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Final Report Shield Project 12rh – Advanced Handheld Mine Detection

J.E. McFee, Y. Das, A.A. Faust
DRDC Suffield

Technical Report
DRDC Suffield TR 2005-159
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Abstract

Between 1995 and 2005, fundamental R&D was conducted under Shield Project 12rh, "Advanced Hand-held Mine Detector", with the aim of developing a hand-held multi-sensor landmine detector. The military sponsor for the project was DLR-7, with J3 Engineering Operations and DCSEM maintaining an active interest. Humanitarian and military mine detection requirements differ, but because there was a common core of R&D needed, Canadian Center for Mine Action Technologies (CCMAT) also provided substantial sponsorship. This report describes the objectives and results of the project.

All three objectives of the project were met. The first was to deliver a multi-sensor hand-held landmine detector concept demonstrator to the CF. The second was to assist DLR 7 in development of a technical specification in support of minor requirements acquisition of a new mine detector. The third objective was to develop a capability to discriminate targets from clutter. Out of the project's 8 milestones, 5 were completed by project end and 3 were partially completed.

Multi-sensor mine detection conducted under this project has involved leading edge research in a variety of scientific areas, including electromagnetic induction, infrared imaging, ground penetrating radar, acoustics, nuclear physics, X-ray imaging, data fusion and robotics. The Threat Detection Group is considered a leader in mine detection research. Group members led or participated in a number of international panels and have co-chaired or been on the program committee of prestigious conferences concerning research on mine detection or related technologies. Over 110 publications related to the project were issued during the project period.

Some of the research conducted under 12rh will continue under Shield Projects 12rl and 12rm, and a 3 year TIF titled "Concept for Neutronic Detection of Improvised Explosive Devices". Research on electromagnetic induction has shifted focus to a study of electromagnetic properties of soils. It is being funded by CCMAT.

Résumé

La recherche fondamentale du projet Shield 12rh << détecteur de mines manuel amélioré >>, ayant pour but de mettre au point un détecteur de mines terrestres manuel à capteurs multiples, a été conduite entre 1995 et 2005. Le commanditaire militaire du projet était DBRT-7, avec Exploitation-Ingénierie J3 et Direction - Gestion de l'équipement d'appui au combat (D Gest EAC) qui maintenaient une participation active. Les besoins en détection de mines à des fins humanitaires diffèrent de ceux de la détection militaire mais puisqu'il existait un noyau de besoins en R & D qui était commun aux deux domaines, le Centre canadien de technologies en déminage (CCTD) a aussi commandité le projet de manière importante. Ce rapport décrit les objectifs et les résultats du projet.

Les trois objectifs du projet ont été atteints. Le premier consistait à livrer un démonstrateur du concept du détecteur de mines terrestres manuel à capteurs multiples aux FC. Le second

consistait à donner de l'assistance à DBRT- 7 dans la mise au point d'une spécification technique soutenant les besoins mineurs nécessaires à l'acquisition d'un nouveau détecteur de mines. Le troisième objectif consistait à mettre au point des capacités visant à discriminer les cibles du fouillis. Le projet comportait 8 étapes dont 5 ont été complétées et 3 ont été complétées partiellement.

La détection des mines à capteurs multiples conduite durant ce projet englobait la recherche de pointe dans une variété de domaines scientifiques dont l'induction électromagnétique, l'imagerie infrarouge, le géoradar, l'acoustique, la physique nucléaire, l'imagerie par rayon X, la fusion des données et la robotique. Le Groupe de détection des menaces est considéré comme étant le leader en matière de recherche en détection des mines. Les membres du groupe ont dirigé ou ont participé à un certain nombre de panels internationaux et ont coprésidé ou appartenu à des comités des programmes de conférences prestigieuses concernant la recherche sur la détection des mines ou sur des technologies qui y sont reliées. Plus de 110 publications reliées au projet ont été issues durant la période du projet.

Une partie de la recherche conduite durant le projet 12 rh continue sous le projet Shield 12rl, 12rm et un FIT de 3 ans appelé : << Concept en matière de détection neutronique des dispositifs explosifs de circonstance >>. La recherche sur l'induction électromagnétique a changé pour s'orienter vers une étude des propriétés électromagnétiques des sols. Elle a été financée par le CCTD.

Executive summary

Final Report Shield Project 12rh - Advanced Handheld Mine Detection

Dr. J. E. McFee, Dr. Y. Das, Dr. A. A. Faust; DRDC Suffield TR 2005-159; Defence R&D Canada – Suffield; December 2005.

Shield Project 12rh, "Advanced Hand-held Mine Detector", was started on 1 April 1995 as the next logical step in a long term research and development program on detection of unexploded ordnance (UXO) and landmines that had been ongoing since 1975. Since 1975, Defence R&D Canada – Suffield (DRDC Suffield) has been the lead centre responsible for all aspects of landmine detection research and development in Canada. Most of the military and humanitarian mine detection research has been conducted in-house at DRDC Suffield by the Threat Detection Group (TDG) of the Military Engineering Section (MES) and under contract to Canadian industry. On occasion, certain elements of the research have been assisted by two other DRDC centres, DRDC Valcartier and DRDC Ottawa. Prior research had focused on four main headings: remote minefield detection, close-in scanning landmine detection, confirmation detection and teleoperated systems. Results of this work had led to the start of the Improved Landmine Detection Project (ILDP) in 1994, which would in 2002 deliver to the Canadian Forces (CF) four teleoperated, vehicle-mounted multi-sensor landmine detectors for roads and tracks in rear areas and Operations Other Than War (OOTW). Research had also been ongoing on sensor technologies to replace or augment hand-held metal detectors (existing hand-held mine detectors) and on technologies to reduce false alarm rates by imaging or detecting the presence of explosives. By 1995, it had become clear to most researchers, driven in large part by TDG researchers, that a single sensor would not be able to achieve reliable detection of low metal landmines with low false alarm rates and that multiple sensors must be employed. Thus, the time seemed appropriate to consider studies aimed at the hand-held multi-sensor landmine detector.

There were three objectives of Project 12rh and all three were met. The first was to deliver a multi-sensor hand-held landmine detector concept demonstrator to the CF. By the end of the project, two such commercial detectors had been delivered for testing. The second objective was to assist DLR 7 in development of a technical specification in support of minor requirements (MR) acquisition of a new mine detector. Not only were technical specifications developed for this specific task, methodologies were developed for more general requirements, such as for humanitarian demining, through in-house R&D and participation in organizations such as ITEP (International Test and Evaluation Program). Further, TDG directly participated in the evaluation of detectors for the CF and recommended the replacement for then existing detector. The third objective was to develop a capability to discriminate targets from clutter. Research on data fusion and confirmation and imaging sensors has led to improvements in discrimination of mines from clutter and future work will continue the improvement. The expected outcome of the project was that the Canadian Forces would acquire a hand-held mine detector with better ability to detect nonmetallic mines and reduced false alarm rate, than the existing in-service mine detector. The Project successfully ended on 31 March 2005.

The military sponsor for the project was DLR-7, the Military Engineers, who are directly tasked with mine clearance. Other interested parties who provided support are J3 Engineering Operations and Directorate Combat Support Equipment Management (DCSEM), who are responsible for life cycle management of hand-held mine detectors and the ILDS vehicle-mounted mine detector system. The CF interest is two-fold. First, they need immediate advice regarding performance and deficiencies for commercial-off-the-shelf low-metal mine detectors and best practices to evaluate them. This enables them to know whether the in-service detectors can do the job for a particular theatre and, if not, what is the best detector that is available for that theatre. Their long term interest lies in the need for an eventual successor to the in-service detector, which would have as good or better a detection rate than a conventional low-metal detector, with a reduced false alarm rate. This would provide safer and faster passage through mined areas, thereby increasing force protection and improving mobility. This requirement dictates a multi-sensor design. Such a multisensor mine detector would obviously also decrease humanitarian demining costs per unit area of land and improve demining safety and thus is of great interest to the Canadian Center for Mine Action Technologies (CCMAT). Because of its mandate, CCMAT could only provide support to those aspects of the research that were directly related to humanitarian demining applications. Requirements for a multisensor mine detector for humanitarian demining are somewhat different from those for a detector for the military. However, there was a substantial common core of R&D necessary to develop detectors for both applications and in the end, CCMAT was able to provide sponsorship worth about twice that of the project funds.

Multi-sensor mine detection conducted under this project has involved leading edge research in a variety of scientific areas, including electromagnetic induction, infrared imaging, ground penetrating radar, acoustics, nuclear physics, X-ray imaging, data fusion and robotics. The Threat Detection Group is considered a leader in mine detection research, as evidenced by, among other things, the extensive publication list during the project period. One group member chaired, and was the only non US member of the RAND Science and Technology Policy Institute study, sponsored by the White House Office of Science and Technology Policy, to develop a plan for future research on humanitarian mine detection. Since 1996, some group members have co-chaired or been on the program committee of the Optical Engineering Society's (SPIE) annual conference on Detection and Remediation of Mines and Mine-like Targets, considered by most in the field to be the premier conference on mine detection research. Other members have been on the program committee of SPIE's Penetrating Radiation Conference.

Out of the project's 8 milestones, 5 were completed by project end. A new mine detector was selected for the CF fleet. A robotic scanner for teleoperated "hand-held" detection was produced. The thermal neutron activation (TNA) confirmation detector for the CF's 4 ILDS systems was significantly improved. The feasibility of impedance tomography to detect surf zone mines was established. A method to simulate X-ray backscatter imaging and hence aid in development of future detectors, was developed. The remaining 3 milestones were partially completed. Testing of COTS multi-sensor hand-held landmine detectors was not completed because such systems became commercially available only very recently.

Nevertheless, two were obtained very near the project end. Initial T&E was conducted in Thailand, UK and Namibia. The remainder of this work will be done under CCMAT sponsorship. Two nuclear-based imaging detectors for false alarm reduction were completed as breadboard prototypes and produced images of mine surrogates. However, they were not considered mature enough for extensive laboratory testing. The imagers will be improved in follow-on work under Project 12rm.

Over 110 publications related to Project 12rh were issued during the project period. These include 7 open literature papers, 20 peer-reviewed technical reports, 46 papers in refereed conference proceedings, 4 patents, 4 patent applications or reports of invention and 32 contractor reports.

Group members were representatives on a number of international panels which studied aspects of mine detection. These included NATO AC/143 Special Group of Experts on Combat Engineering Technology (SGE-CET) Research Study Group 1 (RSG-1, mine detection for countermine) and Group 3, (RSG-3, dual use mine detection), NATO SCI-133 (detection of off-route mines), TTCP SEN AG-8 (mine detection) and SA-14 (landmine detection) of the Australian/Canada MOU. The latter led to the completion of joint hand-held metal detector trials that partially supported the selection of the replacement for the CF mine detector fleet under WBE 12rh01. The TTCP also enabled low cost participation in an international airborne standoff minefield detection experiment (MUST2000), by leveraging off an existing TTCP trial investigating airborne detection of camouflaged vehicles. A TDG member lead the IPPTC (International Pilot Project for Technical Cooperation), an ambitious multinational effort which carried out an extensive evaluation of a large number of landmine detectors for their suitability in humanitarian demining. This project, in turn, laid the foundation for ITEP, a continuing international program for testing of humanitarian mine detection, protection and neutralization equipment. Canada has played a leading role in ITEP since its inception.

Some of the research conducted under 12rh will continue under new projects. Optical trip wire detection research will continue under project 12rl "Optical Imaging of Landmines" which started April 2004. Further work on neutron and X-ray imagers is being conducted under 12rm "Confirmation Sensors" which started April 2005. EIT research is also continuing under 12rm and US funding for surf zone detection is actively being sought. Research on advanced TNA, fast neutron activation (FNA) and related topics is being conducted as part of a 3 year TIF titled "Concept for Neutronic Detection of Improvised Explosive Devices" which started April 2005. Research on electromagnetic induction has shifted focus to a study of electromagnetic properties of soils. This is being followed up solely through CCMAT funding, which up to now had augmented 12rh funds. It is unclear what will become of this subproject when CCMAT ends March 2007.

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Sommaire

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Dr. J. E. McFee, Dr. Y. Das, Dr. A. A. Faust; DRDC Suffield TR 2005-159; R & D pour la défense Canada – Suffield; décembre 2005.

Le projet Shield 12rh << Détecteur de mines manuel amélioré>> a débuté le 1er avril 1995 comme étant l'étape logique faisant succession à un programme de recherche et développement à long terme concernant la détection des munitions non éclatées (UXO) et des mines terrestres qui existe depuis 1975. R & D pour la défense Canada Suffield (RDDC Suffield) est le centre responsable de mener la recherche, depuis 1975, en ce qui concerne tous les aspects de recherche et développement en matière de détection des mines terrestres, au Canada. La plupart de la recherche en matière de détection de mines à des fins militaires et humanitaires a été conduite de manière interne à RDDC Suffield par le Groupe de détection des menaces de la Section d'ingénierie militaire et en vertu d'un contrat avec l'industrie canadienne. À l'occasion, RDDC Valcartier et RDDC Ottawa ont aidé avec certains éléments de la recherche. La recherche antécédente s'était orientée vers quatre domaines principaux : la détection à distance des champs de mines, la détection des champs de mines par balayage à proximité, la détection de confirmation et les systèmes télécommandés. Les résultats de ces travaux ont amené au Projet de détection améliorée des mines terrestres (ILDP) en 1994. En 2002, ce dernier livrait aux Forces canadiennes (FC) quatre détecteurs de mines terrestres à capteurs multiples téléguidés et montés sur véhicules pour des routes et des pistes de zones arrières et pour des opérations autres que celles de la guerre. La recherche s'orientait aussi sur les technologies de capteurs visant à remplacer ou à augmenter les détecteurs manuels de métaux (détecteurs de mines manuels existants) et sur les technologies visant à réduire le taux des fausses alarmes par l'imagerie ou par détection de la présence d'explosifs. Il était devenu évident chez la plupart des chercheurs dès 1995, surtout chez les chercheurs TDG qu'un seul capteur serait incapable de détecter avec fiabilité les mines terrestres de teneur faible en métal en ayant un taux faible de fausses alarmes et qu'il faudrait des capteurs multiples. Il semblait donc opportun de considérer des études qui porteraient sur le détecteur manuel à capteurs multiples de mines terrestres.

