DETECTION OF LANDMINES AND EXPLOSIVES SYSTEMS, PERFORMANCE AND FIELD EXPERIENCE

[1]ABDALLAH MOKHTAR, [2]CHOI SEONG JOO, [3]MANAR MOHAISEN

[1,2]Department Mechanical Engineering, Korea University of Technology and Education
[3]Department of EEC Engineering, Korea University of Technology and Education
E-mail: [1]abdallapro@koreatech.ac.kr, [2]sjchoi@koreatech.ac.kr, [3]manar.subhi@koreatech.ac.kr

Abstract- There is a growing need for efficient and reliable land mine detection.There are more than 100 million of land mines buried in more than 74 countries around the world according to US defense and UNICEF reports; these land mines cause injuries and death of people every hour around the world and represent huge economic and development obstacles. Different parameters must be taken into account for efficient configuration/ design of a detection or demining system from the available solutions and techniques. Thepurpose of this paper is to highlight those parameters showing merits and limitations of different choices among detection and demining methods. In addition, aspects related to detection and demining have been investigated in order to highlight directionswhere researchers can improve the performance of landmines detection systems.

Keywords- Landmines, Mines Detection, Marking, Demining, Detectors, Mine Sensors, Data Transmission

I. INTRODUCTION

Land mines are ready for being exploded once a pressure applied on it, so that multiplerising questions will appear on how to detect the mines without detonating them, what are their characteristics, types, consequences,procedures required for detecting,and how can we deal with them after detection? Limitations and advantages of current detectors and systems have been investigated to enable those who want to select between current technologies of mine detection and demining operations for combining different solutionsto achievebetterdetection performance. Through the reviewed literature in the field,for example ([1], [2],[4] and others,)it is clear that the landmines detection research area still have many gaps and directions for researchers, however there is no complete clear picture about the area/tracks of research in that field. It is also very important to clearly identify which areas are required to be interpreted and investigated to pave the way for researchers to contribute and give advanced solutions. Different combinations of mine detecting unit and carrying vehicles are employed with the aim of detecting all the mines in the desired direction and precisely pin-pointing their locations. Systems and detectors have been interpreted in details (in sections 3 and 4).In a simple way, detection techniques consist of three main units; a sensor to capture a signature of the landmine, a signal or image processing unit to arrange the acquired data in a format suitable for detection, and a decision making unit to decide whether a landmine exists or not. However the research for landmines and explosives detection can be classified in the following directions:

1. Landmines, info, types, facts, consequences;
2. Detection system/ carrying vehicles
3. Detectors (sensors to detect mines)
4. Detected mines' Location identification techniques
5. Data (signal/image) processing techniques and algorithms
6. Data Transmission Techniques
7. Demining methods These directions represent the structure/parts of this paper as well.

This study is set out to investigate the land mine detection techniques and related aspects to highlight the ideal conditions and limitations of different detectors, demining features and share in the debate and challenges for this field of research in accordance with its significant importance for current and future trend. Aspects relating to detection and demining process have been categorized and analyzed to pave the way for combining a suitable solution for specific conditions and also to pave the way for new solutions.

II. LANDMINES FACTS AND CONSEQUENCES

2.1 Landmine

Landmine is a device designed to kill or injure persons and/or destroy vehicles that make contact with it through direct pressure or a trip-wire. Those land mines still represent a hidden killer. They lie under, on or near the ground until a person, vehicle or animal triggers their detonating mechanism as depicted in Fig.1. They contain explosives and some contain pieces of shrapnel.

Fig.1. Anti-personal landmine

2.2 Reasons of using and manufacturing of landmines:

Landmines are easy-to-make, cheap and effective weapons, often laid in groups, called mine fields, designed to prevent enemy movements or passing through a certain area, or sometimes to forcean enemy through a particular area, since the World War I and II [3]. In the Second World War, Germans and Italians improvised antipersonnel land mines with grenades and fuses in order to prevent allied soldiers from deactivating antitank mines placed on already determined defence lines (Russel 2003).Also they have been used in many conflicts, including in the Vietnam War, the Korean War, and theFirst Gulf War.After a while, landmines began to be deployed on a wider scale, often in internal conflicts and started being aimed at civilians.

