Chapter 1

Research at RMA in the Evolving Context of Mine Action

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/66710

The White Rabbit put on his spectacles.

"Where shall I begin, please your Majesty?" he asked.

"Begin at the beginning", the King said, very gravely, "and go on till you come to the end: then stop".

– Alice's Adventures in Wonderland, Lewis Carroll

Abstract

The purpose of this chapter is to put the research of the Royal Military Academy (RMA) in mine action in a historical perspective by providing some background information. The vocabulary used in mine action and the landmine contamination problem are first presented. Formalisation of close-in detection and of area reduction is then proposed. An overview of the research projects, the involved partners and the objectives as well as the list of PhDs performed at RMA are then provided. The chapter ends with an overview of the book and their link with the cited projects.

Keywords: area reduction, close-in detection, landmine contamination, mine action, Royal Military Academy

1. Introduction

RMA has been involved in research for humanitarian demining since 1996. Since these early days, the field of mine action has evolved thanks to the interactions of the different organisations involved: international and national government agencies, Non-Governmental Organisations (NGO), commercial companies, universities and research centres, affected population and individuals involved in that cause. Scope, processes, standards and vocabulary, all defined by the United Nations in the International Mine Action Standards (IMAS) [1], changed along this 20-year period; they are continuously reviewed. This is why having in mind the time frame in which RMA research activities took place is important. In particular, the focus in the early years was put on anti-personnel mines; the problem of Explosive Remnants of War (ERW) was then recognised as an important issue too.

In fact, when drafting a national law to organise mine action, each state may customise the IMAS to fit its environment and context, adapt them to the local threat and produces National Mine Action Standards so that, in practice, the mine action vocabulary does vary not only in time but also in space!

Nevertheless, at the time of this writing in 2016, the mine action community usually agrees on a basic vocabulary; a selection of this vocabulary and the correspondence with the former terminology is provided in the next subsection.

2. Vocabulary in mine action

The terminology provided in this section is defined in Ref. [2]. Terms in italics are defined in the current section.

Table 1 will help the reader linking former and today's terminology.

Current terminology	IMAS	"Old" terminology
General Mine Action Assessment (GMAA)	IMAS 8.10	
Non-Technical Survey (NTS)	IMAS 8.21	Level 1 Survey
Technical Survey	IMAS 8.22	Level 2
Clearance	IMAS 9.10	Level 3

Table 1. Current and old terminology in mine action.

2.1. Mine action

"Activities which aim to reduce the social, economic and environment impact of mines and other *Explosive Remnants of War (ERW)* including cluster munitions". The activities are grouped in five "pillars":

1. Mine/*ERW* risk education.
2. Demining (*survey*, mapping, marking and *clearance*); note that demining is only a part of mine action.
3. Victim assistance.
4. Stockpile destruction.

5. Advocacy against the use of anti-personnel mines and cluster munitions. Note that US do not recognise this as a pillar, since they promote (at least until now) the use of non-persistent mines.

In order to support these five pillars, the United Nations recognises the following necessary activities:

1. Assessment and planning.
2. Mobilisation and prioritisation of resources.
3. Information management.
4. Human skills development and management training.
5. Quality management.
6. Application of effective, appropriate and safe equipment.

2.2. Land release

Land release describes the process of applying all reasonable efforts to identify, define and remove all presence and suspicion of mines/*ERW* through *non-technical survey (NTS)*, *technical survey* (*TS*) and/or *clearance*. The process is detailed in Section 2.11 and in **Figure 1**.

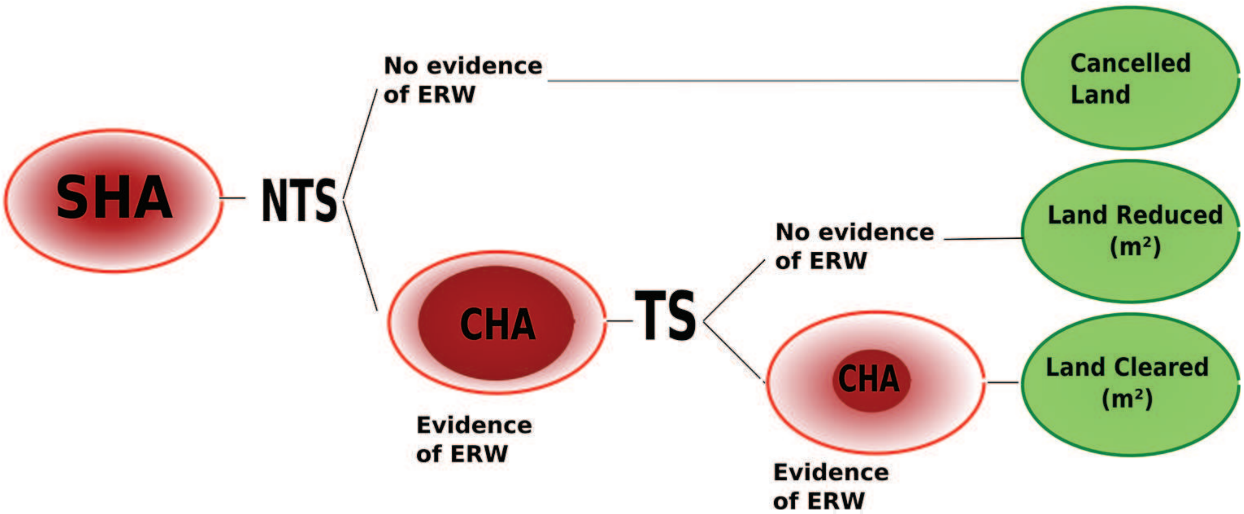

Figure 1. Land release process (adapted from Ref. [5]).

