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The Path to Humanitarian Demining and International Cooperation

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1 Introduction

Many people are concerned about the grisly injuries caused by landmines, and thus about demining activities. Because of exhaustive efforts, the number of landmine victims worldwide is on the decline. Despite this, however, landmines still kill or injure an estimated 10,000 people around the world every year. Efforts to reduce the damage caused by landmines are notable for the involvement of the civic sector as well as government-related institutions. Since the Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on their Destruction (Ottawa Convention) went into effect in 1999, Japan has halted domestic production of landmines, disposed of its stored landmines, and actively engaged in detection and removal of antipersonnel mines in affected countries such as Afghanistan and Cambodia. In addition, with the objective of making a tangible international contribution, the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Economy, Trade and Industry are carrying out research projects to develop scientific and technological approaches to humanitarian landmine detection and removal[1]. Some of these projects have undergone testing and evaluation in affected countries and are now close to practical application. This report describes research trends in Japan and around the world related to humanitarian landmine detection and removal, as well as examples of the development of Japanese technology for antipersonnel mine detection.

2 Humanitarian demining

Landmines have been used as weapons to prevent the advance of armies since before World War I. In the deserts of Egypt, the site of fierce tank battles during World War II, over 23 million landmines remain buried more than 50 years after the end of that war. Used extensively in wars and conflicts since World War II, there are currently an estimated over 110 million landmines buried around the world. In countries were there have been fierce civil wars, such as Afghanistan, Cambodia, the former Yugoslavia, and several African nations, minefields were planted in areas where people live. Even after the end of conflicts, such minefields are a serious problem for residents and a major impediment to national reconstruction.

Countries all over the world have been actively addressing the landmine issue since the 1980s. The Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on their Destruction (Ottawa Convention) was signed in 1997. Subsequently, many other countries including Japan, joined it. The treaty came into effect in March 1999. As of July 2005, there were 153 signatory countries, of which 145 have ratified, and 41 countries that were yet to sign[2]. In addition, many countries and international organizations are actively supporting demining in affected countries.

As domestic implementation mechanisms, Japan passed laws prohibiting the manufacture of antipersonnel mines and regulating their possession when the Ottawa Convention came into effect in March 1999. Meanwhile, countries that have not signed the Ottawa Convention, including the USA, Russia, and China, have not renounced the use of landmines as defensive weapons. Some of the non-signatory countries feel they are not able to abandon the use of landmines as defensive weapons, or they cannot dispose of their antipersonnel mines within the 10 years required by the treaty. The USA and some other countries, however, have developed "intelligent" landmines that will not detonate after a certain period of time or that indicate their positions by radio. These countries assert that this type of landmine will not cause problems after conflicts end. The Ottawa Convention does permit the possession of landmines for the development of detection, removal, and disposal technology and for training.

Landmines are weapons used to impede the advance of armies. Buried landmines explode in response to the pressure exerted when people or vehicles pass over them. In contrast to antitank mines designed to destroy vehicles, which are buried at a depth of about 50 cm and require around 50 kg of weight to trigger them, antipersonnel mines designed to injure and kill passing military personnel are buried at a depth of 10 cm or less and detonate under very light pressure. Antitank mines have a diameter of around 50 cm, while antipersonnel mines are only about 10 cm across. Figure 1 shows one type of antipersonnel mine, the PMN-2 of the former Soviet Union, which is found widely throughout Afghanistan. This mine has been deliberately detonated as part of demining work on antipersonnel mines.

Removal of mines from battlefields so that armies can pass is called "military demining." Since the only goal is for tanks and other vehicles to be able to pass safely, military demining is carried out only in specifically targeted sections of minefields, and the majority of mines are left behind. Furthermore, after wars and conflicts end, there are very few cases where armies have removed the landmines they buried themselves. In contrast to military demining, "humanitarian demining" aims to completely remove all mines after a conflict so that people can return and once more use former minefields as areas for housing, farming, and so on. Humanitarian antipersonnel demining clearly has different goals from military demining and uses somewhat different methods.