2.3 Consequences and Harms

Mines kill or injure a person every 20 minutes, 72 persons a day, or more than 20 000 people a year (Kowalenko 2004). Annually, approximately 15,000-20,000 people are killed by landmines, many of which were planted dozens of years ago.The vast majority of victims are civilians and not only soldiers[4].Buried landmines also affect economic development. For example, in Egypt, according to the ICBL and the government sources, the area contaminated by landmines in the northwest coast denies access to about 22%of Egypt's landmass which is very rich in natural resources (oil, minerals andnatural gas), development potential and tourism development (H. Kasban 2010.)Land mines still make land unusable for farming, schools or living, preventing people from rebuilding lives torn apart by conflict. The removal of landmines has become a global emergency.

2.4 Landmines Types

While more than 350 varieties of mines exist, they can be listed into two categories (according to their target), namely, anti-personnel mines (AP) and anti-tankmines (AT). Although the same basic sensing technologies are used for AT and AP land mine detection. There are important differences in terms of scope and strategy[5].Table 1 shows a comparison between AP and AT land mines.

Type	AP	AT
Target	Human	Vehicle
Operating pressure	9 kg	120~158 kg
Depth of buried	4 ~8 cm below surface	near to surface or on the surface
Weight	Light (100 g:4 kg)	Heavy (3 kg:14 kg)
Height	4-6.5 cm	9-15 cm
Size (dia.)	5–20 cm	20–50 cm
Case material	Plastic, metal, wood Plastic,	Plastic, metal

Table1: AP and AT comparison

2.5 Landmine Contents:

Each landmine consists of three components; the case which may be metal, wood, plastic or mixed, the explosive material which may be TNT, RDX, mixed RDX/ TNT, Tetryl, or other high explosives, and an initiator which may include a pressure sensor, an electronic sensor or any other sensor[2].

III. DETECTION SYSTEMS AND CARRYING VEHICLES

3.1 Human Deminer / Manual System:

It is a process of probing the ground using a mechanical prober (a bayonet, or plastic rod.)Probing is being done at an oblique angle to the ground by a human called deminer, aiming for the rod to encounter the side of the landmine and avoid tripping the fuse; for many years, the most sophisticated technology used for locating landmines. Soldiers are trained to poke the ground lightly with a bayonet and search for buried mines; it's a very dangerous process and very slow.

3.2 Hand-Held Detector:

Artificial sensors or detectors in hand held device;the use of humans equipped with one detection technique (discussed in section 4).

With the hand held detectors,shown Fig.2.the operator can follow the ground profile with the detector head close to the ground without hitting the ground or any objects on it. The operator can also vary the width of sweep to suit a particular situation, and is usually not limited by terrain. "However the manual method is slow, hazardous, manpower-intensive, and stressful to the operation who, as a result, can perform this task only for short periods at a time. As well, errors result due to operator inattentiveness" [1]. There is a growing acceptance that a more universal application of technology may enable mine detection with more cost effectively, quickly, and with less risk [6].

Fig.2.Hand-Held detectors

3.3 Automated systems combined with artificial sensor(s)

A carrying vehicle/equipment or robot which is automated controlled (Advanced robot based demining.)

The system can be in one of the following figures:

- (vehicle-mounted system)Autonomous cars or Automated guided vehicles (AGV)
- Walking robots, animal like... etc.
- Airplanes and copters

And combined of one or more detectors (mine sensors); The option of detecting mines in a surface-laid minefield using autonomous robots is becoming more popular because it decreases the danger and the cost involved in manual detection. Zhang et al.(2001) [7]proposed a probabilistic method for robot landmine search, focusing on optimization search strategy determining location of mines and/or unexploded ordnance. They first extract the characteristics of dispersion pattern of the minefield in order to construct a probability map and then design a path for the robot searching. Artificial sensors attached to vehicle and capture signals at equally spaced positions as the vehicle moves, like the example combined with a GPR in [8], in which the vehicle speed and the height of sensors above the ground surface can be relatively constant. Land mines in this case often produce stable signatures, such as hyperbolic shapes, for detection as shown in [8].Also other examples on using Semi-Autonomousmine detection systems, are introduced and developed in [9] and[10] and a walking mobile robot for mine detection was developed in [11].