2.3. Non-technical survey (NTS)

Non-technical survey includes the collection and analysis of data, without the use of technical interventions, about the presence, type, distribution and surrounding environment of mine/*ERW* contamination, in order to define better where mine/ERW contamination is present, and where it is not, and to support land-release prioritisation and decision-making processes through the provision of evidence.

2.4. Technical survey (TS)

Technical survey includes the collection and analysis of data, using appropriate technical interventions, about the presence, type, distribution and surrounding environment of mine/*ERW* contamination, in order to define better where mine/*ERW* contamination is present and where it is not, and to support land-release prioritisation and decision-making processes through the provision of evidence.

2.5. Clearance

Clearance includes activity to insure the removal and/or the destruction of all mine and *ERW* hazards from a specified area to a specified depth.

2.6. Explosive remnants of war (ERW)

Explosive remnants of war refer to ordnance left behind after a conflict. They are made of unexploded ordnance (UXO) and abandoned ordnance (AXO).

2.7. Suspected hazardous area (SHA)

Suspected hazardous area (SHA) is an area where there is reasonable suspicion of mine/*ERW* contamination on the basis of indirect evidence of the presence of mines/*ERW.*

2.8. Confirmed hazardous Area (CHA)

Confirmed hazardous area (CHA) is an area where the presence of mine/*ERW* contamination has been confirmed on the basis of direct evidence of the presence of mines/*ERW.*

2.9. General mine action assessment (GMAA)

This is a continuous process, which aims

- to assess the scale and impact of the landmine problem on the country and individual communities;
- to investigate all reported and/or suspected areas of mine or UXO contamination, quantities and types of explosive hazards and
- to collect general information such as the security situation, terrain, soil characteristics, climate, routes, infrastructure and local support facilities, and to assist the planning of future mine action projects.

The information gathered during the general mine action assessment (GMAA) process should be sufficient to enable priorities to be established or updated and plans to be developed.

Impact survey, technical survey and post-clearance completion activities are still functional areas of the overall GMAA and new and existing programmes are still requested to make a GMAA if they follow IMAS.

2.10. What is a mine?

A mine is basically an explosive trap that is victim-activated. Its main danger comes from the fact that it might be activated by civilians many years, if not decades, after its main reasons to have been used in the first place have disappeared.

Mines have usually three main components: the explosive, the casing and the fuzing mechanism. Many sensors used to look for mines that actually detect the casing. Metal detectors detect the metallic parts of a mine that could be in the casing or in the fuzing mechanism. Dogs, on the other hand, detect the explosive.

Mines intended to target people are called anti-personnel mines and might include up to 250 g of explosive. Mines intended to destroy vehicles are called anti-tank or anti-vehicle mines and may include a much more important charge of explosive. Mines can also be designed to destroy ships. These are called sea-mines to distinguish them from the others, which are then called landmines.

Landmines are legally defined in two treaties. The Protocol II to the 1980 CCW Convention as amended on 3 May 1996 [3] defines a mine as "a munition placed under, on or near the ground or other surface area and designed to be exploded by the presence, proximity or contact of a person or vehicle".

The Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on their Destruction, 18 September 1997 [4], defines a mine in a very subtly different way: "a munition designed to be placed under, on or near the ground or other surface area and to be exploded by the presence, proximity or contact of a person or a vehicle". The International Mine Action Standards (IMAS) [1] use this definition.

More information on anti-personnel mines, fragmentation mines and blast mines is provided in Chapter 8.

2.11. Land-release process

The land-release process and the related vocabulary are defined in Section 2 and described in **Figure 1** (adapted from Ref. [5]). The process aims at bringing back to the population the land which should be if not "Mine-Free" as requested by the Treaty of Ottawa, at least "Mine-Safe" [6]. In this section, the specific terms are put in light by explaining the whole process.

The removal and destruction of landmines and ERW are relatively straightforward once the location has been clearly identified. The main problem is to precisely define this location. In a study on landmine impact survey, it has been shown that roughly half of the areas identified by the survey is not affected by mines [7], leading to a bad connotation to the term "Land Impact Survey", which has been abandoned since. Usually a mine action centre has only imprecise or incomplete information about these locations. This information may be derived from a database of accidents, or military records or is collected from surveys and discussions with the local population. This broad area with unclear boundaries is called "suspected hazardous area" (SHA). Clearing it would take much time, effort and resources. Indeed, clearing an area requires to prepare the land, that is, to cut the vegetation, divide the areas into smaller areas, use detection tools over each of them, excavate and dispose of suspected objects either on the site or in remote areas, which also means to transport them. If the area is not densely contaminated, the cost per square metre cleared can be huge and, paradoxically, the security of deminers less guaranteed: if they work for a long time in mine-free areas, they become less vigilant and accidents may be more frequent. Therefore, the whole SHA is usually not considered for clearance.