Figure 1 : A Soviet PMN-2 after detonation

In Croatia and other countries where post-conflict demining has been efficiently carried out, the number of inhabitants injured or killed by landmines has fallen sharply. However, where landmines have not been completely removed and where the ground has been contaminated or otherwise left unsuitable for cultivation by metal fragments or explosives left from demining activities, land use is curtailed and economic losses are becoming more serious. For most humanitarian demining activities, demining institutions organized by the United Nations in each affected country bring together local nongovernmental organizations, distribute ODA funds donated by supporting developed countries, allocate demining areas to the NGOs, provide technical support, and so on. Current humanitarian demining systematically determines priorities for the location of demining work by continuously seeking to balance the input of funds for demining with the economic effects that will result. The United Nations institution that carries out antipersonnel demining activities is the United Nations Mine Action Service (UNMAS)[3].

3 Technology to detect and remove landmines

The landmine detection technologies currently in practical use for the removal of buried landmines in affected countries are metal detectors and mine-detection dogs.

Metal detectors utilize electromagnetic

induction by generating a signal at about 10 kHz to induce an eddy current in metals that produces a detectable secondary electromagnetic field. This is the same type of detector used for security screening at airports, to prevent contamination of food by metal objects, and so on. Because metal detectors have been utilized for many years to detect landmines, modern antipersonnel mines are made of plastic and use as little metal as possible. Even when the casing is plastic, there will be a small amount of metal in wires or springs in the detonator that triggers the TNT explosive. Metal detectors now used for landmine detection can find a 10 mg piece of metal in a plastic landmine buried about 10 cm deep with close to 100 percent accuracy.

Figure 2 shows demining work taking place on Bibi Mahro Hill in Afghanistan. An operator uses a metal detector to scan approximately one meter in every direction. When the operator hears a detection signal, she/he prods the ground with a wire-shaped probe. Even when a landmine is found, there is little danger of detonation if the probe touches it from the side, but the work is still very dangerous and demanding. Because the work is extremely nerve-wracking, workers operate in pairs, with one resting every 30 minutes. They are limited to about five hours work per day, during which they can only cover about 50 m^2. Even so, use of handheld metal detectors and prodding is highly adaptable even to sloping sites and is the most common method for detection and removal of antipersonnel mines. However, minefields are littered with unexploded shells, spent cartridges, shell fragments, and other bits of metal, all of which cause much stronger reactions in metal detectors than landmines do. The problem for landmine detection is, therefore, the development of technology that can distinguish landmines from other detected metal. Figure 2 shows Bibi Mahro Hill, where demining work began in October 2002. As of December 2004, 277 landmines had been detected, while 2,135 unexploded shells and 218,320 metal fragments had been removed.

The other landmine detection method that is as practical as metal detectors is the use of mine-detection dogs. Some of the TNT explosive used in landmines vaporizes and reaches the surface after passing through the ground. A dog's sense of smell is powerful enough to detect tiny amounts of TNT ingredients, so dogs are used as a very reliable means of landmine detection.

NGOs operate large facilities in Afghanistan and elsewhere for training mine-detection dogs. There are usually over 100 mine-detection dogs actively working at any one time. However, mine-detection dogs consume a lot of time and money for training and care, and because dogs tire easily, their work hours are severely limited. Their use in landmine detection work is therefore not very efficient.

In addition to these technologies, landmine detection technology based on new principles is also in development. Of these new technologies, ground penetrating radar (GPR) is considered closest to practical application, including application by Japan.

GPR uses approximately 1-GHz electromagnetic waves, which reflect off objects whether metal

Figure 2 : Manual demining work on Afghanistan's Bibi Mahro Hill

Table 1 : Landmine detection methods

Method	Target of detection	Time until practical application
Metal detectors (MD)	Mine shape	In use
Ground penetrating radar (GPR)	Mine shape	Short
Infrared rays	Mine shape	In use
Dual sensors (MD + GPR)	Mine shape	Short
Mine-detection dogs	Explosives	In use
Scent sensors	Explosives	Long
Nuclear quadrupole resonance (NQR)	Explosives	Long
Neutrons	Explosives	Long

or non-metal, that are electrically different from their surroundings, to detect buried objects. Short-pulse electromagnetic waves of 1 ns or less are transmitted from an antenna on the surface, and another receiving antenna on the surface captures the electromagnetic waves that are reflected back from objects in the ground. Moving the transmitting and receiving antennas while receiving reflected waves allows an image of the cross-sectional structure of the ground to be created.