3.4Evaluation of detection systems

Manual systems in 1 and 2 are popular in mine detection operations in the world but the possess potential danger to the lives of the deminers, and is considered slow and inaccurate techniques for landmines detection ([3], [5], [12].) Removal of all mines by those systems would require several hundredof years (it would take one thousand according to a CMAC report based on Cambodian Mine Action Center Current Activities 1998), during which time, more mines might be buried in war zones [1]. Because of the human factor in the handheld detectors or manual methods, the sweeping speed and the sensor-to-ground distance are varying. Hence even advanced detectors are being used as GPR, but land mine signatures are inconsistent and the hyperbolic signatures as observed in the vehicle based system developed in [8].

IV. DETECTORS (SENSORS)

In this part a comparison that shows the ideal conditions and the challenges for each technique has been conducted, in terms of range, cost, limitations, speed, safety, false alarm rate and effect of environmental conditions. See Fig.3.andTable 2, for classification and comparison (page 4).

V. LOCALIZAION AND TRACING OF DETECTED MINES

If the mine is detected, another main job still required which is to mark its location to be defined by one of demining processes (section 8).In manual/mechanical detection the deminer can use any land marking process manually. But for the stream of data coming from a sensor in an automated system, it must work in continuous manner, marking in parallel by giving information about locations of detected mines, marking observed to be done by one of the following methods:

- Physical marking: can be performed using an array of sprayers dispensing die, triggered by the automated system integrating the detection information from the individual sensors[1].
- Electronic marking occurs after correlating the sensor data with high-accuracy GPS data. By deploying a differential GPS configuration, accurate GPS antenna locations can be available in real-time. Once the antenna location is known, the sensor and target locations can be calculated[10]and[3].

VI. DATA (SINGNAL IMAGE) PROCESSING TECHNIQUES

Data processing algorithms play essential role in improving performance. Various image-processing methods introduced in the literature, such as filtering, feature extraction, morphology, contrast enhancement, segmentation, and visualization. In order to overcome this ambiguity problem of signals, most research has been conducted in two ways. First, methods to extract multiple signals from a source or to enhance the ambiguous signal to a noticeable level. Second, many research groups have developed device with multiple sensors, called sensor fusion.

Support vector methods are interesting methods where anomalies in hyperspectral images are identified, therefore improving detection of the spectral signatures of unknown targets [13].An example of a Bayesian sensor fusion for land-mine detection using a dual-sensor hand-held device have been developed in the EEC dept.,2013, university of Coimbra by Jose Pardo, in [14]. Fusion is a developing technique in which information from several detection systems becomes relevant. Output information from different detectors combined for getting full potential from every available method, avoiding the weaknesses of each [15]; also another example on combined detector of GPR +MD have been introduced by Z. Zyada using the data of the dual sensor as the inputs to the fuzzy fusion system. The output from the fuzzy fusion system is a decision if there is a mine and at what depth it would be [16] . Neural networks are another approach for automatic target detection using entropy optimized shared-weight neural networks [17]. Bayesian network (BN) representation of a sensor's measurement process was developed so the problems of sensor fusion and management can be approached from a unified point of view (Ferrari and Vaghi 2006)[18]. Liao et al. (2007)[19] exploited the strengths of existing multi-sensor algorithms in order to achieve the required performance, exceeding those of isolation operating sensor algorithms. This approach is based on signal detection theory using the likelihood ratio. It considers a GPR and a metal detector. Digital filtering for GPR signal enhancement was presented by Potinet al. (2006)[20].