Non-technical survey (NTS) aims at providing a more precise border and prioritising the areas. During this process, where there is no evidence of ERW, parts of the SHA are excluded and labelled as "cancelled land". The areas that are still suspicious have more precise borders; they are called "confirmed hazardous areas" (CHA). These areas are then considered for technical survey (TS). The parts of CHA where there is no evidence of contamination are referred as "reduced land", while the remaining parts are cleared.

3. Mine contamination

3.1. Introduction

The magnitude of the mine problem is often expressed in terms of the number of mines that are still buried, the number of victims of mines, the area that is contaminated by mines and the area that is suspected to be contaminated by mines. Various estimates for these figures have been given throughout the years.

The early estimate of 110 million buried mines was shown to be wrong in 1998 [8] by its own authors. Moreover, the number of mines is no longer considered as a relevant indicator of the scope of the mine problem.

The estimate used in 1993–1997 was about 25,000 casualties every year.[1] The more recent estimate, from Landmine Monitor 2015 [9], is about 4000 every year, although this figure is expected to be underestimated. It includes casualties of mines, victim-activated-improvised explosive devices, cluster munition remnants and other explosive remnants of war.

To our knowledge, there is no global estimate currently available about the area suspected to be mined. Land Mine Monitor 2015 writes that it is not even possible to provide such an estimate. It lists nine countries and one other area where the mine contamination is expected to exceed 100 km^2: Afghanistan, Angola, Azerbaijan, Bosnia and Herzegovina, Cambodia, Chad, Croatia, Thailand, Turkey and Western Sahara.

We propose here a summary of the history of the estimation of the mine problem over the years. It shows the difficulty to estimate the scale of the problem and the evolution in both the estimation and the criteria to be estimated to describe the mine contamination.

[1]That is, more than 2000 every month, i.e., around one victim every 20 min.

3.2. Montreux symposium on anti-personnel mines, April 1993

The Montreux symposium on anti-personnel mines was organised by the International Committee of the Red Cross (ICRC) to collect information to coordinate action on mine action. In its report of the results of the symposium [10], ICRC estimated that 800 people worldwide die from mines each month. Moreover, it estimated that it would take 4300 years to clear Afghanistan of landmines.

Some people have reported that the Director of the United Nations Development programme stated at this symposium that the number of mines still in the ground was around 100,000 with another 100,000 mines in stockpiles.

3.3. US Department of state's first landmine report, September 1993

According to Hidden Killers 1994: The Global Landmine Crisis ([11] see below), “The Department of State's first landmine report, issued in September 1993, indicated that the total number of uncleared landmines in the world was between 65 and 110 million, scattered through 62 countries”.

3.4. Hidden Killers 1994: The Global Landmine Crisis

Hidden Killers 1994: The Global Landmine Crisis [11] is a report to the U.S. Congress on the problem with uncleared landmines and the United States strategy for demining and landmine control prepared by the Office of International Security and Peacekeeping Operations and released on 27 January 1995.

The report states that the global landmine problem cannot be quantified with precision. It nevertheless estimates that there were between 80 and 110 millions of landmines. The report concludes: “The U.S. Government considers the figures in this report to be rough estimates at best”.

As for the number of mine victims, the report states: “The three nations with the largest landmine problem are Afghanistan, Angola, and Cambodia. Collectively, they are besieged by an estimated 28 million mines and suffer 22,000 casualties every year (85 percent of the world's total)”. This leads to a world's total of some 26,000 casualties every year or 2200 every month. This figure includes deaths and injuries.

3.5. United Nations Mine Clearance and Policy Unit, Department of Humanitarian Affairs, September 1997

In September 1997, the UN Department of Humanitarian Affairs gave the estimation of 110 millions of mines and added that 2000 people were killed or maimed by mine explosions every month. They also added that it would take more than 1100 years to clear the entire world of mines [12].

This website cites the following source: United Nations Mine Clearance and Policy Unit, Department of Humanitarian Affairs, September 1997. It is not clear if the UN cited estimations from Hidden Killers 1994: The Global Landmine Crisis or if they reached their conclusions independently.

3.6. Hidden Killers 1998

Hidden Killers: The Global landmine Crisis 1998 [9] was released in September 1998 by the U. S. Department of State, Bureau of Political-Military Affairs, Office of Humanitarian Demining Programs, Washington, DC.

New estimates of the number of uncleared landmines are in the range of 60–70 million.

3.7. Landmine Monitor Report 1999

Landmine Monitor[2] is an "initiative by the International Campaign to Ban Landmines (ICBL) to monitor implementation of and compliance with the 1997 Mine Ban Treaty, and more generally to assess the efforts of the international community to resolve the landmines crisis".

Landmine Monitor released its first report in 1999 [13]. About the estimates from 1993 to 1997, the report warns that previous estimates were repeated and reprinted so many times that they became 'reality'.

The report states that for mine action the sizes of areas affected by mines are a better indicator of the problem than the number of mines in the ground. But they still reprinted the estimates from the U.S. State Department's 1998 report, Hidden Killers.

3.8. Landmine Monitor Report 2015

Landmine Monitor Report 2015 [9] is currently the latest release of the Landmine Monitor Report. It considers that early estimates were inaccurate due to a lack of data.