Le Projet 12rh comportait trois objectifs et tous ont été atteints. Le premier consistait à livrer aux FC un démonstrateur du concept du détecteur de mines terrestres manuel à capteurs multiples. Deux tels détecteurs commerciaux ont été livrés à la fin du projet pour les essais. Le second objectif consistait à donner de l'assistance à DBRT 7 pour la mise au point d'une spécification technique soutenant les besoins mineurs nécessaires à l'acquisition d'un nouveau détecteur de mines. Non seulement les spécifications techniques ont-elles été mises au point pour cette tâche spécifique mais encore les méthodologies ont été mises au point pour des besoins plus généraux tels que le déminage humanitaire avec la R & D interne ainsi que la participation à des organisations tels que le PIEE (Programme international d'essais et évaluations). De plus, TDG a participé directement à l'évaluation des détecteurs pour les FC et a recommandé le remplacement du détecteur existant. Le troisième objectif

consistait à mettre au point des capacités visant à discriminer les cibles du fouillis. La recherche sur la fusion et les capteurs de confirmation et capteurs d'images ont abouti à des améliorations concernant la discrimination des mines dans le fouillis et les travaux futurs continueront les améliorations dans ce domaine. On s'attendait à ce que les résultats de ce projet permettent aux Forces canadiennes d'acquérir un détecteur de mines manuel capable de mieux détecter les mines non métalliques et de réduire le taux des fausses alarmes avec plus de précision que le détecteur de mines actuellement en service. Le Projet qui s'est achevé le 31 mars 2005 s'est avéré être un succès.

Le commanditaire militaire du projet était DBRT-7, les ingénieurs militaires qui ont directement été chargés de déblayer les mines. Les autres parties intéressées qui ont soutenu le programme étaient Exploitation-Ingénierie J3 et Direction - Gestion de l'équipement d'appui au combat (D Gest EAC) qui sont responsables de la gestion du cycle de vie des détecteurs de mines manuels et des systèmes de détecteurs de mines montés sur véhicules ILDS. L'intérêt des FC est à double volets. D'abord, elles ont immédiatement besoin de conseils concernant le rendement et les déficiences des détecteurs de mines standards disponibles sur le marché et de teneur faible en métal ainsi que des pratiques exemplaires pour les évaluer. Ceci leur permettrait de savoir si les détecteurs internes peuvent remplir leurs fonctions dans un certain théâtre et sinon quel serait le meilleur détecteur disponible pour ce théâtre. À long terme, leur intérêt réside dans le fait qu'elles ont besoin d'un successeur éventuel au détecteur interne qui aurait un bon ou meilleur taux de détection qu'un détecteur classique de teneur faible en métal ayant un taux réduit de fausses alarmes. Ceci procurerait un passage plus rapide et plus sécuritaire à travers les zones minées et augmenterait ainsi la protection des forces et améliorerait leur mobilité. Ces besoins dictent un concept à capteurs multiples. Un tel détecteur de mines à capteurs multiples intéresse particulièrement le Centre canadien des technologies de déminage (CCTD) parce qu'il est évident qu'il diminuerait les coûts du déminage humanitaire par unité de surface de sol et améliorerait la sécurité du travail de déminage. À cause de son mandat, le CCTD était seulement en mesure de soutenir les aspects de la recherche directement reliés aux applications de déminage humanitaire. Les besoins en déminage humanitaire concernant un détecteur de mines à capteurs multiples sont quelque peu différents de ceux de l'armée. Il existait cependant un besoin commun en R & D qui était nécessaire pour la mise au point des détecteurs pour les deux applications et le CCTD a été enfin en mesure de commanditer le projet d'une valeur à peu près égale à deux fois celle du fonds du projet.

La détection des mines à capteurs multiples conduites dans ce projet englobait la recherche de pointe dans une variété de domaines scientifiques dont l'induction électromagnétique, l'imagerie infrarouge, le géoradar, l'acoustique, la physique nucléaire, l'imagerie par rayon X, la fusion des données et la robotique. Le Groupe de détection des menaces est considéré comme étant le leader en matière de recherche sur la détection de mines, tel que le prouve parmi d'autres choses, la longue liste des documents qui ont été publiés pendant la période du projet. Le groupe membre qui a présidé était le seul membre non américain de l'étude du RAND Science and Technology Policy Institute, parrainé par le Bureau des sciences et politique technologique de la Maison-Blanche pour mettre au point un plan sur la recherche future dans le domaine de la détection des mines humanitaire. Depuis 1996, quelques groupes membres ont coprésidé ou appartenu à un comité des programmes de la conférence annuelle de Optical Engineering Society (SPIE) sur la détection et les moyens de remédier aux problèmes des mines et des cibles de type mine et qui est considérée comme la première conférence dans le domaine de la recherche sur la détection des mines. D'autres membres ont fait partie du comité de la Conférence sur le Rayonnement pénétrant de la SPIE.

Le projet comportait 8 étapes dont 5 ont été complétées à la fin du projet. Un nouveau détecteur de mine a été sélectionné pour la flotte des FC et un scanner robotique pour la détection manuelle téléguidée a été produit. La détection de confirmation par activation à neutrons thermiques a été grandement améliorée pour les systèmes des 4 ILDS des FC. La faisabilité de la tomographie d'impédance pour détecter les mines à partir des zones de brisance (surf zone) a été établie. Une méthode pour simuler l'imagerie à rétrodiffusion de rayons X et aider ainsi à la mise au point des futurs détecteurs a été mise au point. Les 3 étapes restantes ont été partiellement complétées. L'évaluation des détecteurs manuels à capteurs multiples disponibles sur le marché (COTS) n'a pas été complétée parce que de tels systèmes ne sont devenus disponibles sur le marché que récemment. Deux d'entre eux ont été malgré tout obtenus presque à la fin du projet. Les essais et évaluations initiaux ont été conduits en Tailande, GB et Namibie. Le reste des travaux sera terminé sous le parrainage du CCTD. Deux détecteurs imageurs à base nucléaire pour réduire les fausses alarmes ont été complétés comme prototypes de laboratoire et ont produit des images pour les substituts des mines. Ils n'ont cependant pas été considérés comme assez évolués pour être testés en laboratoire. Les détecteurs imageurs seront améliorés lors de travaux qui seront poursuivis sans interruption avec le Projet 12rm.

Plus de 110 publications reliées au Projet 12rh ont été issues durant la période du projet. Elles contenaient 7 articles de source publiée, 20 rapports techniques évalués par les pairs de source publiée, 46 articles revus par un comité de lecture concernant les travaux de congrès, 4 brevets, 4 demandes de brevet ou rapports d'invention et 32 rapports d'entrepreneurs.

Les membres du groupe avaient été délégués dans un certain nombre de panels internationaux qui étudiaient les aspects de la détection des mines. Ceux-ci comprenaient le Groupe 1 d'études pour la recherche (RSG-1, détection des mines pour le contreminage) et le Groupe 3 (RSG-3, détection des mines à double usage) du Groupe spécial d'experts sur les techniques du génie de combat AC143, SCI-133 de l'OTAN (détection des mines hors itinéraire), SEN AG-8 du Programme de coopération technique (PCT) (détection de mines) et SA-14 (détection des mines terrestres) du Protocole d'entente (PE) entre l'Australie et le Canada. Ce dernier a abouti à la complétion des essais sur le détecteur manuel de métal qui ont partiellement soutenu la sélection et le remplacement de la flotte de détecteurs de mines des FC durant le projet WBE 12rh01. Le PCT a aussi permis de participer économiquement aux expériences de détection à distance et aéroportée des champs de mines (MUST 2000) en optimisant un essai du PCT déjà existant qui étudiait la détection aéroportée des véhicules camouflés. Un membre TDG a dirigé le Projet pilote international de coopération technique), un effort international ambitieux qui a effectué une évaluation extensive sur la pertinence d'un grand nombre de détecteurs de mines terrestres en déminage humanitaire. Ce projet a, à son tour, jeté les fondations du PIEE, un programme international continu qui évalue l'équipement de détection des mines, de protection et neutralisation humanitaires. Le Canada a joué un rôle principal dans le PIEE depuis la création de ce dernier.

Une partie de la recherche conduite durant le projet 12rh est poursuivie par de nouveaux projets. La recherche dans le domaine de la détection des fils-pièges optiques continuera avec le projet 12rl <<Imagerie optique des mines terrestres>> qui a débuté en avril 2004. Des travaux ultérieurs sur les détecteurs imageurs à neutrons et à rayons X sont effectués avec 12 rm <<Capteurs de confirmation>> qui ont débuté en avril 2005. La recherche EIT continue aussi avec 12 rm et un financement américain pour la détection de la zone de brisance est activement recherché. La recherche concernant TNA amélioré et l'activation à neutrons rapides ainsi que des sujets qui y sont reliés a été conduite sous l'égide d'un FIT de 3 ans appelé : <<Concept pour la détection neutronique des dispositifs explosifs de circonstance>> qui ont débuté en avril 2005. La recherche sur l'induction électromagnétique a changé d'orientation pour étudier les propriétés électromagnétiques des sols. Ceci est poursuivi seulement grâce au financement du CCTD qui jusqu'à présent alimentait les fonds du 12rh. On ne sait pas encore ce qu'il adviendra du sous-projet quand le CCTD prendra fin en mars 2007.

Acknowledgements

The authors would like to thank the other members of the Threat Detection Group, Kevin Russell, Wayne Sirovyak and Jack Toews, who have contributed significantly to the successful planning and execution of this project. We would also like to thank the Canadian Forces Engineers who were attached to the Threat Detection Group during the project. Master Gunner Bill MacLean, Major Mark Hache and Captain Dale Melville worked tirelessly on experiments and field trials, provided much needed contacts within the CF and forced us to keep our research relevant to the Canadian Forces. Last but certainly not the least, we thank the many contractors who have worked intimately with us in developing the ideas that have formed the body of the research and in seeing those ideas through.

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Table of contents

List of figures

List of tables

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1 Introduction

Project 12rh, "Advanced Hand-held Mine Detector", was started on 1 April 1995 as the next logical step in a long term research and development program on detection of unexploded ordnance (UXO) and landmines that had been ongoing since 1975. Since 1975, Defence R&D Canada – Suffield (DRDC Suffield) has been the lead centre responsible for all aspects of landmine detection research and development in Canada. Most of the military and humanitarian mine detection research has been conducted in-house at DRDC Suffield by the Threat Detection Group (TDG) of the Military Engineering Section (MES) and under contract to Canadian industry. On occasion, certain elements of the research have been assisted by two other DRDC centres, DRDC Valcartier and DRDC Ottawa. Prior research had focused on four main headings: remote minefield detection, close-in scanning landmine detection, confirmation detection and teleoperated systems. Results of this work had led to the start of the Improved Landmine Detection Project (ILDP) in 1994, which would in 2002 deliver to the Canadian Forces (CF) four teleoperated, vehicle-mounted multi-sensor landmine detectors for roads and tracks in rear areas and Operations Other Than War (OOTW). Research had also been ongoing on sensor technologies to replace or augment hand-held metal detectors (existing hand-held mine detectors) and on technologies to reduce false alarm rates by imaging or detecting the presence of explosives. By 1995, it had become clear to most researchers, driven in large part by TDG researchers, that a single sensor would not be able to achieve reliable detection of low metal landmines with low false alarm rates and that multiple sensors must be employed. Thus, the time seemed appropriate to consider studies aimed at the hand-held multi-sensor landmine detector.

The objectives of Project 12rh were to deliver a multi-sensor hand-held landmine detector concept demonstrator to the CF, to assist DLR 7 in development of a technical specification in support of minor requirements (MR) acquisition of a new mine detector and to develop a capability to discriminate targets from clutter. The expected outcome of the project was that the Canadian Forces would acquire a hand-held mine detector with better ability to detect nonmetallic mines and reduced false alarm rate, than the existing mine detector, which was based on metal detection technology. The Project successfully ended on 31 March 2005 with two commercial detector systems available for testing.

The military sponsor for the project was DLR-7, the Military Engineers, who are directly tasked with mine clearance. Other interested parties who provided support are J3 Engineering Operations and Directorate Combat Support Equipment Management (DCSEM), who are responsible for life cycle management of hand-held mine detectors and the Improved Landmine Detection System (ILDS) vehicle-mounted mine detector. The CF interest at the time was two-fold. First, they had an immediate need for replacement of the in-service Schiebel AN-19 low-metal mine detector fleet, which had a number of serious deficiencies. They needed advice on how to evaluate new commercial detectors and which model to select for their needs. Their long term interest lay in the need for an eventual successor to the replacement mine detector (ultimately a Minelab detector was chosen). Ideally what was wanted was a detector which would have as good or better a detection rate than that of a conventional low-metal detector, with a reduced false alarm rate. This would provide safer and faster passage through mined areas, thereby increasing force protection and improving mobility. As mentioned earlier, this requirement dictated a multi-sensor design. Such a multisensor mine detector would obviously also decrease humanitarian demining costs per unit area of land and improve demining safety and thus was of great interest to the Canadian Center for Mine Action Technologies (CCMAT). CCMAT was created in 1998 by the Government of Canada with the mission to carry out R&D of low cost, sustainable technologies for, among other things, landmine detection, as part of Canada's continuing leadership role in the global movement to eliminate anti-personnel landmines. It has been funded for nine years with CD$25 million from the Canadian Landmine Fund. Because of its mandate, CCMAT could only provide support to those aspects of the research that were directly related to humanitarian demining applications. Requirements for a multi-sensor mine detector for humanitarian demining are somewhat different from those for a detector for the military. However, there was a substantial common core of R&D necessary to develop detectors for both applications and in the end, CCMAT was able to provide sponsorship worth about twice that of the project funds.