Common uses of GPR include locating pipelines buried under roads and exploring archaeological sites. Since it is also effective in finding plastic landmines, it is seen as a promising technology for landmine detection as well. Antipersonnel mines are small, and the electrical characteristics of plastic and TNT are similar to those of soil, so their radar echoes are much weaker than those of gas pipelines or other large objects. In addition, because landmines are buried at shallow depths, they can be confused with reflected waves from the surface, and clutter from uneven ground can conceal echoes from landmines. Furthermore, soil conditions vary by location due to soil quality, moisture content, and so on. Such factors prevent unmodified GPR equipment from being applied to the detection of antipersonnel mines, requiring new development. In recent years, however, some practical use of GPR has begun.

When landmines are on the surface or buried very shallowly, differences in the specific heat of materials means that changes in the ground's surface temperature will cause mine temperature to differ from soil temperature. Thus, infrared cameras can be used to image temperature differences and detect landmines. Research on military applications of infrared landmine detection technology is already underway.

Metal detectors, GPR, and infrared cameras all detect landmines by looking at their shape. In contrast, methods such as mine-detection dogs that directly sense the explosives in landmines raise detection reliability and lower the rate of misidentification. Therefore, scent sensors that artificially reproduce the sense of smell possessed by mine-detection dogs, as well as measurement of high-energy gamma rays emitted when neutron irradiation of the nitrogen included in explosives causes a neutron capture reaction, are being examined as landmine detection methods. In addition, when irradiated with electromagnetic waves of a certain frequency, the nuclear quadrupole moment of the nuclei of the nitrogen in explosives has an electrical field gradient that displays a form of absorption called nuclear quadrupole resonance (NQR) and transmits electromagnetic waves of a resonant frequency. Measurement of the characteristic resonant waves of substances enables landmines to be detected. Due to factors such as size and sensitivity, each of these methods for the direct detection of explosives will require more time and money before practical application.

In order to prevent secondary damage that could be caused by moving landmines, they are removed by detonating them in the ground where they are buried. If done carelessly, however, this can scatter metal fragments around the area, impeding demining activities using metal detectors. In addition, soil can be contaminated, interfering with cultivation. Sandbags are therefore placed around landmines before detonation in order to prevent them from having an effect on the surrounding area. The United Nations institutions and other bodies have established strict protocols for landmine detection with metal detectors and demining through in-situ detonation. This has greatly reduced the danger of on-site work.

In contrast to manual demining work, another method is to drive construction vehicles such as bulldozers and cranes equipped with robust rotating devices across minefields in order to forcibly detonate the mines.

This so-called mechanical demining is also used in humanitarian demining. Mechanical demining is an efficient way to demine wide areas such as airports and it is safe because operators never come in contact with the mines. The machinery used for mechanical demining is already in practical use, and Japan is among the countries providing aid for demining machinery through ODA and other funds. Mechanical demining, however, leaves exploded fragments in the ground and may dislodge antipersonnel mines without detonating them, so 100-percent demining is difficult. This leaves the problem of needing to carry out further landmine detection work even after completion of mechanical demining.

An examination of ways of using unmanned robots for removal work after landmines have been detected is underway, but there is less need for removal than for detection, so demand from NGOs is not strong.

4 Trends in global research

Landmine detection and removal technology is also being developed through military research, but this report will discuss trends related to humanitarian demining, to which general researchers in Japan can make a direct contribution.

As described above, mechanical demining is already in practical use in various countries, and demining machinery is commercially available in Croatia and other countries.

During the 1990s, the EU and the USA undertook major national projects on the use of ground penetrating radar for landmine detection. With the exception of the somewhat late-starting Japan, these landmine detection research projects had all finished by about 2002. All but a few ended at a stage just short of practical application.