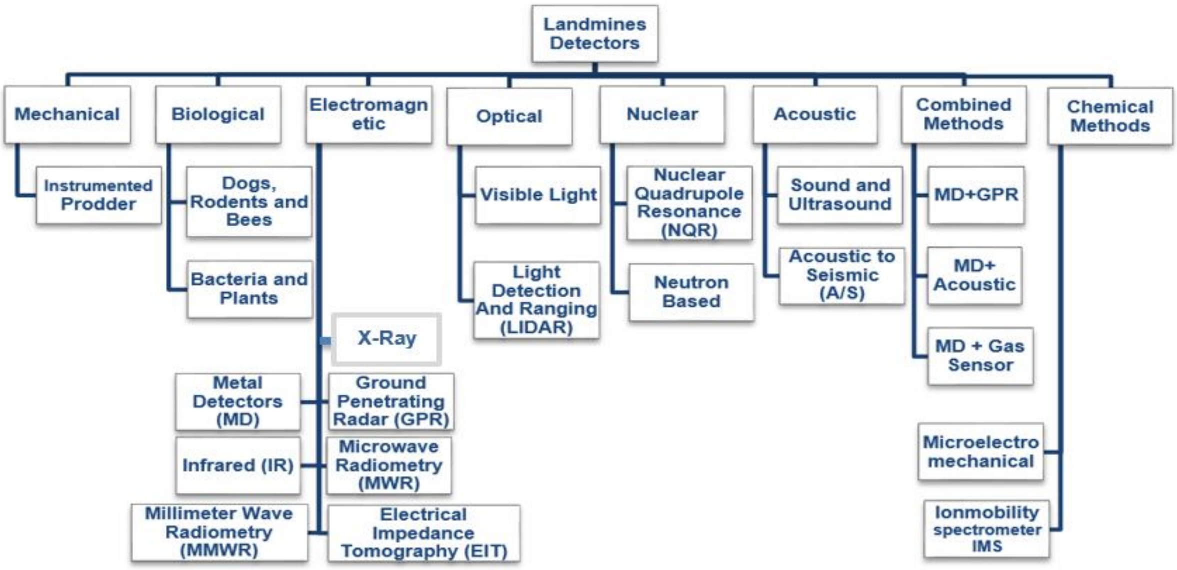

Fig.3. Different Mine Detectors

Technique	Concept	Cost	Weight	Range &Contact with ground	Metal content/ plastic	Adv. &Ideal conditions in	Disadvantages/ Challenges/ limitations
Metal Detectors (MD) [1].	Sense metal content in , by EMI interact with metal	Very Low	light	Up to 10 cm above the ground	Metal only	Metal casing mines all types of soils all weather condition	Low metal content mines. False signals from metal debris
Ground Penetrating Radar (GPR)[21].	Difference of backscattered waves between soil and object of diff. density	Very high	Very heavy	-Long range No contact required	All	Dry soil	-Soil with Wet clay affect the waves. - Very dry reduce electrical contrast.
Microwave Radar MWR[22].	Diff. in reflection time of transmitted shortwaves	M	Medium	-Long range (depend on freq. , mine size.-No ontact	All	Dry soil Large metallic objects	Wet soil Affected by radio freq.
Millimeter Wave Radar MMWR [23].	Backscattering MMW radiation from buried sample. And diff. thermal contrast	M	Medium	Long range -No contact required	All	dry soil, shallowly mines, vegetation, cloud and smoke environment	wet soil, non-uniform background, Affected by radio freq. Slow
EIT [23].	Producing conductivity image of an area using elec. Currents, different contour appeared for metals, plastic and soil	L	Medium	-medium but, - <u>Contact is a must,</u> - <u>So it can't detect from over surface</u>	All	Wet soil, under water	Dry soil, high Environment effect, elec. Noise risky due contact with soil
IR[24].	Diff. thermal properties between mines and surrounding land	H	light	Low range No contact required, Max buried mine (15 cm)	All	all types of soils	high Environment effect, day time, size and mine composition
X-Ray backscatter [5], [25]	Backscattered signals diff. with respect to material density	H	heavy	Low range (max10 cm)	All	All mines Low false alarms	Risk due to radiation
Visible Light[25].	A visual imager gathers light from object point and transforms it into a beam	L	Medium	Long No contact required but <u>Can't detect beneath surface</u>	All	is simple, safe, fast, from airborne platform; for mines that lie of surface	Non flat or Blocked soil high Environment effect, vegetation high false signals
LIDAR[5], [25].	Diff. in waves reflected back by surface laid objects and its speed	H	medium	Very short	All	Non vegetation soil	Vegetation soil
NQR [26], [27].	Interaction of wave with nucleus of explosive	M	heavy	High	Plastic and wood	all types of soils RDX material	Cant TNT material high Environment