Multi-sensor mine detection conducted under this project has involved leading edge research in a variety of scientific areas, including electromagnetic induction, infrared imaging, ground penetrating radar, acoustics, nuclear physics, X-ray imaging, data fusion and robotics. The Threat Detection Group is considered a leader in mine detection research. There are many examples to support this, but only a few will be given here. One group member chaired, and was the only non US member of the RAND Science and Technology Policy Institute study, sponsored by the White House Office of Science and Technology Policy, to develop a plan for future research on humanitarian mine detection [1]. Since 1996, some group members have co-chaired or been on the program committee of the Optical Engineering Society's (SPIE) annual conference on Detection and Remediation of Mines and Mine-like Targets, considered by most in the field to be the premier conference on mine detection research. Other members have been on the program committee of SPIE's Penetrating Radiation Conference. The technical merit of the project has been further confirmed by the over 110 related publications, including 67 peer-reviewed papers or technical reports and 4 patents, during the project period.

2 Approach

We did not want to duplicate research in a number of other countries that were developing multi-sensor mine detectors based on a metal detector/ground penetrating radar combination. Our aim was to look for technology combinations beyond the common choice, while advancing our knowledge of metal detectors and ground penetrating radar in the context of multi-sensor systems. In addition, it was necessary to study methods of integrating information from the different sensors in a multi-sensor system. This naturally led to the formulation of four Work Breakdown Elements (WBE). These are shown in the Project Plan Table (Fig. 1), taken from the CPME data base.

One goal of Sensor Selection and Assessment (12h01) was to study the primary sensors (electromagnetic induction or metal detectors, and ground penetrating radar) used in multi-sensor landmine detectors under development. A second goal was to develop the means of assessing their performance. It had three milestones:

1. New mine detector fleet selection for CF
2. Test and evaluation of Commercial Off-the-Shelf (COTS) multi-sensor hand-held detectors
3. X-ray backscatter imaging simulation

False Alarm Reduction (12rh02) was aimed at developing new technologies to reduce false alarm rates from the primary sensors on multi-sensor hand held landmine detectors under development. It had two milestones:

1. Delivery of prototype X-ray backscatter system
2. Delivery of neutron albedo imaging system prototype

Data Collection Techniques (12rh03) investigated ways of improving how data was collected from sensors and preprocessing of that data. It had two milestones:

1. Speed enhancement to Thermal Neutron Activation (TNA) sensor
2. Study of EIT for surf zone mines

Data Fusion and Imaging (12rh04) investigated how to fuse data from multiple sensors and how to obtain images from non imaging sensors. It had one milestone:

1. Delivery of Improved Scanning Arm

Funding and human resources are given in Fig. 2, which is the Project Summary Table taken from the CPME data base. Total funding over a ten year period was $1767k, or $176k per annum. This would have been hopelessly inadequate to maintain a viable program, if not for the additional CCMAT funds which amounted to $3800k from Fiscal Year (FY) 1998/1999 to the end of FY 2004/2005. This gave an average funding over the project period of about $550K per annum. Total FTEs for the 10 year period were 14.5, which yields only 1.5 FTE per annum. This would have been inadequate except for approximately 20 additional FTEs, leveraged from CCMAT. Further, there was a Military Engineer position that was filled at various times throughout the duration of the project that very roughly contributed 2-3 FTEs.

The deliverables of the project were a number of sensor systems, data fusion and data collection techniques, as listed in the above milestones, which together could be incorporated into a multi-sensor hand-held mine detector. A further deliverable was a copy of any available COTS multi-sensor mine detector which could be subjected to testing. Note that resources were inadequate to develop a Canadian multi-sensor detector, but that technologies developed under the project might be incorporated into a COTS detector at a later date.

Project Structure Definition for Project 12rh: Advanced Hand Held Mine Detection (was 12mf)

ject Code	12rh
Title	Advanced Hand Held Mine Detection (was 12mf)
Status	Active
Start Date	1-Apr-95
End Date	1-Apr-05
ect Leader	M Szymczak
ct Director	J Dick
t Manager	Y Das
No. WBEs	5

CPME Help
CPME Navigator
Project Dictionary
Macros-1
Macros-2

t Modified	16-May-05 @ 5:00:05 PM
odified by	DRDC

Project Objective(s):

	Last Modifie
Objective(s): To demonstrate a multi-sensor hand-held mine detector.	Col A on 12-Mar-04@1:53:1
Delivery Centres : DRDCSuffield / MES	Col B on 12-Mar-04@1:52:3

Work Breakdown Structure Definition:

WBE Code	Title	WBE Type	Status	Start Date	Initial End Date	Current End Date	WBE Leader	Telephone	Email	Notes	Last Modified
12rh_	12rh_ Unassigned WBE Resources	Gen	Approved	1-Apr-95	1-Apr-05	1-Apr-05	Y Das			Reserved for resources that are not yet assigned to a WBE. All resources for the current and	
12rh00	12rh00 Project Management	Gen	Approved	1-Apr-95	1-Apr-05	1-Apr-05	Y Das			Reserved for resources assigned to management of the project, or to	
12rh01	Sensor Selection And Assessment (was 12mf01)	AR	Approved	1-Apr-01	1-Apr-03	1-Apr-05	Y. Das			T&E of COTS multisensor postponed for lack of funds . Need U$130K for PSS-14 ; 65K for ERA unit.	Col C on 11-Feb-05@12:02:24 PM by ichifan
12rh02	False Alarm Reduction (was 12mf02)	AR	Approved	1-Apr-01	1-Jun-04	1-Jun-04	J. McFee			To migrate to 12rm as of 04/2005	Col L on 17-Jun-04@4:29:33 PM by DRDC
12rh03	Data Collection Techniques (was 12mf03)	AR	Approved	1-Apr-01	1-Oct-04	1-Oct-04	Y. Das			To migrate to 12rl 04/2005	Col L on 17-Jun-04@4:30:03 PM by DRDC
12rh04	Data Fusion And Imaging (was 12mf04)	AR	Approved	1-Apr-01	1-Oct-04	1-Oct-04	Y. Das			To migrate to 12rl 04/2005	Col L on 17-Jun-04@4:30:29 PM by DRDC

End-of-WBE-Data

Milestone Definition:

Milestone Description	Completion Date: Previous	Completion Date: Present	Status	% Completed	WBE	Last Modifie
New Mine Detector Fleet selection for CF	1-Apr-03	1-Apr-03	Completed	1	12rh01	Col A on 17-Jun-04@4:19:37 PM by DRDC
T&E of COTS multisensor handhelds	1-Apr-05	31-Mar-06	Partial Completion	50 - 59%	12rh01	Col J on 16-May-05@4:59:57 PM by DRDC
X-Ray backscatter imaging simluation	1-Apr-03	1-Apr-03	Completed	1	12rh01	Col A on 17-Jun-04@4:19:
Delivery of Improved Scanning Arm	1-Sep-02	1-Sep-02	Completed	1	12rh04	Col K on 17-Jun-04@4:31:
Delivery of Prototype X-Ray Backscatter System	1-Apr-05	31-Mar-06	Partial Completion	70-79%	12rh02	Col J on 16-May-05@5:00:
Delivery of Neutron Albedo Imaging System Prototype	1-Sep-03	31-Mar-06	Partial Completion	70-79%	12rh02	Col H on 16-May-05@4:59:
Speed Enhancement to TNA	31-Mar-03	31-Mar-03	Completed	1	12rh03	Col A on 17-Jun-04@4:20:
Study of EIT for surf zone mines	1-Apr-04	1-Apr-04	Completed	1	12rh03	Col A on 17-Jun-04@4:20:25 PM by DRDC

End-of-Milestones

Project Progress/A 17-Jun-04

Col C on 17-Jun-04@4:27:
Col A on 17-Jun-04@4:26:

1. Based on extensive trials a new fleet of mine detectors was selected for deployment by the CF. 2. Planned T&E of COTS multisensor handhelds postponed for lack of funds and lack of available detectors . NEEDED U$130K for US PSS-14 (HStAMIDS) system and

Table 1: *CPME Project Plan Table.*

Summary for Project 12rh: Advanced Hand Held Mine Detection (was 12mf)

oject Code	12rh
Title	Advanced Hand Held Mine Detection (was 12mf)
Status	Active
Start Date	1-Apr-95
End Date	1-Apr-05
ect Leader	M Szymczak
ct Director	J Dick
t Manager	Y Das
No. WBEs	5

CPME Help
CPME Navigator
Project Dictionary

Macros-1

Macros-2

st Modified	16-May-05 @ 5:00:05 PM
Modified by	DRDC

Project Summary for Business Plan/Service Level Agreement

Project: 12rh
Title: Advanced Hand Held Mine Detection (was 12mf)
Start Date: 1-Apr-95 ***End Date:*** 1-Apr-05 ***Status:*** Active
Delivery By DRDCSuffield / MES
Capabilitie: Primary Ops: Protect/Tactical ***Secondary*** Sustain/Tactical
Time Horiz I (0-5 yrs): 40% ***'I (6-10 yrs):*** 40% ***I (>10 yrs):*** 20%

Objective(s): To demonstrate a multi-sensor hand-held mine detector.

Project Summary	*Prev Years*	*FY04/05*	*FY05/06*	*FY06/07*	*FY07/08*	*Future Yrs*	*Totals*
FTEs	13.0	1.5	0.0	0.0	0.0	N/A	14.5
FTE Full Costs	$ 2,565.5	$ 323.6	$ -	$ -	$ -	N/A	$ 2,889.1
Contract/Local Funds	$ 984.0	$ 537.0	$ 0.8	$ -	$ -	$ -	$ 1,521.8
Other DND	$ -	$ -	$ -	$ -	$ -	$ -	$ -
External Funds	$ -	$ -	$ -	$ -	$ -	$ -	$ -
External In-Kind	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Offsets	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total	$ 3,549.5	$ 860.6	$ 0.8	$ -	$ -	$ -	$ 4,410.9

Milestones	**Previous**	**Present**	**Status**
New Mine Detector Fleet selection for CF	01-Apr-03	01-Apr-03	Completed
T&E of COTS multisensor handhelds	01-Apr-05	31-Mar-06	Partial Completion
X-Ray backscatter imaging simluation	01-Apr-03	01-Apr-03	Completed
Delivery of Improved Scanning Arm	01-Sep-02	01-Sep-02	Completed
Delivery of Prototype X-Ray Backscatter System	01-Apr-05	31-Mar-06	Partial Completion
Delivery of Neutron Albedo Imaging System Prototype	01-Sep-03	31-Mar-06	Partial Completion
Speed Enhancement to TNA	31-Mar-03	31-Mar-03	Completed
Study of EIT for surf zone mines	01-Apr-04	01-Apr-04	Completed

Table 2: *CPME Project Summary Table.*

3 Results and Discussion

3.1 Summary of WBE 12rh01 (Sensor Selection and Assessment)

There are presently only two COTS multi-sensor landmine detectors, the HSTAMIDS made by Cyterra, US and the Minehound made by ERA, UK, and at least one system (Japanese) under development. At the start of the project, only the HSTAMIDS was in development. All are essentially two sensor detectors, having an electromagnetic induction sensor (EMI or metal detector) and a ground penetrating radar (GPR). The purpose of this WBE was chiefly to study the primary sensors used in such multi-sensor landmine detectors and to develop means of assessing their performance. The assessment methodology could then be employed on the COTS sensors, if they became available before the project ended. Early in the Project, the CF approached us about helping them to select a replacement for the in-service Schiebel AN-19/2 low-metal mine detector fleet, which had a number of serious deficiencies. They needed advice on how to evaluate new commercial detectors and which model to select for their needs. This was seen as providing an opportunity to complete and exercise a methodology which was being developed for CCMAT on evaluation of metal detectors. The evaluation was a successfully completed milestone and, based on TDG recommendations, the CF selected the Minelab as its new in-service mine detector.

Due to development and production delays, commercial Off-the-Shelf (COTS) multi-sensor hand-held mine detectors only became available for foreign sales very near the end of the project. Thus the test and evaluation of such detectors was not completed by the end of the project. Further, both detectors, being prototypes, were very expensive and funds were not available within the project to buy them. Fortunately, because of CCMAT's strong interest in a multisensor handheld detector for demining, they provided the necessary funds. Two HSTAMIDS detectors and a Minehound were delivered near the end of FY 2004/2005. TDG personnel participated in initial trials and demonstrations of the detectors, sponsored by CCMAT in support of the International Test and Evaluation Program (ITEP), in Thailand, UK and Namibia. This milestone will be completed under CCMAT, with the priority to assess the detectors for humanitarian purposes.

To develop the means to be able to properly evaluate multi-sensor mine detectors, research was conducted on electromagnetic induction (metal detectors) and ground probing radar and passive infrared imaging, which was a serious contender for inclusion in multi-sensor hand-held detectors at the start of the project. Research was also conducted on optical tripwire detection, since rapid detection of tripwires would greatly enhance safety of a multi-sensor mine detector. See Annex A for further details. A small pilot study was done on simulation of X-ray backscatter imaging. It was successfully completed. Since it was found, by virtue of its speed, to be more appropriate to confirmation detectors, which are used for false alarm reduction, further work was done under 12rh02, where it is reported.

3.2 Summary of WBE 12rh02 (False Alarm Reduction)

This WBE was aimed at developing new technologies that could be added to a multi-sensor hand-held landmine detector to reduce false alarm rates from the primary sensors.

Sensors which are used to reduce false alarm rates are called confirmation sensors and are generally slower than the primary scanning sensors. To limit the scope of this WBE, only two image-based nuclear sensors were considered, an X-ray backscatter imager and neutron albedo or moderation imager. By the end of the project, breadboard prototypes of both instruments were completed and initial images were obtained. However, the imagers, the image collection time and the image quality were suboptimal and not ready for extensive laboratory testing. Thus these two milestones are listed as only partially completed, even though strictly speaking, prototypes were delivered on time.