The report gives the following information about the mine contamination:

It gives a list by expected magnitude of contamination. Nine countries and one other area have a mine contamination expected to exceed 100 km^2: Afghanistan, Angola, Azerbaijan, Bosnia and Herzegovina, Cambodia, Chad, Croatia, Thailand, Turkey and Western Sahara.

In 2014, more than 3500 casualties were recorded. The incidence rate is 10 casualties per day for 2014.

The report, however, warns: "In many states and areas, numerous casualties go unrecorded, especially in conflict settings; therefore, the true casualty figure is anticipated to be much higher".

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[2]http://www.icbl.org/.

4. Formalising the problem

The next two subsections have been partly published in Refs. [14, 15] (©2007 EAGE Publications, The Netherlands); content from the latter is reproduced with kind permission from EAGE.

4.1. Formalising close-in detection

In the context of humanitarian demining, detection refers to the discovery of the presence of mines or unexploded remnants of war (ERW) [2]. Below, "close-in detection" refers to the discovery at short range of the presence of mines or unexploded ordnances. Typical examples of close-in detectors include manual prodders, metal detectors, ground-penetrating radars, and so on. Most of them emit an alarm close to a suspect object. In order to understand the incurred risks, let us consider the event A: "occurrence of an alarm" in a given position $x = (x,y)$. Clearly, this event depends on the detection system used and especially on the field reality. Further, let us define the following events M: "the presence of mines" and $\overline{M}$ "the absence of mine" which both are contradictory. Then, the alarm occurrence probability $p_A(x)$ in a location $x = (x,y)$ is given by

$$p_A(x) = p_M(x) \cdot p_{A/M}(x) + p_{\overline{M}}(x) \cdot p_{A/\overline{M}}(x) \quad (1)$$

which clearly explains the importance of the parameters describing the mine detection problem, that is, the detection probability and the false alarm probability:

- The *mine occurrence probability* in a given position x of a minefield, $p_M(x) = 1 - p_{\overline{M}}(x)$ expresses the local mine density of that minefield. It is impossible to control this parameter which depends on the field reality. Nevertheless, this parameter is very important for assessing the probability of an alarm in a given location x of the minefield.
- The *detection probability*, $p_{A/M}(x)$ is the probability of having an alarm in a given position x of a minefield for a given sensor system, if there is at least one mine in that position. This probability gives an indirect measure of the non-detection probability of that sensor system as well.
- The *probability of false alarm*, $p_{A/\overline{M}}(x)$ also called false alarm rate, is the probability of having an alarm, for a given sensor system, in a given location x if there is no mine in that location.

The two latter definitions are extremely important to understand the mine action problem and to design mine clearance systems. Note that a more precise expression for Eq. (1) should in particular take into account additional factors such as a sensor sensitivity area around the mine, but this is out of the scope of this summary.

The detection probability $p_{A/M}(x)$ should be as close as possible to one. Evaluating the detection probability also amounts to evaluating the risk $p_{\overline{A}/M}(x)$ of the occurrence of a mine that is not detected, since $p_{\overline{A}/M}(x) = 1 - p_{A/M}(x)$. This risk is linked to *human safety* and is therefore of the utmost importance. It is an absolute requirement that a mine clearance system should decrease the probability of such a risk to the lowest upper bound possible.

As a matter of fact, it is imperative to evaluate the detection probability when optimising the performances of a system. However, the detection probability $p_{A/M}(x)$, as defined above, assumes that a mine is present in the considered position x. During organised trials, the position of the mines is well known, so the condition of the presence of a mine in the given position x, where the performances of a system must be evaluated, is always fulfilled. This is of particular importance because it justifies the organisation of trials and the construction of models, to be validated by trials, in order to evaluate the detection probabilities. It also justified the implementation of test and evaluation organisations for mine action technologies such as the International Test & Evaluation Programme (ITEP).[3] A demining method, which minimises the false alarm rate $p_{A/\overline{M}}(x)$ leads to an acceleration of the demining operations. All other things being equal, a faster demining results indirectly in spending less money and reducing the risk that human being entered a mined area.

Therefore, any demining operation enhancement must result in the highest possible detection probability $p_{A/M}(x)$ (close to one) and in the smallest possible false alarm rate $p_{A/\overline{M}}(x)$, while keeping the price reasonably low. Unfortunately, increasing the detection probability generally results in increasing the false alarm rate. The most efficient way for increasing the detection probability while minimising the false alarm rate consists in using several complementary sensors in parallel and in fusing the information collected by these sensors.