In the USA, universities formed a consortium with the support of the Army to carry out coordinated research while avoiding redundancy on each technology. A unique method causing landmines to vibrate using a loud sound directed at the ground and detecting them with ground penetrating radar and laser strain meters was also developed. The military evaluated research results at military facilities and provided feedback for technical development. In some cases, university researchers used equipment developed by the military to obtain data that they used in their research into disposal methods. Sometimes, however, university researchers were not informed of all experimental conditions, and in the end it was the military that evaluated the results.

In Europe, meanwhile, a group comprising universities, national laboratories, and private-sector corporations carried out research with the support of the EU. Especially, it is a requirement for EU research funding for a research group to consist of several countries, so sensors were developed separately for subsequent integration into the completed system. Joint research spanning several countries is very worthwhile in the sense that it promotes interaction among universities and their students and researchers.

The subjects of this research and development in Europe and the USA are mainly the sensors described in Section 3 of this report, such as GPR, infrared, neutrons, NQR, and so on, as well as their integration into multi-sensor systems. Some systems combine two or more sensors for relatively large vehicles to allow simultaneous observation and detection. One result of this research is handheld "dual sensors" combining GPR and metal detectors, which workers operate manually. The US Army has begun putting them into practical use[4-6].

ODA and other funds are used to procure the landmine detection equipment, which is the outcome of this R&D, for demining activities in affected countries. Since several hundred units are procured at once, careful selection of equipment is important. In many cases, however, demining organizations in affected countries lack the sufficient technical knowledge for equipment selection. A number of factors, such as local soil conditions and climate, as well as the degree of skill of operators from demining organizations, can prevent a landmine detector's full performance potential from being attained. International standards organizations that can provide technical advice and support are therefore a necessity.

One example is the International Test and Evaluation Program for Humanitarian Demining (ITEP)[7]. Belgium, Canada, the Netherlands, Sweden, the UK, the USA, Germany, and the EC formed this organization in 2000. Its purpose is to collect, evaluate, and disseminate technologies for humanitarian demining. In addition, the Geneva International Centre for Humanitarian Demining (GICHD)[8], which supports Humanitarian Mine Action, is an independent institution formed by 18 countries. It carries out work support, research, and technical guidance for humanitarian demining activities.

These organizations focus on metal detectors, which are widely used for humanitarian demining. They have evaluated the performance of various commercial metal detectors and created selection standards for metal detectors according to soil type. In addition, the United Nations has led the standardization of protocols for landmine detection methods using metal detectors. It keeps up with current research and development activities and plans to set technical standards for evaluating handheld “dual sensor” devices to ensure their efficient and effective application in demining activities.

In Japan, development of dual-sensor equipment is a major goal of the research project of the Japan Science and Technology Agency (JST). The level of development now conforms to international technical standards, and from now on JST will be actively engaged in the setting of such standards.

5 Research trends in Japan

Whether humanitarian antipersonnel demining activities strictly accord with the three statutory principles governing the export of weapons depends on a 1997 speech by the Deputy Vice Minister. This address confirmed that even if goods used to support landmine detection and other humanitarian antipersonnel demining activities include items that can be referred to as weapons, they do not violate the three principles governing the export of weapons. In Japan, humanitarian demining technical development carried out with the participation of universities and other bodies adheres to these principles.

Along with signing the 1997 Ottawa Convention, Japan expressed its support for aid for antipersonnel demining and landmine victims. Through international organizations, governments, NGOs, and so on, Japan already provides active support for antipersonnel demining in Cambodia and other countries where landmines are buried. In Japan, the number of corporations, NGOs, and researchers engaged in research and development on relevant technology has increased.