See Annex B for further details.

3.3 Summary of WBE 12rh03 (Data Collection Techniques)

Both this WBE and WBE 12rh04 were originally envisioned as providing support to the major development project "Improved Landmine Detection Project (ILDP)". This $6M project, which would today be called a Technology Demonstrator Project (TDP), developed a prototype vehicle-mounted multi-sensor, teleoperated landmine detector for roads and tracks in peacekeeping, and eventually led to 4 units in service with the CF. It started in 1994 and ended in 1998 and used most of a division (about 50 technical people) for its completion. Thus for the first 3 years of the 12rh project, much of the effort was tied up in ILDP-related work. This WBE was aimed at improving how data were collected from sensors and preprocessing of that data. Much of the work was aimed at the ILDP Thermal Neutron Activation (TNA) sensor, since this was the least mature of all the sensors. The TNA was developed initially under ILDP, but this WBE developed hardware and software improvements to its signal processing chain. A completed milestone was a study of methods to reduce TNA dwell times by speeding up the electronics and identifying faster detectors.

A second area of investigation was the use of electrical impedance tomography to image nonmetallic mines. If successful, such a system would be much lighter and possibly faster than the TNA, allowing significant weight reduction in ILDP and improved data collection for the confirmation sensor. A sensor was built and evaluated. In the end, limitations to the technology prevented it from being used as a confirmation sensor on ILDP. However, it was thought that it might have a valid role for detection of mines in surf zone areas. The milestone of building the instrument and establishing its feasibility for surf zone mine detection was successfully completed.

See Annex C for further details.

3.4 Summary of WBE 12rh04 (Data Fusion and Imaging)

The goal of this WBE was to investigate how to fuse data from multiple sensors. At the project inception, work on this subject had been ongoing for a year under the ILDP major project. The work in progress had a short term goal of developing a data fusion methodology that was operationally acceptable, but of low enough technical risk to allow its incorporation into the ILDP system by project end (1998). It was determined that additional efforts were required both to support the immediate research necessary for ILDP, while looking at more advanced but higher technical risk methodologies for improved performance that might be used for mid-life versions of ILDP. Some funding for immediate improvements to and debugging of ILDS (the production version of ILDP) was provided to TDG by DCSEM.

A long term goal of TDG's threat detection research program is to develop a multi-sensor teleoperated vehicle-mounted landmine detector system, analogous to ILDP, but intended to replace the operator of hand-held detectors. Such a system would detect AP mines in the areas where ILDP could not go, while at the same time, removing the operator from harm. This Canadian Sensor Integration Concept (CANSIC) [2] would use data fusion principles similar to those of ILDP, but with smaller sensors suited for AP mines. It is sometimes desirable and necessary to include non imaging sensors in such a system. Often, non imaging sensors (e.g., EMI sensors) are much smaller and lighter than their imaging counterparts. This can lead to a reduction of platform size and power requirements. Some technologies (e.g., trace vapour detectors) are not amenable to forming images directly (so-called "point sensors"). To enable the use of non imaging sensors, an arm was needed which could semi-autonomously scan a sensor over uneven ground and simultaneously collect position-registered data from the sensor. In addition to enabling scanning of a point sensor in a programmable, repeatable fashion, the arm would enable non imaging sensors to form images and would allow accurate rescanning of regions. The latter, something that humans can do, but multi-sensor vehicle-mounted systems with fixed imaging arrays find difficult, can be very useful for reducing false alarm rates. This, then, was the motivation for development of the Articulated Robotic Scanner (ARS). One of the successfully achieved milestones was the delivery of an improved version of the ARS.

See Annex D for further details.

3.5 Success and Impact of 12rh

Out of the project's 8 milestones, 5 were completed by project end. A new mine detector was selected for the CF fleet. A robotic scanner for teleoperated "hand-held" detection was produced. The TNA confirmation detector for the CFs 4 ILDS systems was significantly improved. The feasibility of impedance tomography to detect surf zone mines was established. A method to simulate X-ray backscatter imaging and hence aid in development of future detectors, was developed. The remaining 3 milestones were partially completed. Testing of COTS multi-sensor hand-held landmine detectors was not completed because such systems became commercially available only very recently. Nevertheless, two were obtained very near the project end. Initial T&E was conducted in Thailand, UK and Namibia. The remainder of this work will be done under CCMAT sponsorship, but because of its mandate, the emphasis will be on assessing the detectors in a humanitarian role. Two nuclear-based imaging detectors for false alarm reduction were completed as breadboard prototypes and produced images of mine surrogates. However, they were not considered mature enough for extensive laboratory testing. The imagers will be improved in follow-on work under Project 12rm.

Over 110 publications related to Project 12rh were issued during the project period. These include 7 open literature papers, 20 peer-reviewed technical reports, 46 papers in refereed conference proceedings, 4 patents, 4 patent applications or reports of invention and 32 contractor reports (see bibliography at the end of the report).

To facilitate international collaboration and data exchange, group members were representatives in a number of international organizations which studied aspects of mine detection. These included NATO AC/143 Special Group of Experts on Combat Engineering Technology, Research Study Group 1 (SGE-CET RSG-1 - mine detection for countermine), NATO AC/143 SGE-CET RSG-3 (dual use mine detection), NATO SCI-133 (detection of off-route mines), TTCP SEN AG-8 (mine detection) and SA-14 (landmine detection) of the Australian/Canada MOU. The latter led to the completion of joint hand-held metal detector trials that partially supported the selection of the replacement for the CF mine detector fleet under WBE 12rh01. The TTCP also enabled participation at low cost in an international airborne standoff minefield detection experiment (MUST2000), by leveraging off an existing TTCP trial investigating airborne detection of camouflaged vehicles. A TDG member lead the IPPTC (International Pilot Project for Technical Cooperation), an ambitious multinational effort which carried out an extensive evaluation of a large number of landmine detectors for their suitability in humanitarian demining. This project, in turn, laid the foundation for ITEP (International Test and Evaluation Program), a continuing international program for testing of humanitarian mine detection, protection and neutralization equipment. Canada has played a leading role in ITEP since its inception.

4 Lessons Learned

The main lesson that the CF should take away from this project is that landmine detection is a very complex subject area. There is no short term solution, but R&D can provide incremental improvements to existing commercial and laboratory prototype detectors that will significantly enhance CF operational abilities. However, such work takes time and the CF must be patient. ILDS is an excellent example of this. It does not solve the complete mine detection problem, but does provide an operational solution for roads and tracks in rear areas during conflicts and in OOTW. Although ILDS took about 8 years to go from concept to fielded system, it is a product of long term R&D by TDG that dates back 15 years before the start of the ILDP project.

A corollary to this lesson is that DRDC must choose very carefully the topics for landmine detection research. This concept has been recognized for many years by TDG researchers and they have applied it to conduct research that is recognized worldwide for its excellence and innovation. The Canadian R&D budget for countermine and humanitarian landmine detection is small compared to other programs within DRDC and tiny compared to that of other G8 countries, with the possible exception of Italy. During the time period of Project 12rh, two Canadian countermine detection projects were underway simultaneously (the second related to standoff minefield detection), with a total annual budget of approximately CD$500K and about 3 FTEs per annum. Fortunately, because of common interests between the core R&D necessary for humanitarian and military applications, CCMAT was able to provide an additional ∼CD$600K per annum and 3 FTEs from Fiscal Year (FY) 1998/1999 to the end of FY 2004/2005. This is a minuscule amount compared to, for example, the annual US countermine detection R&D funding of many tens of millions of dollars and dozens of FTEs. Given the small resources and the hundreds of potential technologies to investigate, a plan has been developed over the years to select areas of research. The state-of-the-art in numerous technologies is continuously monitored and is regularly assessed in review papers(e.g. [3, 4]). Technologies and areas within technologies undergo a heavy triage process. The assessment criteria are detailed elsewhere [3], but essentially involve looking for gaps in the worldwide R&D effort which must be filled in order to solve the overall problem. Sometimes a different role for a technology is envisioned than was previously tried or a recent or possible improvement in a technology is identified which might make a previously unsuccessful method feasible. The technical expertise must exist within DRDC and CCMAT and, of course, it must fit within the tight budget constraints.

This means that high profile R&D, such as development of hand-held GPR and nuclear quadrupole resonance (NQR) detectors and construction of multi-sensor GPR/ EMI hand-held mine detectors cannot and probably should not be done by Canada. Such programs are already addressed by well-funded programs in the US, UK and other countries. Further, DRDC has limited expertise in these areas and the costs of performing acceptable R&D are very high - far beyond DRDC's budget. Instead, Canada should and does select peripheral areas of research that augment these high profile programs. Examples from project 12rh are confirmation technologies, such as TNA, nuclear imagers and electrical impedance tomography, to reduce false alarm rates. At the same time, DRDC maintains a watching brief on other technologies not actively under investigation, so they can provide scientific advice to the CF. This plan also allows us to trade research in our unique areas for information from other foreign programs and maintain world leadership in our areas of work.

The project expended its budget each year. This was rather easy since the initial project budget was inadequate to achieve any measure of success, and was further cut throughout the duration of the project. However, by leveraging from CCMAT funds, it was possible to complete the major objectives of the project. This raises an important issue. At present, full funding of CCMAT is expected to end in March 2006, with reduced funding for one more year. As has been mentioned, CCMAT provides more resources per annum than do the combined mine detection projects. The loss of resources will have a devastating impact on the program. Technologies that can be adapted to IED detection may be able to obtain additional funding through either ARP, PSTP or CRTI channels. Technologies more specific to mine detection will likely be unfunded. This could have a large negative impact on the ability to provide advice to the CF.

Out of the project's eight milestones, five were completed by project end and three milestones were partially completed. Of the latter three, two milestones involved construction of detectors, which were completed. However, the completed versions were not ready for laboratory testing and thus it was felt reasonable that the milestones be considered incomplete.

The main objectives of Project 12rh were to deliver a multi-sensor hand-held landmine detector concept demonstrator to the CF, to assist DLR 7 in development of a technical specification in support of minor requirements (MR) acquisition of a new mine detector and to develop a capability to discriminate targets from clutter. All three objectives were met. The first objective was met by the delivery of two COTS detectors at the end of FY 2004/2005. The second was met and exceeded when TDG assisted in the testing and recommended the replacement detector. The third was met by world-leading research and development in confirmation sensors, a field pioneered by TDG.

There have been a number of tangible benefits to the Canadian Forces from this project. First, under Project 12rh, TDG designed a test plan for replacement of the previously in-service hand-held mine detector and assisted in the testing of candidates. TDG then recommended the replacement detector, which is currently in service. Because of its world class expertise in metal detection, TDG continues to provide advice to the CF on conventional mine detector use. Second, DRDC obtained two different commercial multi-sensor (EMI/GPR) hand-held mine detectors that are ready to be tested. These may prove to be superior in performance to the in-service EMI mine detector, thereby reducing operator risk and speeding detection rates. The latter is particularly important in hasty breach operations. Third, TDG provides regular, valuable advice to the CF on methods of operation and improvements to the ILDS in-service multi-sensor teleoperated vehicle-mounted mine detector system, the only system of its kind in service in the world. This is possible because TDG led the design and construction of the prototype of ILDS, under major project ILDP, and has continued to do research under Project 12rh related to aspects of ILDS such as data fusion and false alarm reduction. Fourth, world class research in pioneering confirmation sensors will lead to sensors that will reduce false alarm rates in both hand-held and vehicle-mounted multi-sensor systems.

DRDC has also derived significant benefits from Project 12rh. The Threat Detection Group has maintained its world class expertise and reputation in landmine detection. Group personnel have had a significant impact on other foreign programs. The expertise of group members has also saved DRDC and CCMAT substantial amounts of money by allowing them to critically analyse dozens of research proposals from industry for mine detection R&D that seemed good on the surface but were not technically sound.

5 Conclusions

There were three objectives of Project 12rh and all three were met. The first objective was to deliver a multi-sensor hand-held landmine detector concept demonstrator to the CF. By the end of the project, two such commercial detectors had been delivered for testing.

The second objective was to assist DLR 7 in development of a technical specification in support of minor requirements (MR) acquisition of a new mine detector. Not only were technical specifications developed for this specific task, methodologies were developed for more general requirements, such as for humanitarian demining, through in-house R&D and participation in organizations such as ITEP. Further, TDG directly participated in the evaluation of detectors for the CF and recommended the replacement for the then in-service detector.

The third objective was to develop a capability to discriminate targets from clutter. Research on data fusion and confirmation and imaging sensors has already led to improvements in discrimination of mines from clutter and future work will continue the improvement.

6 Future Work

Some of the research conducted under 12rh will continue under new projects. Optical trip wire detection research will continue under project 12rl "Optical Imaging of Landmines" which started April 2004. Further work on neutron and X-ray imagers is being conducted under 12rm "Confirmation Sensors" which started April 2005. EIT research is also continuing under 12rm and US funding for surf zone detection is actively being sought. Research on advanced TNA, FNA and related topics is being conducted as part of a 3 year TIF titled "Concept for Neutronic Detection of Improvised Explosive Devices" which started April 2005. Research on EMI has shifted focus to a study of EM properties of soils. This is being followed up solely through CCMAT funding, which up to now had augmented 12rh funds. Of course, this means that the emphasis has to be on issues related to humanitarian demining. It is unclear what will become of this subproject when CCMAT ends March 2007.

Annex A: WBE 12rh01 (Sensor Selection and Assessment)

A.1 Electromagnetic induction

Since the mid 1970s, DRDC Suffield has extensively studied various aspects of metal detection using the principle of electromagnetic induction (EMI). This work has ranged from theoretical and experimental investigations to the design, development and testing of practical systems which have included both single sensors as well as arrays of metal detectors. Among many other accomplishments, this DRDC research pioneered methods of location, identification and classification of buried objects by analysing their electromagnetic induction signatures. This research continues. Some of this early work on object classification has been rediscovered, is now called electromagnetic induction spectroscopy, and is being further researched by several groups worldwide.