Table2: Landmines Detectors Comparison and Evaluation

	material				only	Very low false alarm rate	effect, Difficult for outdoor use (radioactive material
Neutron based [28].	interactions between neutrons (gamma) soil and mines	H	Very heavy (shield)	High	All	all types of soils	Risky (radiation) High power consumption
A/S [29].	Diff. acoustic response between mines and soil.	H	light	Low range, fall in deeper mines		Wet soil, a high sensitivity and low false rates	Vegetation soil Slow method
US [30]. [6].	collect active signal reflections from surroundings, speed of sound	M	Medium	Medium	All	All conditions , good in Very wet, he only sensor used for underwater	-Dry soil -high false signals -the interface between the air and the ground
Mechanical [31].	Probing the ground and mechanical sensing mine casing	L	light	-	All	-	Non flat soil high false signals Risky
Dogs, Rodents and Bees [12][32]	They are trained to sniff out vapors coming from the explosive	L	-	Contact	All	All kinds of soil	Explosives that they are not trained to them high Environment effect
Plants [33].	Specific plants with some treatment that changed color in response explosives	M	-	Contact	All, but with TNT content only	Cover large area , fast	Can't detect RDX material Rocks and very dry soil high Environment effect
Bacteria [6], [33].	bacteria fluoresces under ultraviolet light after exposure to TNT material	H	-	Contact	All, but with TNT content only	-	Cant detect RDX Risky high Env effect
IMS,[22]. [34]. **MEMS** [35]	vapor from explosives, that transferred by molecular diffusion and other methods	H	light	No contact	All	The best way for detect plastic mines	Still on spot-checking research
Combined methods [14],[36],[37]	Different principles of combined sensors	H	-	Benefits of good conditions of the two sensors			Data processing needed to be efficient

As a conclusionfor detectors; landmines can simply be detected by exploring and detection the existing metal in its contents, physical changes from backscattered signals after hitting the mines (thermal, sound,..), however the most effective method is to detect the explosive material itself, to avoid false signals from scrap metals, and low metal content mines, or wrong signals due to environmental effects surrounding the mines. The eventual solution trends which look for the explosive in mines, especially if these sensors can be used in safe, cheap, and reliable methods. The most promising paradigm for mine detectors recently and for the future trend is the use of dual sensors by selecting two different kinds of sensors in a combined technique since every approach has good results within limited conditions; aiming to gain the merits of both of them.

VII. DATA TRANSMISSION TECHNIQUES

In the stream of remotely controlled systems of landmines detection, data transmission happens between the remote control point and the moving detection system. Data transmission are not being covered in depth in this research, however, there are some examples and solutions that have been introduced in this direction such as:Wireless data transmission using data sockets and different examples of remote panels have been introduced in [38],[10], [39] and [40].In other cases Wi-Fi, ZigBee protocols connections have been introduced, however the field of data transmission still have big potential for researchers for more effective solutions, especially for the visualization and monitoring aspects; for trace of the detection/the sweeping of robot, speed and visualization of detected mines with respect to maps and coordinates of land.

VIII. DEMINING TECHNIUES

8.1 Manually by human who will remove the detected mine away for further detonation process.
8.2 Mechanical methods: using a big clearing machines/vehicles or to remove the mines and/or explode them especially for anti-personal mines.

In which a flail machine, almostused by military when there is not enough time and not suited for humanitarian demining;This technique is quick but there it leaves the area virtually destroyed, and the machines can easily miss mines. This technique cannot achievethe humanitarian demining accuracy and safety standards and it is environmentallynot friendly.
8.3 Automated method by robots to carry the detected mine away for further detonation processFig.4.Hemapala,2013 University of Genova, Italy , introduced Landmines Removal Robot [3].