Let us first consider the case of the detection probability. If the event $\overline{A}$: "absence of an alarm", means the event $\overline{A}_1\overline{A}_2\overline{A}_3\ldots\overline{A}_N$: *"absence of an alarm for all sensors and associated signal processing"*. Then, the overall detection probability is described by

$$p_{A/M}(x) = 1 - p_{\overline{A}/M}(x) = 1 - p_{\overline{A}_1/M}(x) \cdot p_{\overline{A}_2/M\overline{A}_1}(x) \cdot p_{\overline{A}_3/M\overline{A}_1\overline{A}_2}(x)\ldots. \tag{2}$$

The latter expression shows that the detection probability increases with the number of sensors. This justifies the use of several sensors to increase the detection probability. Moreover, if the events $A_1, A_2, \ldots, A_N$ are statistically independent,

$$p_{A/M}(x) = 1 - p_{\overline{A}/M}(x) = 1 - p_{\overline{A}_1/M}(x) \cdot p_{\overline{A}_2/M}(x) \cdot p_{\overline{A}_3/M}(x)\ldots. \tag{3}$$

In this case, maximising the overall detection probability $p_{A/M}(x)$ of a set of sensors, acting independently, clearly amounts to the same as maximising the detection capabilities of each sensor individually (e.g. $p_{A/M}(x) = 1 - p_{\overline{A}_k/M}(x)$ for the k^{th} sensor), by optimising separately the design of each sensor and its associated signal processing.

[3]ITEP's mission was to develop standards, coordinate and perform tests of materials and methods, and spread information about the results to all other interested parties.

http://dx.doi.org/10.5772/66710

Let us analyse the probability of false alarm in more detail. Current sensor systems (e.g. metal detectors) are affected by their high false alarm rate ($p_{A/\overline{M}}(x)$), that is, the probability of having an alarm if there is no mine (e.g. metallic garbage detected with a metal detector), making demining operations slow, tedious and demanding many resources. Unfortunately, the use of a set of different sensors without associated data fusion techniques will dramatically decrease efficiency. Indeed, the probability of false alarm can be expressed as

$$p_{A/\overline{M}}(x) = 1 - p_{\overline{A}/\overline{M}}(x) = 1 - p_{\overline{A}_1/\overline{M}}(x) \cdot p_{\overline{A}_2/\overline{M}\overline{A}_1}(x) \cdot p_{\overline{A}_3/\overline{M}\overline{A}_1\overline{A}_2}(x) \dots \tag{4}$$

The latter expression shows that the probability of false alarm increases if the number of sensors increases. Further, if the events $A_1, A_2, \dots, A_N$ are independent, we can write

$$p_{A/\overline{M}}(x) = 1 - p_{\overline{A}/\overline{M}}(x) = 1 - p_{\overline{A}_1/\overline{M}}(x) \cdot p_{\overline{A}_2/\overline{M}}(x) \cdot p_{\overline{A}_3/\overline{M}}(x) \dots \tag{5}$$

In this case, minimising the overall false alarm rate $p_{A/M}(x)$ of a set of sensors, acting independently, clearly amounts to the same as minimising the false alarm rate of each sensor individually (e.g. $p_{A_k/\overline{M}}(x) = 1 - p_{\overline{A}_k/\overline{M}}(x)$ for the k^{th} sensor), by optimising, separately, the design of each sensor and its associated signal processing.

Since most sensors used for mine detection are, actually, anomaly detectors (detector of metal, of the difference in dielectrical permittivity, etc.), it is very difficult to estimate the risk of false alarm as it is especially difficult to define, in a general way, what is not a mine. The problem of estimating the false alarm risk becomes even more complex when data coming from different sensors are fused, which favours the manual or automatic cancellation of false alarms. In this context, it should be particularly inappropriate that a demining system, whatever it may be, makes a decision instead of the final user whose own safety is involved. Therefore, a well-designed system should help the user in the decision-making, not by replacing him, but by implementing efficient data fusion methods. To make the process more feasible and accurate, methods, which are able to deal with uncertainty by making proposals including the doubt to the user, as a Dempster-Shafer framework does, prove to be promising (see Chapter 4).

4.2. Formalising area reduction

Area reduction is an important challenge consisting of finding where the mines are not. Mine-suspected area reduction, recognised by the mine action community as a mine action activity at least as crucial as close-in detection, enables to reduce mine clearance time and resources.

Mine-suspected area reduction means finding the set of positions x for which $p_M(x)$ equals zero. Under this condition, Eq. (1) yields

$$p_A(x) = p_{A/\overline{M}}(x) \tag{6}$$

and mine-suspected area reduction with classic tools (e.g. metal detectors) is affected by the high false alarm rate ($p_{A/\overline{M}}(x)$) of current sensors, making the corresponding operations slow, tedious and resource demanding. Further, long-term empirical data from the Croatian Mine

Action Centre (CROMAC) show that around 10–15% of the suspected area in Croatia is actually mined. The minefield records alone, beyond the fact that they are not always reliable and complete, do not contain enough information for the proper allocation of limited mine clearance resources to really mined areas. Decision-makers need additional information.