In recent decades, development of EMI landmine detectors has been driven primarily by private industry. This led DRDC Suffield to recognize the need for systematic scientific assessment of commercial-off-the-shelf detectors for their ability to meet the requirements of the military as well as of humanitarian demining organizations. As a complement to the in-house research, DRDC Suffield routinely procured commercial detectors to remain aware of the state-of-the-art, over the years developed an expertise and a testing methodology for hand-held metal detectors, and promoted the need for such systematic assessment. The testing addresses performance parameters such as detection sensitivity, electronics stability, susceptibility to moisture, mineralized soils and other environmental factors. This work has been crucial in providing the Canadian Forces with unbiased advice on their equipment selection and has provided information and a valuable service to the international demining community. DRDC Suffield teams have been called upon to assist in the testing and selection of landmine detectors by a number of demining organizations including the Cambodian Mine Action Centre (CMAC), the UN Mine Action Centre in Bosnia and the Mine Action Program in Afghanistan (MAPA). DRDC effort in this area has inspired, if not directly led to, a number of international activities. Notable among these are the IPPTC (International Pilot Project for Technical Cooperation) project and a CEN (European Standards Organisation) Workshop Agreement. The IPPTC project was an ambitious multinational effort which carried out an extensive evaluation of a large number of landmine detectors for their suitability in humanitarian demining. Under the CEN Workshop Agreement, international guidelines for testing of metal detectors used in humanitarian demining were developed.

In addition to providing a valuable service, DRDC work in test and evaluation uncovered new effects and revealed a lack of adequate understanding of certain aspects, the influence of electromagnetic properties of soils for example, on the operation of the metal detector, a technology widely considered to be mature. An important by-product of the work for CMAC was the discovery that even a very small amount of moisture collecting on the sensor head caused severe and potentially dangerous loss of sensitivity of a widely used detector. The cause of this effect was subsequently investigated and a remedy was recommended. Performing detector trials in different locations having a variety of soils reaffirmed the importance of soil electromagnetic properties on the performance of detectors. This finding has led to new Canadian as well as international research efforts currently being pursued. These include: (1) rigorous modeling and experimental verification of the effect of soil electromagnetic properties, magnetic viscosity in particular, on the response of metal detectors; (2) analysing soil properties and specifying instruments and protocols to measure them; (3) designing tests and soil test lanes for valid comparison of detector performance; and (4) the development of a database of relevant properties, with particular emphasis on magnetic properties, of soils found in landmine affected regions.

A.2 Optical tripwire detection

Military and civilian deminers at present use thin feeler rods to detect landmine tripwires by contact. These are unreliable and dangerous. There are currently no technologies available for standoff tripwire detection, which would reduce operator risk and stress and could improve efficiency. Such a detector could be attached to a hand-held landmine detector and look ahead of it (either in the scan direction of the landmine detector or the forward direction of the operator). A tripwire detector would also be useful for detection of landmine tripwires in a vehicle-mounted role, detection of off-route mines and improvised explosive devices (IEDs).

Itres Research, in collaboration with DRDC Suffield, has been conducting research on optical detection of tripwires since 1996. Funding has come from the Canadian Space Agency, Itres, DRDC Suffield (including Project 12rh) and CCMAT. During a proof of concept study, a spreadsheet model was developed to enable predictions of performance for various scenarios with a minimum of experimentation. A breadboard test bed was constructed and VIS, NIR and UV images and VNIR/SWIR spectra of trip wire samples and representative terrestrial/sky backgrounds for representative scenarios were acquired. Various segmentation, edge pixel detection and linear feature detection algorithms were investigated. Limited tests on the imagery showed that the better algorithms were readily able to detect military and improvised trip wires, even partially obscured ones. Detection was done off-line and probabilities of detection and false alarm rates were not determined for practical scenarios. Key findings were that there was no particular narrow band where detection was significantly enhanced over broad band detection and that it was very important to have as high a spatial resolution as possible.

Research was then directed to developing a proof-of-concept imager, initially for vehicle mounted role, where size and power constraints were not so stringent. The imager chosen was the Rockwell Scientific Procam-1. It was based on a 1936 $\times$ 1086 CMOS array of 5 μm pixels. The sensor was highly integrated and multiplexed. It had an embedded 12-bit digitization circuit and flexible addressing capabilities for windowing and sub imaging. The conventional C-mount lens included with the sensor provided adequate resolving power. Power consumption was 200 W. The sensor was connected to a dual 733 MHz Pentium III computer, with a digital acquisition card to handle data capture and analysis. The analysis software consisted of a Canny edge detection filter, a Hough transform for linear feature extraction and a peak search module. To assist rapid prototyping, the software ran in "quasi-real-time" in a high level language (IDL[1]). Approximately 3 s were required

[1]Research Systems, Boulder CO

to process one image frame, due to the slow computation speed of IDL and the slow data transfer caused by the interface with IDL. By coding the analysis software in C or C++, it should be straightforward to achieve true real-time operation. Preliminary tests of the imager took place in the outdoor MinePen at DRDC Suffield in January 2003. Taut, sagging and undulating tripwires were partially hidden, often nearly invisible to the naked eye, in a number types of local vegetation. Results, obtained in "quasi-real-time" showed that many of the wires were detected, although a significant number of false alarms also occurred. As expected, due to the nature of the present algorithm, sagging and undulating wires were difficult to detect.

Ongoing work is aimed at achieving real-time operation and then thoroughly characterizing performance of the breadboard instrument. Effort into developing algorithms for bent, sagging and undulating wires is being carried out and a recent three colour version of the sensor is being considered. Once performance is acceptable, the system will be miniaturized for hand-held use. The largest component at present is the computer. It will be reduced in size by the use of DSPs and application-specific integrated circuits (ASICs). A research group at Mannheim University developed a prototype of such an ASIC for the Hough transform a few years ago and it is hoped that this will become more widely available in the near future.

A.3 Passive infrared detection

An infrared (IR) imager, often called a "FLIR", is a commonly proposed component of multi-sensor landmine detector systems. DRDC Suffield, in support of ILDP and with some image processing support from DRDC Valcartier, began studying passive thermal imaging of buried simulant mines in 1994. Consistent with the research of others, variations of image contrast as a function of many parameters, such as time of day, depth of burial and weather conditions, were observed and probabilities of detection of mines and false alarm rates were seen to be highly variable with time of day, season and environmental factors. Methods of improving reliability and, more importantly, being able to predict performance of IR imaging, were investigated. Research on automatic image enhancement and dynamic range compression of the infrared imagery was conducted and applied to ILDP. Methods of monitoring soil subsurface temperature profiles to reliably predict IR detection performance before commencing a mission were investigated. Such *a priori* knowledge allows the operator to ignore the IR detector if necessary or to weight the information appropriately compared to the other detectors. Recent studies show that such a method is feasible in practice and buried probes can predict IR camera performance several kilometers away. In 1998 US GSTAMIDS trials, in which ILDP competed against 5 US vehicle-mounted landmine detectors, Canada used the buried probe method and was the only team which had prior information on the optimal time to use its IR camera. This was partly responsible for the superior trial results of ILDP.

However, military operators would prefer not to have the logistic burden imposed by having to bury sensors prior to conducting a detection exercise. Thus present research is aimed at acquiring simple models that can predict IR performance based on readily available meteorological information. To assist in this goal, preparations have been underway for some time to conduct a long-term experiment to obtain infrared images of a controlled area of ground, packed to simulate a secondary road, in which mines are buried. Broad band images in the mid range (MWIR) and thermal (TIR) infrared will be obtained from the moment the mines are buried, at regular, short time intervals around the clock for at least a year. Simultaneous measurements of soil thermal gradients, landmine thermal gradients, meteorological properties, solar flux, down-welling radiation and soil moisture will be made. The data will be used to study the "aging" process of mines in the soil and to develop performance prediction models that do not require in-ground sensors. It will also be made available to the demining community and it will be used to test a number of proposed methods of enhancing infrared imaging for landmine detection. The planned start date is autumn 2005.

A.4 Hand-held GPR landmine detector

Every nation conducting R&D in landmine detection has an active program in ground penetrating radar (GPR). Such research is mainly aimed at developing stand-alone or integrated multi-sensor systems meant for deployment. DRDC Suffield has conducted GPR research in the past, looking at step frequency radar, the feasibility of airborne radar and microwave radiometry and the commercial vehicle-mounted Elta radar used in the ILDP system. More recently DRDC Suffield has investigated enhancements to the Elta radar and has conducted soil measurement studies. All this previous work has emphasized airborne or vehicle applications for the detection of large antitank mines.

CCMAT assessment of current GPR technology indicates that although GPR is quite successful in detecting large anti-tank mines, even after years of development, its capabilities fall far short of reliably detecting small plastic anti-personnel mines under conditions relevant to humanitarian demining. Canada does not have a program in hand-held GPR development and instead of opting to initiate a research program to develop a GPR system, it was decided to carry out an experimental and analytical feasibility study. This study, conducted by Sensors and Software of Toronto, investigated, through systematic measurements with precisely known spatial position of the sensor and careful analysis, the limits imposed by a number of real-world variables on the ability of a GPR to detect antipersonnel mines. Variables studied included antenna height over ground, surface roughness, soil type including magnetic soil, soil moisture content, landmine type and its metal content. The study produced recommendations on the method of operation, spatial accuracy and real-time data processing that would be needed to improve detection of AP mines using GPR technology. A prototype system incorporating the ability to collect spatially registered GPR data was produced to allow in-situ data collection in the field.

Annex B: WBE 12rh02 (False Alarm Reduction)

B.1 Neutron Moderation Imaging

Research in neutron moderation detection of landmines has been conducted since the early 1950s, mainly for the US Army. A number of countries, including the US, Netherlands and South Africa continue to do research on the subject. A number of weak isotopic sources and accelerator sources have been used with a variety of non-imaging detectors. The technique has not been very successful to date. Natural variations in hydrogen content in the soil, chiefly due to water, surface irregularities and detector height uncertainty, produce enough false alarms to make the method impractical for ground moisture contents in excess of 10%.

One method of reducing false alarms is to image the neutrons coming from the ground. Although this has been proposed previously, to date it has not been tried. DRDC Suffield, DRDC Ottawa and BTI initiated a project to develop a landmine detector based on neutron moderation imaging. Neutron detection technologies were reviewed and the most appropriate for the problem was selected. A conceptual design of the neutron imager was formulated. The design consisted of three main components; a novel thermal neutron imaging system, based on a neutron-sensitive scintillator screen and optical fiber position readout; a unique Cf sheet source to uniformly irradiate the ground under the entire imaging system and software for data collection and image enhancement. Realistic Monte Carlo simulations were then performed for various soil types, moisture contents, ground height and sensor height variations and different types of explosives and other materials. The simulations revealed that image quality could be good enough to significantly improve detector performance and reduce false alarm rates compared to non-imaging albedo detection, particularly in moist soils and where surface irregularities exist.

Based on the simulation results, design and fabrication of a prototype detector was started in autumn 2000. The imager is complete and initial images obtained (to approximate the weak uniform sheet source, a point neutron source was used for a longer imaging time at some distance from the image plane). The sheet source is now under development and is expected to be installed by late 2005 or early 2006. Detailed characterization of the detector will occur at that time. Plans are ongoing to improve the detector by use of advanced scintillator materials or neutron-sensitive microchannel plate technologies and by improvements to the readout system.

B.2 X-ray backscatter imaging

X-ray backscatter is a subset of photon backscatter, which involves irradiating a target area with source photons (X-ray or gamma) and detecting the return photon flux. Characterization of the return spectrum through energy or spatial density, or temporal distributions, can then be used to distinguish material distributions in the instrument's field of view (FOV). Variations in the properties of the soil matrix, such as those caused by the presence of a landmine, change the absorption and scattering probabilities and affect the return photon flux.

US researchers have in recent years developed a vehicle-mounted system, Lateral Migration X-ray Tomography, which uses information from singly and multiply scattered photons to image buried landmines. A focused beam scans over the target area in order to render a spatially registered image. However, beam control requires additional equipment, which has not yet been presented in a form that can be used in a hand-held system. DRDC Suffield's goal is to develop a hand-held X-ray backscatter imaging detector that will provide sufficient speed, contrast and spatial resolution to detect AP landmines and Improvised Explosive Devices (IEDs). Present constraints dictate a detector that can be fielded on a small robotic platform. In order to achieve this, research has focused on imaging methods that avoid tight collimation and instead bathe the whole FOV in source photons. One such approach is known as coded aperture imaging.

Coded aperture imaging has been used by the observational gamma astronomy community for a number of years. Recent advances in the field of medical nuclear imaging have allowed for the application of the technique to a backscatter scenario. Advances in X-ray detection, driven by medical requirements, are continually being made, and detectors are now being produced that are faster, cheaper and lighter than those only a decade ago. Consequently, a coded aperture hand-held imaging system has only recently become a possibility.

An ongoing collaboration with researchers at the University of California, San Diego (UCSD) is developing a proof-of-principle IED imaging system, built around the UCSD developed HEXIS detector and DRDC Suffield algorithms. This system is seen as a stepping stone toward the development of hand-held X-ray backscatter imager for landmine detection. A laboratory breadboard prototype has been used to image AP mines, shallowly buried in soil, as well as hidden small cubes of materials of varying atomic number and density in an IED geometry. Further, the variation in response with X-ray energy differs for different materials, allowing the possibility of material discrimination. The present breadboard detector hardware and software take many minutes to an hour or more to form a high quality image, although an IED may be marginally detectable in as little as 1.5 minutes. On-going and future work is aimed at completing a prototype detector that can be used to obtain images in the field and to decrease data collection and analysis times to allow near real-time detection of both mines and IEDs.