Fig.4.Robot-Aided Mine Sweeper (RAMS)[3]

IX. RESULTS AND DISCUSSION

Controlling dangerous applications from remote distance for enhancing the security of persons as an applications of remote labs [42].According to the different aspects relating to the mine detection system discussed before, different figures and paradigms are being expected/deployed as follows:

- Handheld: swing, detect, localize, stop, and mark
- Vehicular: move forward, detect, mark, and stop
- Vehicular: move forward, detect, mark, and overpass.

The "swing, detect, localize, and stop" paradigm is for handheld systems where the operator is performing the localization based on visual or auditory feedback from the sensor(s). A simple metal detector, for example, usually gives an auditory feedback that increases in pitch with signal strength, so it's easy to imagine swinging the sensor to localize the signal left and right, then fore and aft, then marking the spot somehow, then not stepping on the spot. Most vehicular systems depend on uniform forward motion to acquire a volume of data and, in the case of GPR data, trace out the hyperbolic land mine signature. In the "move forward, detect, mark, and stop" paradigm, the vehicle would halt while the location on the ground was probed, determined to be a real land mine or a false alarm. The vehicle would then continue forward, acquiring sensor data.In the "overpass" paradigm, a vehicle with tracks or large, low-pressure tires would have a sufficiently low ground footprint to not detonate an AT mine. The vehicle's undercarriage could be armored to withstand the blast from AP mines. Demining are being done by Military to remove a sufficient number of landmines to create a safe corridor for troops and/or vehicles to move through. Also conducted through Humanitarian Demining to free the entire land area from landmines [41].

Sources of errors like missing of some mines, false signals of non-dangerous buried items, repeated signals of same mine, explosion/detonation of mines, missing of accurate location information techniques. All of these problems lead to danger on lives, wasting of time and costly operations. Another notice that, although the design of new sensors can contribute to reduce the time needed to detect a landmine, it does not mean that it increases operator safety responsible for the demining tasks because a mere mistake can cost them their lives. For this reason, training is an essential aspect when we refer to enhance security and efficiency of demining tasks.

CONCLUSIONS

This paper concludes in detailed survey on landmines/explosives detection anddemining. Over the last two decades the applied research in humanitarian demining has made progress to some extent, but an international exchange of research results are urgent to find out the most promising measures for application. The widespread use of plastic land mines necessitates development and deployment of additional detection technologies, increasing the probability of detection, reducing the false alarm rate, and planning out usable deployment scenarios. Detection systems;

Attention towards armored vehicle or a portable unit with multiple sensors. Future work in the image processing area will also involve fusion. A global method, able to accept data from multiple sensors and to visualize them is an essential area of data processing methods for mine detection applications. In a system with no contact with ground like airplanes or copters with low cost keeping a fixed distance with ground, and can be through a multi-agent systems to increase the speed of land scanning.

ACKNOWLEDGMENTS

Gratitude to VILAB & Mobile-LAB /KoreaTech University and KOICA for their cooperation and Support.

REFERENCES

[1] K. Nonami, S. Masunaga, and D. Waterman, “Mine Detection Robot and Related Technologies for Humanitarian Demining,” no. February, 2008.

[2] L. Robledo, M. Carrasco, and D. Mery, “A survey of land mine detection technology,” Int. J. Remote Sens., vol. 30, no. 9, pp. 2399–2410, May 2009.

[3] W. Ghribi, A. S. Badawy, M. Rahmathullah, and S. B. Changalasetty, “Design and Implementation of Landmine Robot,” vol. 2, no. 11, pp. 250–256, 2013.

[4] “UN Mine Action Service, UN Landmine Database.” [Online]. Available: http://www.un.org/Depts/dpko/mine.

[5] H. Bach and J. Phelan, “Alternatives for landmine detection,” Altern. landmine Detect., vol. 1608, pp. 285–99, 2003.

[6] C. P. Gooneratne, S. C. Mukhopahyay, and G. Sen Gupta, “A Review of Sensing Technologies for Landmine Detection : Unmanned Vehicle Based Approach,” Auton. Robots, pp. 401–407, 2004.