This means that a broader approach is needed, which has to include a priori knowledge. Indeed, if no a priori knowledge is available about context as conflict history, strategies and tactics of the parties, communication networks, terrain configuration, power lines, land use, and so on, the a priori probability of having a mine in a given location is distributed uniformly and the only method to clear mines is the classic close-in detection $p_M(x)$. If on the contrary a priori information is available on the distribution of $p_M(x)$, especially by deducing from the context where the mines are certainly not (e.g. agricultural fields in use) and where the mines are possibly present (e.g. along the confrontation lines, in the vicinity of trenches, on top of hills that are possible artillery positions, etc.), it makes sense to build a risk map ($p_{M/\text{context}}(x)$) of the affected areas. This assumes to define a list of indicators of mine presence ($p_{M/\text{context}}(x)$ is not negligible) and absence ($p_{M/\text{context}}(x)$ is close to zero) as well as a list of tools and methods to detect them. One of the most appropriate methods to build a risk map is associating airborne and satellite data, with context and ground truth data collected during field campaigns (see Chapters 5, 6 and 9). Analysing the collected data with modern remote-sensing tools, such as land use classification, anomaly detection and change detection, considered as experts, and fusing the "opinions" of those experts enable to produce the so-called risk or danger maps. The main advantage of airborne methods rests in the possibility to reduce areas located in regions that cannot be accessed without very costly safe lanes and full safety procedures that are mandatory when entering the minefields. Further, the assessment of areas for reduction and assessment of spatial danger distribution can be performed in short time over large areas.

In the context of mine action, a frequently asked question is the possibility of directly detecting mines using high-resolution airborne sensors. As part of their policy to assist developing countries, the European Commission (the former DG-VIII) and the participating member states have funded in 1997 a "Pilot project on airborne minefield detection in Mozambique" which has clearly shown that it is impossible to find reliably anti-personnel landmines even with a very high-resolution (order of magnitude of a few millimetres) airborne sensors neither using objective signal-processing tools nor using subjective photo-interpretation.

In summary, instead of addressing the mine detection it is suggested to address "Indicators of Mine Presence" and "Indicators of Mine Absence" (see Chapters 5 and 6).

4.3. Formalising current dual sensors

There are now several dual sensors combining metal detectors and ground-penetrating radars: AN/PSS-14 (formerly known as HSTAMIDS), VMR3 and VMR3G (MINEHOUD) and ALIS. Although these systems could theoretically be used to detect plastic mines, the ground-penetrating radar is usually used to confirm, or not, an alarm from the metal detector.

Let $\boldsymbol{p}_{\boldsymbol{A}^{\mathrm{MD}}/\overline{\boldsymbol{M}}}(\boldsymbol{x})$ be the probability that the metal detector gives an alarm at location x if there is no mine and $\boldsymbol{p}_{\boldsymbol{A}^{\mathrm{GPR}}/\overline{\boldsymbol{M}}}(\boldsymbol{x})$ the probability that the ground-penetrating radar gives an alarm at location x if there is no mine.

The probability that a dual sensor as those cited above gives a false alarm at location is therefore

$$p_{A/\overline{M}}(x) = p_{A^{\mathrm{MD}}/\overline{M}}(x) \cdot p_{A^{\mathrm{GPR}}/\overline{M}}(x) \tag{7}$$

We can see that if the probability of false alarm of the ground-penetrating radar $\boldsymbol{p}_{\boldsymbol{A}^{GPR}/\overline{\boldsymbol{M}}}(\boldsymbol{x})$ is low then the probability of false alarm of the dual sensor is reduced compared to the usually high probability of false alarm of a metal detector. This is the main advantage of these dual sensors.

This advantage, however, does not come without a drawback. The probability that the dual sensor gives an alarm at location $\boldsymbol{x}$ when there is a mine is

$$p_{A/M}(x) p_{A^{\mathrm{MD}}/M}(x) \cdot p_{A^{\mathrm{GPR}}/M}(x) \tag{8}$$

We can see that in this condition, the detection rate of the dual sensor cannot be higher that the detection of the metal detector alone. Therefore, the ground-penetrating radar used as a confirmation sensor can only reduce the probability of detection. It is therefore paramount that the radar does not miss any mine detected by the metal detector.

5. Overview of RMA research in mine action

RMA research in mine action has been mainly focused on the "Demining" pillar except for the TIRAMISU project (see www.fp7-tiramisu.eu/and Chapters 5, 6, 8 and 9) coordinated by RMA, where the aim was to develop tools for pillars 1, 2 and 4.

In the late 1990s, the Royal Military Academy coordinated a Belgian research programme, called HUDEM for Humanitarian Demining, where many Belgian universities worked together to improve the detection of landmines by developing many technologies. This led to a project called HOPE co-funded by the European Commission which developed a prototype for a multi-sensor handheld mine detector. The research on detection continued in the late 2000s with the Belgian programme BEMAT for Belgian Mine Action Technologies.

In parallel, work was done to help non-technical survey by using remote sensing. It stated in the late 1990s by a project co-funded by the European Commission to detect mines by airborne surveys. In the 2000s, the focus moved to detect indirect indicators of the presence or absence of mines by remote sensing, which was implemented in the SMART project co-funded by the European Commission.

The investigation of the use of information management system could be carried out with the programme PARADIS, which is described in more detail subsequently.

The Robotics Department of the Royal Military Academy also investigated the use of robots for demining in the CLAWAR and VIEWFINDER programmes, both co-funded by the European Commission.

The Royal Military Academy was also the representative of Belgium to the International *Test and Evaluation* Program for Humanitarian Demining (*ITEP*) during the 10 years of its duration, from 2000 to 2010.

All these research activities later gave birth to the TIRAMISU programme, co-funded by the European Commission, which, together with the SPRINT programme, deepened and extended the experience gather in the last 15 years or so.

During these years, 10 phD thesis have been produced by researchers working at the Royal Military Academy in partnership with European schools or universities, and in particular, the first thesis delivered by the Royal Military Academy in 2006.