Annex C: WBE 12rh03 (Data Collection Techniques)

C.1 Thermal neutron activation (TNA)

Whereas most of the detectors on ILDP were commercially available, the TNA detector was conceived, designed and built specifically for the project by DRDC Suffield, DRDC Ottawa, Bubble Technology Industries (BTI, Chalk River, Canada) and SAIC Canada (Ottawa). The prototype TNA detector used a 100 μg ^{252}Cf neutron source surrounded by four 7.62 cm NaI(Tl) detectors. Extensive radiation transport modeling, careful selection of specialized shielding materials and development of high rate, fast pulse processing electronics were employed in the design. In less than one minute, the TNA could confirm the presence of all surface-laid or shallowly buried anti-tank mines. In less than five minutes, it could confirm the presence of anti-tank mines buried to a depth of 20 cm and anti-personnel mines with more than 100 g of nitrogen. Although intended as a prototype laboratory system, the original model of the TNA performed well in extremes of heat, cold and moisture both as a part of ILDP and in independent stand-alone tests in Canada and the 1998 US GSTAMIDS trials. The development team from DRDC Suffield, DRDC Ottawa, BTI and SAIC Canada won the 2000 J.S.Hewitt achievement award from the Canadian Nuclear Society for the TNA.

Four units of a production version of the TNA are now in service on the Canadian Forces four ILDS (production version of ILDP) vehicle-mounted teleoperated multi-sensor landmine detection systems. The production version is rugged and user-friendly with improved radiation safety features for source handling. It employs new signal processing electronics, one-third the size of that of the prototype, that dramatically reduce temperature-related long term drifts and instabilities, can handle much higher input count rates and are much easier to use. Tests have shown that the electronics functioned well, detecting nitrogen with neutron source strengths of up to 3.5 times that of the prototype's fresh ^{252}Cf source. The electronics also has the capability to accommodate a neutron generator. Two Peltier heater/coolers are included to keep the internal temperature stable over a wide range of ambient temperatures.

A next generation TNA sensor prototype has been under development for a few years by BTI, DRDC Suffield and DRDC Ottawa for possible ILDS mid-life upgrade. It can use either an isotopic source or a neutron generator and, in preliminary experiments, has better detection performance compared to the first prototype. A newly designed sensor head, which houses the neutron source, detectors and shielding, has six NaI(Tl) detectors instead of the previous four, arranged to significantly reduce the undesirable variation in the azimuthal response of the first prototype. Sensitivity to nitrogen targets is improved through novel choice and configuration of shielding, moderating and neutron multiplication materials. The neutron source is incorporated in a central shielded core which can be easily removed from the main shield, allowing interchange of ^{252}Cf or accelerator sources. This flexibility leads to a slightly larger head. Studies using sophisticated radiation transport codes and Van de Graaff accelerator experiments determined the optimum pulse width, repetition rate and other operating parameters necessary for an accelerator-based neutron generator. This led to the development of a specially packaged DT neutron generator, which can produce a neutron flux similar to the first prototype's fresh ^{252}Cf source under conservative operating conditions. The studies also showed that, with judicious selection of detection timing and shielding, an accelerator-based source could achieve the same, and possibly significantly greater, performance compared to the prototype system. Construction of the second generation TNA detector was completed in spring 2000. Initial testing verified the calculations from the design stage and showed that the neutron generator TNA out-performed the isotopic TNA in all tested cases, particularly where the landmine was deeply buried or when the source was not directly over the explosive. Improvements to the scintillator resolution have been made and improvements to calibration, stabilization, detection algorithms and automation are ongoing.

Ongoing research is examining emerging, short lifetime scintillator materials that can improve sensitivity to nitrogen by reducing pulse pileup. Development of a much more user friendly DT generator is underway. Following the completion of the improvements to the detector, detailed testing will be done. Investigations are also ongoing to determine feasibility of combining TNA with a fast neutron analysis to improve the response to explosives. The initial research was aimed at landmine detection, but present work, which will continue under the TIF 12rm03 titled "Concept for Neutronic Detection of Improvised Explosive Devices", will examine the suitability of TNA/FNA for IED detection.

C.2 Electrical impedance tomography

In electrical impedance tomography (EIT), electrical potentials are measured at grid points on the ground surface, for a number of current injection (excitation) sites. This ensemble of surface potential measurements is then used to solve the associated electromagnetic inverse problem to estimate the subsurface conductivity distribution, which could have caused the measured potentials. EIT has been attempted with some success for geophysical and biomedical imaging. Between 1979 and 1989, DRDC Suffield directed Quantic Electroscan to investigate EIT for the detection of buried unexploded ordnance (UXO) and landmines. This work showed some potential for imaging buried objects whose conductivity contrasted with the surrounding medium. At that time, a number of serious theoretical and practical problems were not overcome. The research effort failed to reliably reconstruct accurate 3D volume conductivity images of ordnance from single sided (top surface) voltage measurements. Images were poor or convergence failed due to the ill-conditioned nature of the problem.

In landmine detection the "quasi-two dimensional" geometry and lower conductivity contrast improve the conditioning. This makes it potentially useful as a low cost confirmation detector. EIT works best in moist, electrically conductive soils, such as marsh, beach or surf zone. These are scenarios where many other types of detectors perform poorly. This may make EIT a good complementary system. A joint General Dynamics Canada/DRDC Suffield project was started in 1998 to develop a field prototype EIT apparatus that was rugged enough to ensure that the detector performance could be evaluated under realistic environmental conditions.

Laboratory tests demonstrated that it is possible to reliably reconstruct conductivity perturbations due to a shallow, buried mine-like object, in a variety of soils, at realistic depths. The results indicated reliable detection down to depths of the order of 1 - 1.5 electrode spacing ($\sim$14 - 21 cm for a 64 electrode, 1 m $\times$ 1 m array) in a variety of soils (black earth, clay and sand). Reliable information on conductivity perturbations on the scale of the electrode spacing (in width and depth) were achievable. Field experiments were conducted at DRDC Suffield in autumn 1999. The instrument proved to be rugged and excellent images of mines were obtained in a variety of soils. There were, however, problems with electrical contact in very dry, packed soils and excessive insertion pressure was sometimes required for reliable electrode contact. Further, the simple, linear reconstruction algorithm occasionally performed poorly, which may have been due to the layered soil or possibly normalization problems.

Ongoing research is examining the use of more sophisticated algorithms that can handle general media, including layered and very inhomogeneous media. The chief drawback to EIT is the logistics of inserting probes in the ground in proximity to a mine, but in special cases such as landmine detection in swamps, bogs, and the surf zone or verification of landmine clearance berms, the method may be better than other techniques and may be made more acceptable by teleoperation. Thus ongoing and future research is examining EIT detection of landmines in underwater environments.

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Annex D: WBE 12rh04 (Data Fusion and Imaging)

D.1 Improved Landmine Detector Project (ILDP)

The Improved Landmine Detector Project (ILDP) was initiated in autumn 1994 to develop a prototype, teleoperated, vehicle-mounted landmine detector for low metal content and nonmetallic mines to meet the Canadian requirements for rear area mine clearance in combat situations and peacekeeping on roads and tracks. The relatively relaxed requirements, such as low speed and reduced detectability of completely nonmetallic mines, greatly increased the likelihood of success. The ILDP system consisted of a unique teleoperated vehicle carrying a forward looking infrared imager, a 3 m wide down-looking highly sensitive electromagnetic induction detector and a 3 m wide down-looking ground probing radar, which all scanned the ground in front of the vehicle. This scanning sensor information was then combined using a suite of navigation sensors and custom algorithms. Information about suspected targets was then passed back to a thermal neutron analysis (TNA) detector at the rear of the vehicle, for subsequent target confirmation. A key element to the success of the system was the combination of sensor information, which required coordinated communication between the sensors and navigation system and well designed sensor co-registration, spatial correspondence and data fusion methodologies. The advanced development model was completed in October 1997. In US government tests (GSTAMIDS, summer 1998), the ILDP advanced development model (ADM) placed first or second out of five competitors on every test. Further, ILDP was and still is the only such system with a confirmation detector (TNA) which could lower the false alarm rate, by at least an order of magnitude, to an operationally useful level.[2] ILDP was conceived, designed and built by DRDC. The IP from ILDP was transferred to General Dynamics Canada (GDC), who incorporated it into the now commercially available ILDS. DRDC Suffield TDG personnel remain as technical consultants to GDC. A follow-on project with GDC was initiated in 1999 to build four production ILDS units for the Canadian Forces. The first unit was delivered in April 2002 and remaining three were delivered by Spring 2003. ILDP is the first multi-sensor, teleoperated, vehicle-mounted landmine detection system in production and the only one fielded by a military. Current and future work is aimed at improvements for mid-life upgrade of ILDS. It includes improvements to the data fusion and improved and novel sensors.

D.2 Articulated Robotic Scanner (ARS)

Vehicle-mounted landmine detector systems employ an array of sensor elements to achieve a required detection swath (typically 2 - 4 m wide). Some systems employ more than one type of sensor technology. These systems, while being very useful, are expensive, complex and often are not flexible. A human operator, on the other hand, sweeps a landmine detector from side to side while moving forward to cover ground. The operator can follow the ground profile with the detector head close to the ground without hitting the ground or any objects on it. He/she can also vary the width of sweep to suit a particular situation, and is usually

[2] The TNA could not be used in the US trials, largely because of mine lane time constraints imposed by the trial organizers and the fact that many of the mines had no explosives.

not limited by terrain. DRDC Suffield has developed a concept for a system that will have the flexibility of a manual system and the rapid and safer mechanized scanning of the vehicle-mounted systems but at a reduced cost and complexity. Engineering Services Inc. (ESI, Toronto, Canada), under contract to DRDC Suffield, developed a prototype articulated robotic device capable of automatically moving mine detection sensor(s) over natural ground surfaces including roads and tracks in a manner similar to a human operator. The system could also easily be used to place a confirmatory point sensor at a specific location if needed. A proof-of-concept prototype, which incorporated only a metal detector for a landmine sensor, implemented ground following by using a laser range finder and ultrasonic sensors. A grey-level plot of the metal detector output as a function of spatial position of the detector head was presented to the operator. This first prototype, completed in autumn 1998, demonstrated the automatic sweeping of a mine detector over relatively flat natural terrain including those covered with grass up to 15 cm tall. It could also work over smoothly undulating terrain, but it could not negotiate sharp changes in terrain and had difficulty avoiding certain obstacles. As well, standing water caused the Laser Range Finder System (LRF) to produce false readings and caused the detector head to strike the ground.

A follow-on contract, started in spring 1999, developed and integrated more sophisticated and robust terrain sensing techniques and control strategy so that the system could be used to scan a wider variety of practical terrain. The work was completed in fall 2002. Because of the high robotics content in the subproject, ARS was handed over to the Autonomous Intelligent Systems Section (AISS) for integration on a DRDC Suffield teleoperated platform and further development.

References

[1] J.MacDonald, J.R.Lockwood, J.E.McFee, T.Altschuler, T.Broach, L.Carin, R.Harmon, C.Rappaport, W.Scott, and R.Weaver (2003), Alternatives for Landmine Detection, (Technical Report MR-1608-OSTP (ISBN 0-8330-3301-8)), RAND Science and Technology Policy Institute for White House Office of Science and Technology Policy (OSTP).

[2] A.A.Faust, J.E.McFee, R.Chesney, Y.Das, and K.L.Russell (2002), Canadian Sensor Integration Concept - The Way Ahead for multi-sensor anti-personnel landmine detection (U), (Technical Memorandum 2002-110), Defence R&D Canada – Suffield, Medicine Hat, AB, Canada. UNCLASSIFIED.

[3] J.E.McFee and Y.Das (1999), A research and development plan for land mine detection technologies for the Canadian Center for Mine Action Technologies (CCMAT) (U), (DRES Technical Report 1999-022), Defence Research Establishment Suffield, Medicine Hat, AB, Canada. UNCLASSIFIED.

[4] A.Carruthers, J.E.McFee, D.Bergeron, Y.Das, R.Chesney, and K.L.Russell (1999), Scoping study for humanitarian demining technologies (U), (DRES Technical Report 1999-121), Defence Research Establishment Suffield, Medicine Hat, AB, Canada. UNCLASSIFIED.

[5] J.E.McFee, R.Ellingson, J.Elliott, and Y.Das (1996), A magnetometer system to estimate location and size of long horizontal ferrous rods, *IEEE Transactions on Instrumentation and Measurement*, 45, 153–158.

[6] A.R.Carruthers and J.E.McFee (1996), Landmine detection - an old problem requiring new solutions, *Canadian Defence Quarterly*, 25(4), 16–18.

[7] T.Cousins, T.A.Jones, J.R.Brisson, J.E.McFee, T.J.Jamieson, E.J.Waller, F.J.LeMay, H.Ing, E.T.H.Clifford, and B.Selkirk (1998), The development of a thermal neutron activation (TNA) system as a confirmatory nonmetallic land mine detector, *Journal of Radioanalytical and Nuclear Chemistry*, 235, 53–58.

[8] E.T.H.Clifford, H.Ing, J.E.McFee, H.R.Andrews, and T.Cousins (2000), Second generation thermal neutron activation sensor for confirmatory landmine detection, *Transactions of the American Nuclear Society*, 82, 101–102.

[9] T.Cousins, T.A.Jones, J.R.Brisson, J.E.McFee, T.J.Jamieson, E.J.Waller, F.J.LeMay, H.Ing, E.T.H.Clifford, and B.Selkirk (2000), Using thermal neutron activation to detect non-metallic landmines, *Canadian Nuclear Society Bulletin*, 21(2), 40–44.

[10] J.E.McFee, H.R.Andrews, E.T.H.Clifford, A.A.Faust, H.Ing, T.Cousins, and D.Haslip (2003), The feasibility of neutron moderation imaging for land mine detection, *Subsurface Sensing Technologies and Applications*, 4(3), 209–240.

[11] T.J.Katsube, G.M.Lecheminant, J.B.Percival, N.Scromeda, D.Walker, and Y.Das (1995), Petrophysical Testing of Limestone Samples from Former Yugoslavia, Current Research Series, Geological Survey of Canada.