[7] Y. Zhang, M. Schervish, E. U. Acar, and H. Choset, “Probabilistic methods for robotic landmine search,” Proc. 2001 IEEE/RSJ Int. Conf. Intell. Robot. Syst. Expand. Soc. Role Robot. Next Millenn. (Cat. No.01CH37180), vol. 3, 2001.

[8] K. C. Ho and P. D. Gader, “A linear prediction land mine detection algorithm for hand held ground penetrating radar,” IEEE Trans. Geosci. Remote Sens., vol. 40, no. June, pp. 1374–1384, 2002.

[9] A. El-Shenawy, “The construction of autonomous electric vehicle for Land mine detection and localization,” Proc. 2012 1st Int. Conf. Innov. Eng. Syst. ICIES 2012, no. Ii, pp. 91–96, 2012.

[10] D. Few, R. Versteeg, and H. Herman, “Semi autonomous mine detection system,” Proc. SPIE - Int. Soc. Opt. Eng., vol. 7664, p. The Society of Photo–Optical Instrumentation Engin, 2010.

[11] P. Gonzalez de Santos *, E. Garcia, J. Estremera, and M. a. Armada, “DYLEMA: Using walking robots for landmine detection and location,” Int. J. Syst. Sci., vol. 36, pp. 545–558, 2005.

[12] S. Masunaga and K. Nonami, “Controlled metal detector mounted on mine detection robot,” Int. J. Adv. Robot. Syst., vol. 4, no. 2, pp. 237–245, 2007.

[13] A. Banerjee, P. Burlina, and C. Diehl, “A support vector method for anomaly detection in hyperspectral imagery,” IEEE Trans. Geosci. Remote Sens., vol. 44, no. 8, 2006.

[14] J. Prado, G. Cabrita, and L. Marques, “Bayesian sensor fusion for land-mine detection using a dual-sensor hand-held device,” IECON Proc. (Industrial Electron. Conf., pp. 3887–3892, 2013.

[15] C. Rennie and M. Inggs, “Sensor fusion in the detection of land mines,” Proc. 1997 South African Symp. Commun. Signal Process. COMSIG ’97, 1997.

[16] Z. Zyada, T. Matsuno, Y. Hasegawa, S. Sato, and T. Fukuda, “Advances in GPR-based landmine automatic detection,” J. Franklin Inst., vol. 348, no. 1, pp. 66–78, 2011.

[17] M. A. Khabou and P. D. Gader, “Automatic target detection using entropy optimized shared-weight neural networks.,” IEEE Trans. Neural Netw., vol. 11, no. 1, pp. 186–193, 2000.

[18] S. Ferrari and A. Vaghi, “Demining sensor modeling and feature-level fusion by bayesian networks,” IEEE Sens. J., vol. 6, no. 2, pp. 471–483, 2006.

[19] Y. Liao, L. W. Nolte, and L. M. Collins, “Decision Fusion of Ground-Penetrating Radar and Metal Detector Algorithms—A Robust Approach,” IEEE Trans. Geosci. Remote Sens., vol. 45, no. 2, 2007.

[20] D. Potin, E. Duflos, and P. Vanheeghe, “Landmines Ground-Penetrating Radar Signal Enhancement by Digital Filtering,” IEEE Trans. Geosci. Remote Sens., vol. 44, no. 9, 2006.

[21] L. Capineri, S. Ivashov, T. Bechtel, a Zhuravlev, P. Falorni, C. Windsor, G. Borgioli, I. Vasiliev, and a Sheyko, “Comparison of GPR Sensor Types for Landmine Detection and Classification,” 12th Int. Conf. Gr. Penetrating Radar, pp. 1–10, 2008.

[22] A. Jeremic and A. Nehorai, “Landmine detection and localization using chemical sensor array processing,” IEEE Trans. Signal Process., vol. 48, no. 5, 2000.

[23] P. Church, J. E. McFee, S. Gagnon, and P. Wort, “Electrical impedance tomographic imaging of buried landmines,” IEEE Trans. Geosci. Remote Sens., vol. 44, no. 9, pp. 2407–2420, 2006.

[24] N. Trung Thành, H. Sahli, and D. Nho Hào, “Infrared thermography for buried landmine detection: Inverse problem setting,” IEEE Trans. Geosci. Remote Sens., vol. 46, no. 12, pp. 3987–4004, 2008.