Below, the research projects are listed; the funding source and the time frame are put in parenthesis; the other collaborating partners (if any), and the objectives of the research and the references to the chapters are also provided. The list of PhD thesis is also provided afterwards.

5.1. Research projects

Airborne minefield detecion: pilot project

(EC, Goverments of B, G, P, UK, and ITC: 1997–1999) see Chapter 5

Partners: ITC (N), CAE Aviation (L), EOS (UK), VUB(B), Eurosense (B), Geograf (P), SSC (S), ZEO (G), Aerodata (B), Aerosensing (G), IGI (G), Recon Optical (UK), CND (Moz), NPA (N).

Objective: Detecting minefield by airborne survey

BEMAT (MoD: 2006–2009) see Chapters 3 and 4

Belgian Mine Action Technology

Objective: Develop technology for mine action

CLAWAR (EC: 1998–2002, 2002–2005) see Chapter 9

Thematic network on Climbing and Walking Robots including the support technologies for mobile robotic machines

Partners: Consejo Superior de Investigaciones Científicas (ES), H Enwesa Operaciones SA—Madrid (ES), Forschungszentrum Informatik an der Universität Karlsruhe (DE), Robotsysteme Yberle GmbH. (DE), Universität Kaiserslautern (DE), Forward Industries LTD (GB), Gravatom Engineering Systems Ltd. (GB), Secretary of State for Defence—Ministry of Defence (GB), Portsmouth Technology Consultants Ltd. (GB), Transtech Parallel Systems Limited (GB), University of Salford (GB), Helsinki University of Technology (FI) Inox Pneumatic AS (DK), Instituto de Soldadura e Qualidade (PT) Instituto Nacional de Engenharia e Tecnologia Industrial (PT), Kentree Ltd.—Cork (IE) Risø National Laboratory (DK) SGS—Thomson Microelectronics s.r.l. (IT), Università degli Studi di Catania (IT).

Objective: Coordinate WG Robotics in Humanitarian Demining

ITEP (MoD: 2000–2010) see Chapter 1, Section 1.5, and Chapter 10

http://dx.doi.org/10.5772/66710

International Test and Evaluation Program for Humanitarian Demining

Partners: EU (JRC), MoD CAN (CCMAT), NLD (MoD), GER (MoD), SWE (SWEDEC), UK (QinetiQ), US (HDP)

Objective: Develop standards, coordinate and perform tests of materials and methods and disseminating results to interested parties.

HOPE (EU: 1999–2001) see Chapter 2

Handheld multi-sensor operational demining system

Partners: Vallon GmbH, BATS, EC DG-INFSO, ISL, MAG, NPA, ONERA CERT, POLIMI – DEI, RST AG.

Objective: Develop and build an efficient handheld demining tool.

HUDEM (MoD: 1996–2001) see Chapters 3, 4 and 9

Humanitarian Demining

Partners: Belgian Universities (KU Leuven in collaboration with Kings College London, UGent, UCL, ULB, and VUB) and APOPO.

Objective: study tools that could help landmine detection (sensors, robots, rats, etc.)

MRN Studies (MoD: 2005–2015) see Chapter 11

MRN06 (2005–2011), MRN13 (2011–2015) and EDA-DMD (2011–2014), research was conducted under two CMRE NATO-STO Joint Research Programs, MCM-D&C (Mine Countermeasures, Detection and Classification) and MIAMS (Machine Intelligence for Autonomous Mine Search).

Partners: Belgian Navy, EDA (EU), DGA (FR), Thales (FR), DCNS.

Objective: the automatic detection of small threats on the sea surface, such as drifting mines, swimmers, debris and small boats.

MRN10 (2010–2013) and MRN16 (2014–2017)

Under the UMS Project BURMIN

Partners: TNO (NL), CTM (PL), DGA/Technology Naval (FR), ECA (FR), Thales (FR), WTD-71 (GE), IPHT (GE), Atlas Elektronik (GE), as well as the Ministries of Defense of Belgium, France, Germany, Poland and The Netherlands.

Objectives: to eliminate technological gaps in the field of bottom/buried mine detection and neutralisation, and to establish common standards for the future European Unmanned Maritime Systems.

MRN09 (2008–2014) and MRN17 (2015–2018) are conducted under two CMRE NATO-STO Joint Research Programmes, MCM-D&C (Mine Countermeasures, Detection and Classification) and MIAMS (Machine Intelligence for Autonomous Mine Search).

Objective: to develop automatic target recognition algorithms and environmentally adaptive sensing for mine search.

MSMS (JRC: 1999–2003) see Chapters 2–5 and 10

Joint Multi-Sensor Mine Signature Measurement Campaign

Partners: EU/JRC, DLR, FGAN,Kayser-Threde GmbH

Objective: execute a campaign for collecting data of buried landmines with multiple sensors.

PARADIS (MoD and Belspo: 1999–2001; MoD: 2002–2006; APOPO: 2007) see Chapter 7.

A Prototype for Assisting Rational Activities in Humanitarian Demining using Images from Satelites.