[12] Y.Das, J.D.Toews, D.Rutkay, and J.E.McFee (1996), Effect of Moisture on Canadian Forces AN19/2 Mine Detector (U), (Technical Memorandum 1484), Defence Research Establishment Suffield. UNCLASSIFIED.

[13] J.-R.Simard (1997), Theoretical and Experimental Characterizations of the IR Technology for the Detection of Low-metal and Nonmetallic Buried Landmines (U), (Technical Report DREV-R-9615), Defence Research Establishment Valcartier. UNCLASSIFIED.

[14] K.L.Russell (1998), Electronic Marking Used by the D6300 Project and a Proposal for Real-Time Electronic Marking for the US GSTAMIDS ATD (U), (Technical Memorandum 1512), Defence Research Establishment Suffield. UNCLASSIFIED.

[15] Y.Das, J.Toews, K.L.Russell, and S.Lewis (2000), Results of In-Air Testing of Metal Detectors (U), (Technical Report 2000-185), Defence R&D Canada – Suffield, Medicine Hat, AB, Canada. UNCLASSIFIED.

[16] Y.Das and J.D.Toews (2001), A Plan for In-Air Testing of Metal Detectors (U), (Technical Memorandum 2000-184), Defence R&D Canada – Suffield, Medicine Hat, AB, Canada. UNCLASSIFIED.

[17] M.Hache (2001), D6300 Improved Landmine Detection Project Trial Report (U), (Technical Report 2001-068), Defence R&D Canada – Suffield, Medicine Hat, AB, Canada. UNCLASSIFIED.

[18] Y.Das (2003), Electromagnetic Induction, Number MR-1608-OSTP (ISBN 0-8330-3301-8), Ch. Appendix A, RAND Science and Technology Policy Institute. Invited Paper.

[19] J.E.McFee (2003), Neutron Methods for Landmine Detection, Number MR-1608-OSTP (ISBN 0-8330-3301-8), Ch. Appendix N, RAND Science and Technology Policy Institute. Invited Paper.

[20] K.L.Russell (2003), Contact Methods, Number MR-1608-OSTP (ISBN 0-8330-3301-8), Ch. Appendix W, RAND Science and Technology Policy Institute. Invited Paper.

[21] J.D.Toews and W.Sirovyak (2003), Metal Detector Trial - Colombia. Results from 2002 (U), (Technical Memorandum 2003-099), Defence R&D Canada – Suffield, Medicine Hat, AB, Canada. UNCLASSIFIED.

[22] A.A.Faust (2003), Applications of X-ray Backscatter Radiation for the Detection of Explosive Devices (U), (Technical Report 2003-163), Defence R&D Canada – Suffield, Medicine Hat, AB, Canada. UNCLASSIFIED.

[23] NATO AC/243 - RSG1 Panel (C.J.Lowe, Editor) (1997), Remote detection of minefields and close-in detection of mines (U), (Technical Report AC/243(CET)TR/1), NATO Defence Research Group AC/243 Special Group of Experts on Combat Engineering Technologies RSG1, Brussells, Belgium. NATO RESTRICTED.

[24] Y.Das, J.T.Dean, D.Lewis, J.H.J.Roosenboom, and G.Zahaczewsky (Editors) (2001), Final Report of the International Pilot Project on Technology Co-operation (IPPTC) for the Evaluation of Metal/Mine Detectors, (Technical Report EUR 19719 EN), European Commission, Joint Research Centre, Ispra, Italy. Published on behalf of the participants.

[25] J.-R.Simard (1995), 3-D imaging of minelike targets at 10.6 microns using an active range imager, In A.C.Dubey, I.Cindrich, J.M.Ralston, and K.Rigano, (Eds.), *Detection Technologies for Mines and Mine-like Targets*, Vol. 2496 of *Proceedings of SPIE*, pp. 168–179.

[26] J.E.McFee and Y.Das (1995), Location and identification of compact metallic objects by magnetics and electromagnetic induction, In *Proceedings of the Environmental and Engineering Geophysical Society SAGEEP 95 Conference on Application of Geophysics to Engineering and Environmental Problems.*

[27] J.-R.Simard (1996), Improved Landmine Detection Capability (ILDC): Systematic approach to the detection of buried mines using passive IR imaging, In A.C.Dubey, R.L.Barnard, C.J.Lowe, and J.E.McFee, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets*, Vol. 2765, pp. 489–501.

[28] J.E.McFee and A.Carruthers (1996), A multisensor mine detector for peacekeeping - Improved Landmine Detector Concept (ILDC), In A.C.Dubey, R.L.Barnard, C.J.Lowe, and J.E.McFee, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets*, Vol. 2765, pp. 233–248. Invited Paper.

[29] J.E.McFee, T.Cousins, T.Jones, J.R.Brisson, T.Jamieson, E.Waller, F.LeMay, H.Ing, E.Clifford, and B.Selkirk (1998), A thermal neutron activation system for confirmatory non-metallic land mine detection, In A.C.Dubey, J.F.Harvey, and J.T.Broach, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets III*, Vol. 3392, pp. 553–564.

[30] A.C.Dubey, R.L.Barnard, C.J.Lowe, and J.E.McFee, (Eds.) (1996), SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets, Vol. 2765, The International Society for Optical Engineering, Bellingham, WA, USA.

[31] B.M.Cain and T.V.Meidinger (1996), The Improved Landmine Detection System, In *The Detection of Abandoned Landmines: A Humanitarian Imperative Seeking a Technical Solution*, Vol. Publication Number 431, pp. 188–192, EICC, Edinburgh, UK.

[32] K.L.Russell, J.E.McFee, and W.Sirovyak (1997), Remote performance prediction for infrared imaging of buried mines, In A.C.Dubey and R.L.Barnard, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets II*, Vol. 3079, pp. 762–769.

[33] J.E.McFee, V.Aitken, R.Chesney, Y.Das, and K.L.Russell (1998), A multisensor, vehicle-mounted, teleoperated mine detector with data fusion, In A.C.Dubey, J.F.Harvey, and J.T.Broach, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets III*, Vol. 3392, pp. 1082–1093.

[34] Y.Das and J.Toews (1998), Issues in performance evaluation of metal detectors, In *Proc. UXO/Countermine Forum 1998*, pp. 17–28.

[35] K.L.Russell, Y.Das, J.E.McFee, and R.Chesney (1999), A real-time target detection technique for metal detector arrays - an image processing approach, In A.C.Dubey, J.F.Harvey, J.T.Broach, and R.E.Dugan, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets IV*, Vol. 3710, pp. 887–894.

[36] Y.Das, K.L.Russell, N.Kircanski, and A.A.Goldenberg (1999), Articulated robotic scanner for mine detection: a novel approach to vehicle mounted systems, In A.C.Dubey, J.F.Harvey, J.T.Broach, and R.E.Dugan, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets IV*, Vol. 3710, pp. 1396–1404.

[37] P.Wort, P.Church, and S.Gagnon (2001), Preliminary assessment of electrical impedance tomography technology to detect mine-like objects, In A.C.Dubey, J.F.Harvey, J.T.Broach, and R.E.Dugan, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets IV*, Vol. 3710, pp. 895–905.

[38] E.Clifford, H.Ing, J.E.McFee, H.R.Andrews, and T.Cousins (1999), High rate counting electronics for a thermal neutron analysis land mine detector, In F.P.Doty, (Ed.), *Penetrating Radiation Systems and Applications*, Vol. 3769, pp. 155–167.

[39] S.K.Babey, J.E.McFee, C.D.Anger, A.Moise, and S.B.Achal (2000), Feasibility of optical detection of landmine tripwires, In A.C.Dubey, J.F.Harvey, J.T.Broach, and R.E.Dugan, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets V*, Vol. 4038, pp. 220–231.

[40] V.C.Aitken, K.L.Russell, and J.E.McFee (2000), Geometrical and optical calibration of a vehicle-mounted IR imager for landmine localization, In A.C.Dubey, J.F.Harvey, J.T.Broach, and R.E.Dugan, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets V*, Vol. 4038, pp. 189–199.

[41] P.Church, P.Wort, S.Gagnon, and J.E.McFee (2001), Performance assessment of an electrical impedance tomography detector for mine-like objects, In A.C.Dubey, J.F.Harvey, J.T.Broach, and V.George, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets VI*, Vol. 4394, pp. 120–131.

[42] Y.Das, J.Toews, K.L.Russell, and J.E.McFee (2001), Laboratory in-air testing of metal detectors, In A.C.Dubey, J.F.Harvey, J.T.Broach, and V.George, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets VI*, Vol. 4394, pp. 8–19.

[43] D.S.Haslip, T.Cousins, H.R.Andrews, J.Chen, E.T.H.Clifford, H.Ing, and McFee, J.E. (2001), DT neutron generator as a source for a thermal neutron activation system for confirmatory land mine detection, In R.B.James, (Ed.), *Hard X-Ray and Gamma-Ray Detector Physics III*, Vol. 4507, pp. 232–242.

[44] C.Brosinsky, R.Eirich, B.Digney, and K.L.Russell (2001), The Application of Telematics in the Canadian Landmine Detection Capability, In *Proceedings of Telematics Applications in Automation and Robotics, 1st IFAC Conference*, Vol. TA 2001, pp. 17–23.

[45] M.R.Ito, S.Duong, J.E.McFee, and K.L.Russell (2001), Towards real-time detection of landmines in FLIR imagery, In O.E.Drummond, (Ed.), *Statistical Signal Processing for Landmine Detection*, Vol. SSAP 01, pp. 154–157.

[46] J.E.McFee, H.R.Andrews, H.Ing, T.Cousins, A.A.Faust, and D.Haslip (2002), A neutron albedo imager for land mine detection, In T.Broach, R.Harmon, and G.Dobeck, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets VII*, Vol. 4742, pp. 490–501.

[47] Y.Das and J.E.McFee (2002), Limitations in identifying objects from their time-domain electromagnetic induction response, In T.Broach, R.Harmon, and G.Dobeck, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets VII*, Vol. 4742, pp. 776–789.

[48] T.J.Katsube, R.A.Klassen, Y.Das, K.Benn, M.E.Best, and R.Ernst (2002), Electromagnetic characteristics of Cambodian soil: Implication for landmine detection in soil containing ferromagnetic minerals, In T.Broach, R.Harmon, and G.Dobeck, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets VII*, Vol. 4742, pp. 821–835.

[49] A.A.Faust (2002), Detection of explosive devices using X-ray backscatter radiation, In H.B.Barber, H.Roehrig, F.P.Doty, L.J.Porter, and E.J.Morton, (Eds.), *Penetrating Radiation Systems and Applications IV*, Vol. 4786, pp. 17–28.

[50] K.L.Russell (2002), September 2001 test results of an acoustic instrumented prodder, In *Proc. UXO/Countermine Forum 2002*, pp. 17–28.

[51] R.H.Chesney and Y.Das (2002), Terrain adaptive scanning of conventional mine detectors, In *Proceedings of the IARP Workshop on Humanitarian Demining (HUDEM '02)*, pp. 69–74, International Advanced Robotics Program, Vienna, Austria.

[52] J.E.McFee, Y.Das, and A.A.Faust (2003), Canadian landmine detection research program, In *Proc. SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets VIII*, Vol. 5089, pp. 767–782, Orlando, FL, USA.

[53] J.E.McFee, Y.Das, and A.A.Faust (2003), Defence R&D Canada research on nuclear methods of landmine detection, In *Proc. SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets VIII*, Vol. 5089, pp. 1–12, Orlando, FL, USA.

[54] Y.Das, J.E.McFee, K.L.Russell, G.Cross, and T.J.Katsube (2003), Soil information requirements for humanitarian demining: the case for a soil properties database, In *Proc. SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets VIII*, Vol. 5089, pp. 1146–1157, Orlando, FL, USA.

[55] A.A.Faust, R.E.Rothschild, and W.A.Heindl (2003), Development of a coded aperture backscatter imager using the UC San Diego HEXIS detector, In *Proc. SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets VIII*, Vol. 5089, pp. 95–106, Orlando, FL, USA.

[56] T.J.Katsube, R.A.Klassen, Y.Das, R.Ernst, T.Calvert, G.Cross, J.Hunter, M.Best, R.DiLabio, and S.Connell (2003), Prediction and validation of soil electromagnetic characteristics for application in landmine detection, In *Proc. SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets VIII*, Vol. 5089, pp. 1219–1230, Orlando, FL, USA.

[57] D.Redman, P.Annan, and Y.Das (2003), GPR for anti-personnel landmine detection, In *Proc. SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets VIII*, Vol. 5089, pp. 358–374, Orlando, FL, USA.

[58] J.E.McFee, H.R.Andrews, E.T.H.Clifford, A.A.Faust, H.Ing, and T.Cousins (2003), Preliminary results from a prototype neutron moderation imager, In *Proc. SPIE Conference on Penetrating Radiation Systems and Applications V*, Vol. 5199, pp. 111–123, San Diego, CA, USA.

[59] J.E.McFee and C.Weickert (2003), Canadian landmine detection research and development program, In *Proc. EUDEM2-SCOT 2003 International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO*, Vol. 1, pp. 9–16, Vrije Universiteit, Brussels, Belgium.

[60] A.J.Schoolderman, Dijk, S.G.M.van, D.Deurloo, and K.L.Russell (2003), Instrumented Prodder: preliminary results of the technology demonstrator evaluation, In *Proc. EUDEM2-SCOT 2003 International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO*, Vol. 2, pp. 673–679, Vrije Universiteit, Brussels, Belgium.

[61] J.A.MacDonald, J.R.Lockwood, and J.E.McFee (2003), Research plan for a multi-sensor landmine detector, In *Proc. EUDEM2-SCOT 2003 International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO*, Vol. 2, pp. 625–632, Vrije Universiteit, Brussels, Belgium.

[62] J.E.McFee, S.Achal, T.Ivanco, A.Tam, G.Baker, and C.Anger (2004), A proof-of-concept optical tripwire detector, In *Proc. SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets IX*, Vol. 5415, pp. 722–733, Orlando, FL, USA.

