugged into D-BOX too. The concept of Functional Tool Chains will be extended to support the implementation of a variety of essential capabilities for mine action. It must be noted that D-BOX is not just a piece of software, but a system that is orientated to the needs of the End User, wo that the information is delivered as requested, providing procedures and guidelines to interpret and use the data. In summary D-BOX will be a comprehensive multifaceted platform which will be instrumental in creating links between the different stakeholders of mine actions, including technology suppliers.

Our vision for the future is very simple: there are D-BOX Tools, there are TIRAMISU Tools, there are GICHD Tools and there are existing tools. Why not to converge them all towards a unique multifaceted platform for Mine Action?

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