Partners: SEDEE-DOVO, IGEAT (ULB)

Objective: Plan and report demining campaigns

SMART (EU: 2001–2004) see Chapter 5

Space and airborne Mine Area Reduction Tools

Partners: DLR, CROMAC, IGEAT (ULB), TRASYS, ENST, Zeppelin, RST, IXL.

Objective: finding parts of mine-suspected areas that are not mined

SPRINT (Belspo: 2013) see Chapter 6

Spaceborne Radar Interferometric Techniques for Humanitarian Demining Land Release

Partner: CROMAC

Objective: Differentiate human-induced effects from natural ones based on the analysis of time series SAR satellite data

TIRAMISU (EU fp7: 2011–2015) see Chapters 5, 8 and 9.

Toolbox Implementation for Removal of Anti-Personnel Mines, Submunitions and UXO

Partners: DLR, ISR, CSIC, Univ. of Catania, Univ. of Genova, PLUS, USTAN, ULB-IGEAT, FGUNIZ, IMM, CTRO, WITI, SPINATOR, PROTIME, SPACETEC, SatCen, DIALOGIS, Brimatec, Vallon, IDS, Cen, NOVELTIS, Pierre, Snail Aid, Tohoku University.

Objective: Build a toolbox for Mine Action

VIEW-FINDER (EU, 2006–2009) see Chapter 9

Partners: Sheffield Hallam University,Eidikos Logariasmos Erevnon Dimokriteiou Panepistimiou Thrakis, Galileo Avionica—S.P.A., Intelligence For Environment & Security Srl—Ies Solutions Srl, Przemyslowy Instytut Automatyki I Pomiarow, South Yorkshire Fire And Rescue Service, Space Applications Services, Universita Degli Studi Di Roma “La Sapienza”.

Objective: Robotics assistance for dangerous tasks

5.2. PhD thesis in mine action

Pascal Druyts: Analysis of Environmental Effects on Electromagnetic Induction Sensors, PhD dissertation, Université catholique de Louvain & Royal Military Academy, 2011.

Diederik Borghys: Interpretation and Registration of High-Resolution Polarimetric SAR Images, PhD Dissertation, Ecole Nationale Supérieure des Télécommunications, 2002

Damien Closson: Exploiting SAR coherence in time, PhD dissertation, Université de Liège, 2005.

Eric Colon: COROBA, an open framework for distributed robot control and sensor networks. PhD dissertation, Vrije Universiteit Brussel & Royal Military Academy, 2006.

Jean-Claude Habumuremyi: Adaptative neuro-fuzzy control for a walking robot with six pantograph-based legs, PhD dissertation, Free University of Brussels, 2004. C

Olga Lopera: Development of data fusion techniques to support multi-sensor landmine detection, PhD dissertation, Université catholique de Louvain & Royal Military Academy, 2008.

Nada Milisavljevic: Analysis and fusion using belief function theory of multisensor data for close-range humanitarian mine detection, PhD Dissertation, Ecole Nationale Supérieure des Télécommunications (Paris), 2001.

Bart Scheers: Ultra-Wideband Ground Penetrating Radar, with Application to the detection of Anti Personnel Landmines, PhD dissertation, Université Catholique de Louvain, 2001.

Catherine Steukers: Etude de la faisabilité de la neutralisation de mines antichar enterrées à l'aide de micro-ondes de forte puissance,Thèse de doctorat, Fondation Universitaire Notre Dame de la Paix, Namur, 1998.

Idesbald van Den Bosch: Modeling the ground penetration radar, PhD dissertation, Université catholique de Louvain & Ecole Royale Militaire, 2006.

6. Conclusions

During 20 years, since 1996, RMA has been involved in research for mine action, associating end users such as the SEDEE-DOVO (the Mine Clearance Service of the Belgium Defence also known as the "explosive ordnance disposal (EOD) Battalion") or the CROMAC (the Croatian Mine Action Centre) in order to better answer the mine action needs and to collaborate in the design of field tests and missions. In this sense, RMA answers a critic often addressed to the Mine Action Research Community that would "ignore field reality". Moreover, RMA research addressed several activities of mine action; they are presented in the various chapters of the current book [16]. **Close-In Detection** is addressed in Chapter "Positioning System for a Hand-Held Mine Detector", in Chapter "Ground-penetrating Radar for Close-in Mine Detection" and in Chapter "Data fusion for close-range detection". **Area Reduction** and **Land Release** are addressed in Chapter "Remote Sensing for Non-Technical Survey" and "InSAR Coherence and Intensity Changes Detection" where remote-sensing data and dedicated processing are presented. Information Management, a concern for all mine action activities, is presented in Chapter "PARADIS: Information Management for Mine Action" with a focus on the data needed for the planning of humanitarian demining campaigns. Protective Equipment used for **Clearance** is addressed in Chapter "Assessing the Performance of Personal Protective Equipment". Vehicles presented in Chapter "Unmanned Ground and Aerial robots for Mine Action" are designed for **Non-Technical** and **Technical Survey**. Sea-Mines are addressed in Chapter "The Special Case of Sea-mines". Finally, the Chapter "Testing and evaluating results of research in mine action" summarises the involvement of RMA in **Tests and Evaluation**. This large scope shows that the focus of RMA research has not been limited to the detection of buried mines, another critic often addressed to the Mine Action Research Community [17].

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