[25] and J. M. MacDonald, Jacqueline, J.R. Lockwood, “Alternatives For Landmine Detection,” 2003.

[26] V. T. Mikhaltsevitch and A. V. Beliakov, “Polarization enhancement of NQR signals for explosive detection,” Solid State Commun., vol. 138, no. 8, pp. 409–411, 2006.

[27] A. Jakobsson, M. Mossberg, M. D. Rowe, and J. A. S. Smith, “Exploiting temperature dependency in the detection of NQR signals,” IEEE Trans. Signal Process., vol. 54, no. 5, pp. 1610–1616, 2006.

[28] R. Ponticelli, E. Garcia, P. G. de Santos, and M. Armada, “A scanning robotic system for humanitarian de-mining activities,” Industrial Robot: An International Journal, vol. 35, no. 2. pp. 133–142, 2008.

[29] M. S. Korman and J. M. Sabatier, “Nonlinear acoustic techniques for landmine detection.,” J. Acoust. Soc. Am., vol. 116, no. 6, pp. 3354–3369, 2004.

[30] J. Paik, C. P. Lee, and M. A. Abidi, “Image Processing-Based Mine Detection Techniques : A Review,” Subsurf. Sens. Technol. Appl., vol. 3, no. 3, pp. 153–202, 2002.

[31] Y. Das, J. E. McFee, and G. Cross, “Soil Properties Database for Humanitarian Demining: A Proposed Initiative,” in International Union of Soil Science at the 17th World Congress of Soil Science, 2002, no. August, pp. 14–21.

[32] D. W. Wesson, “Sniffing behavior communicates social hierarchy,” Curr. Biol., vol. 23, no. 7, pp. 575–580, 2013.

[33] A. A. Berhe, “The contribution of landmines to land degradation,” Land Degradation and Development, vol. 18, no. 1. pp. 1–15, 2007.

[34] I. Sample, “Why PETN explosive is hard to detect,” 2010. [Online]. Available: The Hindu. http://www.hindu.com. [Accessed: 04-Jan-2015].

[35] D. Kong, Y. Qi, L. Zhou, B. Lin, Z. Li, R. Zhu, and C. Chen, “MEMS based sensors for explosive detection: Development and discussion,” in 3rd IEEE International Conference on Nano/Micro Engineered and Molecular Systems, NEMS, 2008, pp. 265–269.

[36] U. S. Khan, W. Al-Nuaimy, and F. E. Abd El-Samie, “Detection of landmines and underground utilities from acoustic and GPR images with a cepstral approach,” J. Vis. Commun. Image Represent., vol. 21, no. 7, pp. 731–740, 2010.

[37] D. M. Kim, S. H. Kim, S. Lee, and K. Kim, “Combined metal detector and ground-penetrating radar sensor experiments in a

variety of soil conditions," Int. Geosci. Remote Sens. Symp., vol. 4, pp. 601–604, 2009.

[38] K. Prema, N. S. Kumar, and S. S. Dash, "Online control of DC motors using fuzzy logic controller for remote operated robots," J. Electr. Eng. Technol., vol. 9, no. 1, pp. 352–362, 2014.

[39] A. Anuar, S. Yussof, I. Said, J. Tan, and T. Chuan, "the Development of an Autonomous Personal Mobile Robot System for Land Mines Detection on Uneven Terrain : an Experience," Adv. Technol. Congr., pp. 1–8, 2003.

[40] K. T. M. U. Hemapala and R. P. Razzoli, "Design and development of a landmines removal robot," Int. J. Adv. Robot. Syst., vol. 9, pp. 1–7, 2012.

[41] H. Kasban, O. Zahran, S. M. Elaraby, M. El-Kordy, and F. E. Abd El-Samie, "A Comparative Study of Landmine Detection Techniques," Sens. Imaging An Int. J., vol. 11, pp. 89–112, 2010.

[42] A. Mokhtar, "A Survey on Remote Laboratories for E-Learning and Remote Experimentation," vol. 7, no. 29, pp. 1617–1624, 2014.

★★★