In order for Japan to make a more active contribution to this sector, a course must be set for the research, development, and commercialization of demining technology and its provision through ODA to countries where landmines are buried. Since July 2000, relevant government agencies have been discussing policies aimed at supporting research and development into technologies related to the demining of antipersonnel mines in a liaison conference. In December 2000, the Ministry of Foreign Affairs, the Ministry of Education, Sports and Culture (now the Ministry of Education, Culture, Sports, Science and Technology), the Ministry of International Trade and Industry (now the Ministry of Economy, Trade and Industry), the Japan Defense Agency, and the Science and Technology Agency (now the Ministry of Education, Culture, Sports, Science and Technology) published a report on “new initiatives on antipersonnel demining.” The report declared that the ministries would implement support for research and development of new technologies, including those for the demining of antipersonnel mines.

In addition, the JST accepted research proposals from universities, research-oriented independent administrative agencies, and private-sector corporations, and since October 2002 has been engaged in an R&D promotion project on humanitarian antipersonnel mine detection and demining technology as part of its project to promote strategic creative research[1]. This is based on “Promoting R&D for Humanitarian Demining” (May 2002), the report of the Ministry of Education, Culture, Sports, Science and Technology’s Committee of Experts on Humanitarian Demining Technology. The goals of the project are the development of new sensing technology combining sensor technology and robots, as well as access and control technologies. Since FY 2004, Research and Development for Supporting Humanitarian Demining of Anti-personnel Mines has been an independent JST project. Table 2 shows the topics covered.

Looking at this in more detail, in the short term there are six R&D projects set for completion in FY 2005. They include sensing technology that can safely and efficiently detect antipersonnel mines by distinguishing the relative differences

Table 2 : JST research and development topics

Development of compact landmine search vehicles (short term)	
Development of wearable SAR-GPR for landmine detection	Motoyuki Sato (Tohoku University)
Development of landmine search radar using reflected waves and transmittance waves	Ikuo Arai (University of Electro-Communications)
Demining support by landmine search robots and unmanned disposal vehicles (Figure 7: Mine Hunter Vehicle)	Kenzo Nonami (Chiba University)

Development of large landmine search vehicles (short term)	
Research and development of environmentally-responsive high-performance antipersonnel mine search systems	Toshio Fukuda (Nagoya University)
Research and development of access machinery for landmine search units	Tomohiro Ikegami (Tadano Ltd.)
Other development (buggies equipped with remote-control arms, Mine Hand) Development of mine-search and demining support systems using buggies, remote-control arms, etc. (Figure5: Gryphon)	Shigeo Hirose (Tokyo Institute of Technology)

Medium-term research and development topics	
Development of landmine search technology using micro electrical discharge neutron source	Kiyoshi Yoshikawa (Kyoto University)
Development of advanced high-speed gamma ray analysis systems for mine searching	Tetsuo Iguchi (Nagoya University)
Development of SQUID-NQR landmine chemical detection technology	Hideo Itozaki (Osaka University)

in the physical properties of mines and soil, remote-control access equipment that can safely and efficiently bring sensors and manipulators into minefields, and manipulator and control technology to operate that machinery.

In the medium term, research and development sets for completion in FY 2007 will focus on the explosives used in landmines. Three projects (as of April 2005) are developing technology for the safer and more efficient detection of antipersonnel mines. When JST presented the results of its short-term research topics at a meeting in March 2005, it was well attended by the representatives of international demining organizations engaged in Afghanistan, Croatia, and so forth.

Meanwhile, the Ministry of Economy, Trade and Industry provided support for research to develop landmine detection and demining technology from the perspectives of economic recovery and humanitarian aid in areas with buried landmines such as Afghanistan. This was done through an agenda-setting aid project (Technological Development for Underground Material Detection and Clearance) of the New Energy and Industrial Technology Development Organization (NEDO) during FY 2002 and 2003. This assistance was used to support R&D for six projects that were aiming to develop portable antipersonnel mine detectors, landmine detection vehicles, and demining machinery for antipersonnel mines.

Using new technology for humanitarian landmine detection and demining developed with the support of the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Economy, Trade and Industry, the Ministry of Foreign Affairs[9] provided support for the Afghanistan Research Project for Developing Mine Clearance-related Equipment. The Japan International Cooperation System (JICS) carried out the project on behalf of the Department of Mine Clearance, Department of Disaster Preparedness of the Transitional Government of Afghanistan. Testing and evaluation of nine machines from seven groups decided through open bidding were carried out in minefields in Afghanistan from July 2004 through February 2005. The machines included mechanical demining machinery developed through the NEDO support project, which proved practical utilization. Adoption by Afghanistan, Cambodia, and other affected countries is expected.