[63] Y.Das (2004), A preliminary investigation of the effects of soil electromagnetic properties on metal detectors, In *Proc. SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets IX*, Vol. 5415, pp. 677–690, Orlando, FL, USA.

[64] T.J.Katsube, P.K.Keating, H.McNairn, Y.Das, R.DiLabio, V.Singhroy, S.Connell-Madore, M.E.Best, J.Hunter, R.Klassen, and L.Dyke (2004), Soil moisture and electrical conductivity prediction and their implication for landmine detection technologies, In *Proc. SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets IX*, Vol. 5415, pp. 691–704, Orlando, FL, USA.

[65] P.Church and J.E.McFee (2004), Laboratory evaluation of the EIT technology capability to detect minelike objects buried in an underwater sediment layer, In *Proc. SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets IX*, Vol. 5415, pp. 342–350, Orlando, FL, USA.

[66] A.A.Faust and J.E.McFee (2004), Defence R&D Canada research on nuclear methods for explosive device detection, In *Proc. 8th International Symposium on the Analysis and Detection of Explosives (ISADE)*, Ottawa, ON, Canada.

[67] J.E.McFee, A.A.Faust, H.R.Andrews, E.T.H.Clifford, and H.Ing (2004), Preliminary results of a comparative study of fast scintillators for a thermal neutron activation landmine detector, In *Proc. IEEE Nuclear Science Symposium*, Vol. 5199, Rome, Italy.

[68] J.E.McFee, V.C.Aitken, Y.Das, K.L.Russell, C.A.Brosinsky, R.H.Chesney, P.Church, G.Gundesen, E.T.H.Clifford, B.Selkirk, H.Ing, R.O.Ellingson, S.G.Penzes, M.Saruwatari, K.Saruwatari, and C.Poulsam (2000), Multisensor vehicle-mounted mine detector. U.S. Patent 6,026,135.

[69] J.-R.Simard (1996), IR contrast prediction of shallowly buried objects by characterizing the temperature gradient of the soil. DRDC Report of Invention.

[70] K.L.Russell, B.E.Fairbrother, D.R.Fenrick, and J.E.McFee (2000), Mechanical reproduction training landmines (MRTL). DRDC Report of Invention.

[71] J.E.McFee (2000), Solar infrared ground clutter suppressor. U.S. Patent Application 09/661,287.

[72] J.E.McFee (2001), Solar infrared ground clutter suppressor. Canadian Patent Application 2,421,568.

[73] R.O.Ellingson, S.G.Penzes, M.Saruwatari, K.Saruwatari, and C.Poulsam (2001), Gel-based marker system. U.S. Patent 6,203,846.

[74] Y.Das, K.Russell, N.Kirkanski, and A.Goldenberg (2001), Cantilevered manipulator for autonomous non-contact scanning of natural surfaces for the deployment of landmine detectors. U.S. Patent 6,333,631.

[75] J.E.McFee (2004), Solar infrared ground clutter suppressor. European Patent 1317680.

[76] S.Nacson (Scintrex) (1995), Investigation of Effect of Environmental Parameters on Explosive Vapour Migration in Soils, (Contract Report W8477-2-CB08/02-SV - Phase III), Chief Research and Development (CRAD), Ottawa ON, Canada. UNCLASSIFIED.

[77] S.Nacson (Scintrex) (1995), Analysis of Results and Feasibility Assessment, (Contract Report W8477-2-CB08/02-SV - Phase IV), Chief Research and Development (CRAD), Ottawa ON, Canada. UNCLASSIFIED.

[78] T.J.Jamieson and F.Lemay (SAIC Canada) (1995), Feasibility and Costing Study for the Use of Thermal Neutron Activation Analysis (TNA) As a Primary Non-metallic Mine Detection System, (Contract Report CR 1999-115), Defence Research Establishment Suffield. UNCLASSIFIED.

[79] T.J.Jamieson, E.J.Waller, and Canada), F.Lemay (SAIC (1995), Development of a Thermal Neutron Analysis (TNA) System for Confirmatory Detection of the Existance of Non-metallic Mines, (Contract Report CR 1999-119), Defence Research Establishment Suffield. UNCLASSIFIED.

[80] Bubble Technology Industries (1995), Development of a Thermal Neutron Analysis (TNA) System for Confirmatory Detection of the Existance of Non-metallic Mines- Addendum to Final Report - Signal Processing in MineSCANS, (Contract Report CR 1999-118), Defence Research Establishment Suffield. UNCLASSIFIED.

[81] Geonics Ltd. (1996), Final Report on Development of a Novel Metal Detector Array, (Contract Report 97-10), Defence Research Establishment Suffield. UNCLASSIFIED, LIMITED to Defence Departments only.

[82] Bubble Technology Industries (1996), BTI Pile-up Detector for use with MineSCANS - Manual, (Contract Report CR 1999-117), Defence Research Establishment Suffield. UNCLASSIFIED.

[83] Schiebel Systems Ltd. (1997), VAMIDS Vehicular Array Mine Detection System - Final Report, (Contract Report 97-39), Defence Research Establishment Suffield. UNCLASSIFIED, LIMITED.

[84] SAIC Canada (1997), MineSCANS Land Mine Detector Radiation Safety Manual, (Contract Report CR 1999-116), Defence Research Establishment Suffield. UNCLASSIFIED.

[85] E.J.Waller, F.Lemay, T.J.Jamieson, and H.R.Andrews (SAIC Canada and BTI) (1997), Feasibility of Using a Neutron Generator Source in the MineSCANS System, (Contract Report CR 1999-114), Defence Research Establishment Suffield. UNCLASSIFIED.

[86] Bubble Technology Industries (1998), Design of a Thermal Neutron Analysis (TNA) Detector Based on a Pulsed Neutron Generator, (Contract Report CR 1999-173), Defence Research Establishment Suffield. UNCLASSIFIED.

[87] Bubble Technology Industries (1998), Production of Final Field Version of MineScans Electronics, (Contract Report CR 1999-172), Defence Research Establishment Suffield. UNCLASSIFIED.

[88] Computing Devices Canada (1998), EIT confirmatory landmine detector - final report phase I, (Contract Report 98-33), Defence Research Establishment Suffield. UNCLASSIFIED.

[89] Itres Research Ltd. (1999), Detection of land mine trip wires by optical imaging, (Contract Report CR 1999-171), Defence Research Establishment Suffield. UNCLASSIFIED.

[90] H.Hudema (Technical Authority) (1999), Instrumentation and operation of ILDP surrogate vehicle for sensor evaluation in detection and localization of buried mines, (Contract Report CR 1999-130), Defence Research Establishment Suffield. UNCLASSIFIED.

[91] H.Hudema (Technical Authority) (1999), Activity report: Instrumentation of surrogate vehicle for infrared detection and localization of buried mines, (Contract Report CR 1999-131), Defence Research Establishment Suffield. UNCLASSIFIED.

[92] ADGA Group (1999), ILDP surrogate vehicle minimum metal detector and infrared camera installation, (Contract Report CR 1999-132), Defence Research Establishment Suffield. UNCLASSIFIED.

[93] H.Harding and D.Fenrick (HF Research Inc.) (1999), Instrumented Prodder - Final Report, (Contract Report CR 1999-108), Defence Research Establishment Suffield. UNCLASSIFIED.

[94] H.Harding, D.Fenrick, E.Bakelaar, and B.Grona (HF Research Inc.) (1999), Instrumented Prodder - Final Report, (Contract Report CR 1999-109), Defence Research Establishment Suffield. UNCLASSIFIED.

[95] HF Research Inc. (1999), Automated testing of instrumented Prodders, (Contract Report CR 1999-159), Defence Research Establishment Suffield. UNCLASSIFIED.

[96] G.Cross (1999), Soil properties and GPR detection of landmines - a basis for forecasting and evaluation of GPR performance, (Contract Report CR 2000-091), Defence Research Establishment Suffield. UNCLASSIFIED.

[97] Benbrack Ltd. (2000), Cambodian Maghemite Bearing Lateritic Soil, (Contract Report CR 2000-092), DRDC Suffield. UNCLASSIFIED.

[98] C.G.Coffey, D.Lonson, S.O'Greysik, and C.Milner (Amtech Aeronautical) (2000), Development of a Low-metal Mechanical Positioner for Hand-held Mine Detectors, (Contract Report CR 2000-217), DRDC Suffield. UNCLASSIFIED.

[99] HF Research Inc. (2000), Instrumented Prodders (Final Report), (Contract Report CR 2000-081), DRDC Suffield. UNCLASSIFIED.

[100] General Dynamics Canada (2002), EIT confirmatory landmine detector - final report phase II project, (Contract Report CR 2002-037), DRDC Suffield. UNCLASSIFIED.

[101] Bubble Technology Industries (2002), Feasibility study of neutron moderation imaging for landmine detection - Final Report, (Contract Report CR 2002-038 (BTI-00/03-31)), DRDC Suffield. UNCLASSIFIED.

[102] Bubble Technology Industries (2002), Production of a Sensor Head Based On a Pulsed Neutron Generator for a Confirmatory Thermal Neutron Analysis (TNA) Mine Detector - Final Report, (Contract Report CR 2002-039), DRDC Suffield. UNCLASSIFIED.

[103] HF Research Inc. (2002), Force and temperature compensation for the instrumented prodder - Final Report, (Contract Report CR 2002-114), DRDC Suffield. UNCLASSIFIED.

[104] Sensors & Software Ltd. (2003), Evaluation of Hand-held GPR System for AP Landmine Detection - Final Report, (Contract Report CR 2003-119), DRDC Suffield. UNCLASSIFIED.

[105] Bubble Technology Industries (2003), Feasibility of Nuclear Power Cells for Nanotechnology - Final Report, (Contract Report CR 2003-126 (BTI-03/05-30)), DRDC Suffield. UNCLASSIFIED.

[106] Bubble Technology Industries (2004), Feasibility of Fast Neutron Analysis (FNA) for Detection of Buried Landmines, (Contract Report CR 2004-201), DRDC Suffield. UNCLASSIFIED.

[107] CDL Systems (2004), RDVCS for ILDS Extension TNA and GPR Improvement, (Contract Report CR 2004-255), DRDC Suffield. UNCLASSIFIED.

[108] S.Desilets, L.Haley, and U.Thekkadath (1998), Trace explosives detection for finding landmines, In A.C.Dubey, J.F.Harvey, and J.T.Broach, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets III*, Vol. 3392, pp. 441–452.

[109] J.-R.Simard, P.Mathieu, V.Larochelle, and D.Bonnier (1998), An airborne far-IR minefield imaging system (AFIRMIS): description and preliminary results, In A.C.Dubey, J.F.Harvey, and J.T.Broach, (Eds.), *Detection and Remediation Technologies for Mines and Mine-like Targets III*, Vol. 3392, pp. 84–95.

[110] J.-R.Simard, P.Mathieu, G.R.Fournier, V.Larochelle, and S.Babey (2000), Range-gated intensified spectrographic imager: an instrument for active hyperspectral imaging, In G.W.Kamerman, (Ed.), *Laser Radar Technology and Applications V*, Vol. 4035, pp. 180–191.

[111] L.Sevigny (1996), Contrast enhancement of the IR signature of landmines buried in roads, (DREV Technical Report 9526), Defence Research Establishment Valcartier, Courcelette, PQ Canada. UNCLASSIFIED.

[112] S.Desilets, N.Gagnon, T.F.Jenkins, and M.E.Walsh (2001), Residual Explosives in Soils Coming From Buried Landmines, (DREV Technical Report 2000-125), Defence Research Establishment Valcartier, Courcelette, PQ Canada. UNCLASSIFIED.

[113] R.Durocher, S.Desilets, P.Noel, C.Bordeleau, T.F.Jenkins, and M.E.Walsh (2001), Evaluation des Vapeurs Provenant de Mines Enfouies: Theorie de la Partition et du Transport des Explosifs dans les Sols, (Rapport CRDV CRDV RT 1999-120), Centre de recherches pour la defense Valcartier, Courcelette, PQ Canada. NONCLASSIFIÉ.

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Between 1995 and 2005, fundamental R&D was conducted under Shield Project 12rh, “Advanced Hand-held Mine Detector”, with the aim of developing a hand-held multi-sensor landmine detector. The military sponsor for the project was DLR-7, with J3 Engineering Operations and DCSEM maintaining an active interest. Humanitarian and military mine detection requirements differ, but because there was a common core of R&D needed, Canadian Center for Mine Action Technologies (CCMAT) also provided substantial sponsorship. This report describes the objectives and results of the project.

All three objectives of the project were met. The first was to deliver a multi-sensor hand-held landmine detector concept demonstrator to the CF. The second was to assist DLR 7 in development of a technical specification in support of minor requirements acquisition of a new mine detector. The third objective was to develop a capability to discriminate targets from clutter. Out of the project's 8 milestones, 5 were completed by project end and 3 were partially completed.

Multi-sensor mine detection conducted under this project has involved leading edge research in a variety of scientific areas, including electromagnetic induction, infrared imaging, ground penetrating radar, acoustics, nuclear physics, X-ray imaging, data fusion and robotics. The Threat Detection Group is considered a leader in mine detection research. Group members led or participated in a number of international panels and have co-chaired or been on the program committee of prestigious conferences concerning research on mine detection or related technologies. Over 110 publications related to the project were issued during the project period.

Some of the research conducted under 12rh will continue under Shield Projects 12rl and 12rm, and a 3 year TIF titled “Concept for Neutronic Detection of Improvised Explosive Devices”. Research on electromagnetic induction has shifted focus to a study of electromagnetic properties of soils. It is being funded by CCMAT.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title).

landmine detection
research and development
test and evaluation
electromagnetic induction
metal detectors
ground penetrating radar
infrared imaging
x-ray imaging
thermal neutron analysis
fast neutron analysis
electrical impedance tomography
confirmation sensors
optical tripwire detection
robotics
teleoperation
multi-sensor
data fusion