6 R&D and practical application in a JST project

As an example of Japanese technical contributions to demining of antipersonnel mines, this section describes landmine detection technology developed at Tohoku University. This is one of the topics in the JST project[10-13].

As described above, although landmine detection using only metal detectors is highly reliable, work efficiency is extremely low. Researchers at Tohoku University therefore developed the Advanced Landmine Imaging System (ALIS), which combines metal detectors with GPR in a dual-sensor system.

ALIS is a compact sensor system for use as a handheld landmine detector. Demining workers manually move their metal detectors back and forth over the ground, listening for the detectors' response to locate the position of underground metal fragments. Unlike metal detectors, GPR can image the plastic casings of antipersonnel mines, thereby significantly reducing the number of misidentifications. Several systems that integrate GPR and metal detectors into the new dual-sensor handheld systems have been developed internationally. With the exception of ALIS, however, handheld dual-sensor systems cannot track antenna position during measurement, which prevents them from utilizing GPR's most important characteristic, the ability to image targets. ALIS solves this problem by equipping the sensor handle with a CCD camera to confirm sensor position in real time. This enables imaging of metal detectors and GPR signals so operators can determine landmine positions from the images.

Figure 3 shows ALIS in operation. The operator carries GPR equipment and a PC in a backpack. When the operator moves the sensor, its position appears in real time in a head-mounted display in the operator's goggles. The operator can ascertain the position of the metal object and at the same time prevent gaps unobserved by sensors, thus preventing accidents.

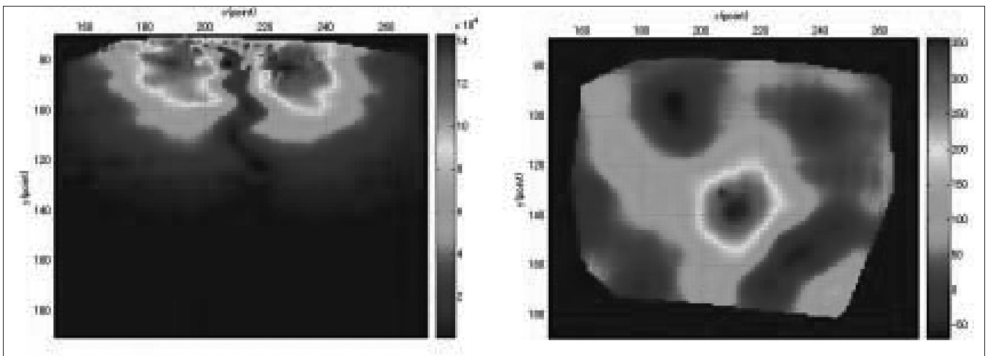
ALIS is also notable in that its operating method is basically the same as that of conventional metal detectors. The operator stands in a safe area from which any landmines have already been cleared and scans approximately one meter in each direction to obtain data. After two or three minutes, the scan is complete and signal processing takes place and a GPR image is formed.

Figure 4 shows images generated by a metal detector and a GPR from ALIS. A buried landmine is clearly depicted. The metal detector uses a differential sensor where symmetrical responses to the right and left of a metal object appear, with the object located where the signal is zero. With GPR, the round shape of landmines can be seen directly. The ALIS metal detector sensor and GPR antenna are separate, so in Figure 4 their positions are about 20 cm apart.

The three-dimensional structure of the ground can be determined from the images, enabling the position of any landmines to be confirmed.

Figure 3 : Testing and evaluation of ALIS on Bibi Mahro Hill, Afghanistan

Figure 4 : Typical ALIS detection images CDS site in Afghanistan. The target is an inactive PMN-2 landmine.



(a) Metal detector image (b) GPR image

Operators basically perform the same scan as with conventional equipment, but the addition of images to the audio signal increases reliability. In effect, the operator is not working with a new method, but instead is obtaining additional data while carrying out the same work. This enables reliability to be maintained while efficiency is enhanced.

A major goal of Japanese research and development is landmine detection technology that adds technology for access and control with robots and unmanned vehicles to sensing technology. The JST project has therefore developed a vehicle equipped with landmine detection sensors and a robot arm for scanning. Loading ALIS on an unmanned vehicle equipped with a robot arm can make work more efficient. Figure 5 shows Gryphon, a buggy developed as a JST project, equipped with ALIS.

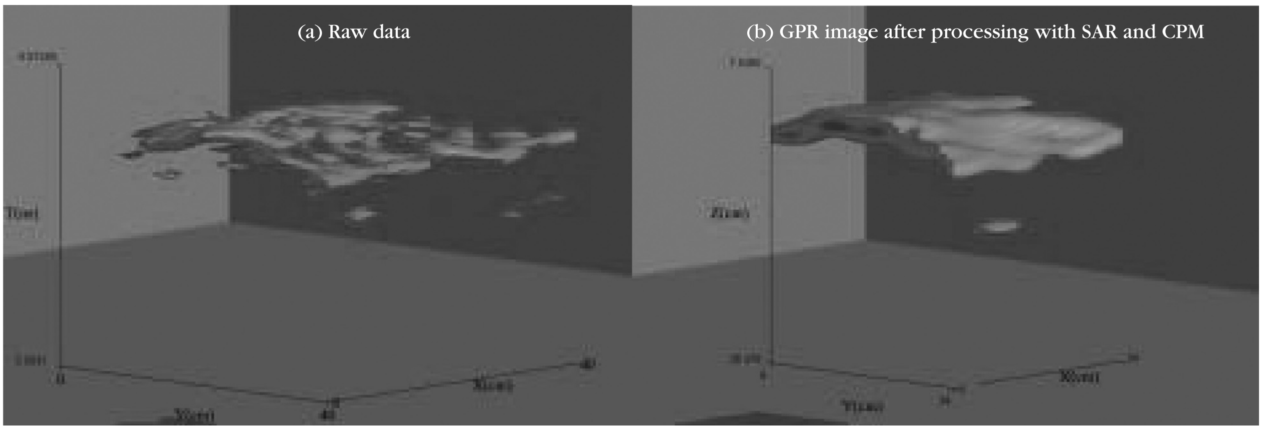
In addition, larger robot arms enable the use of larger, higher-performance sensors. ALIS uses broadband GPR and migration to control the clutter that causes problems with GPR landmine detection, but SAR-GPR is a higher-performance system for equipment with robot arms.

Figure 5 : The compact buggy Gryphon (Tokyo Institute of Technology) equipped with ALIS (Tohoku University)

SAR-GPR uses an array antenna for clutter removal. The Vivaldi antenna newly developed for efficient broadband performance has a frequency range from 10 MHz to 4 GHz, and its flat shape makes it easy to fabricate and to position in an array. Clutter is random signals sent to the antenna, while, in contrast, reflection from artificial objects such as landmines has a strong spatial correlation. Therefore, a signal-processing algorithm was developed to combine CMP stacking and migration that superimpose correlated reflected signals from landmines while changing the position of the sending and receiving antennas. Figure 6 shows three-dimensional SAR-GPR imaging of a buried landmine. Figure 6 (a) shows raw radar data obtained by SAR-GPR, while Figure 6 (b) shows the same data after signal processing. In Figure 6 (b), there is a clear separation between the surface of the ground and the buried landmine, while in Figure 6 (a) they form an indistinct mass and cannot be distinguished from one another.

SAR-GPR radar equipment itself utilizes a vector network analyzer, which is a type of high-frequency measuring instrument. Commercially available, general use vector network analyzers weigh more than 30 kg and are precision instruments unsuited for outdoor use, but a 1.5-kg board-type vector network analyzer has been newly developed. As a measuring instrument, this vector network analyzer is suitable for broadband high-frequency measurement. Its expected future applications include not only GPR for landmine detection, but also use in the development, research, and maintenance of communications and

Figure 6 : Three-dimensional GPR image of buried landmine from SAR-GPR (Tohoku University)



information technology devices. Figure 7 shows the completed SAR-GPR mounted on the compact Mine Hunter vehicle developed by the JST project. The SAR-GPR is packed in a case at the end of the arm. Including antennas, it weighs 17 kg. This rig has six transmitting and receiving antennas and three vector network analyzers.

In advance of on-site testing of SAR-GPR in affected countries, JST carried out domestic evaluation and testing with measurement tests in Sakaide, Kagawa Prefecture in February and March 2005. After testing in calibration lanes where the position and shape of buried mock landmines was known in advance, testing was carried out in blind lanes where the position of buried landmines was unknown.

Figure 8 shows an example of data obtained from the blind lane and the results of landmine position determination. The chart shows images from (a) metal detectors and (b) horizontal GPR images at three depths. Finally, (c) shows where landmines were judged to exist. The results suggest that metal detectors can find landmines buried shallowly, but not those buried at a depth of about 20 cm. However, GPR successfully detected landmines buried about 20 cm deep, proving the effectiveness of dual sensors. Except where a pair of landmines buried about 15 cm deep were in close proximity to one another and were judged to be a single mine, all landmines were detected. The rate of false positives was also low.

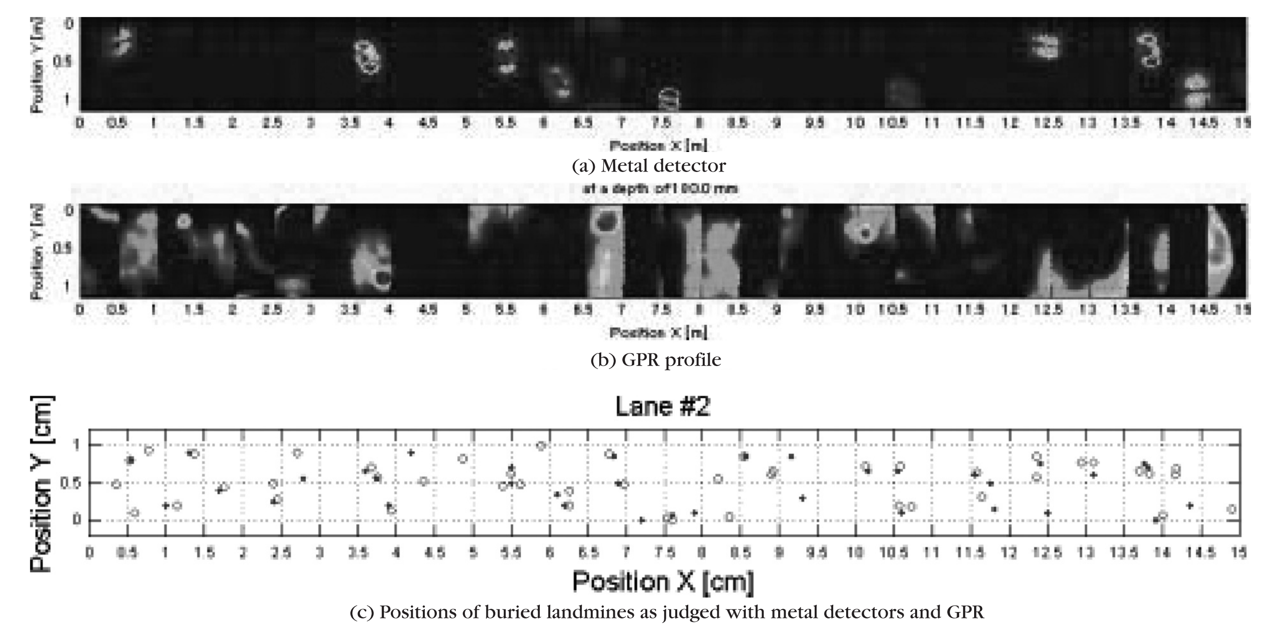
Figure 7 : A compact Mine Hunter Vehicle (Chiba University) equipped with SAR-GPR (Tohoku University)

7 Evaluation and testing in affected countries

How well technologies will work in the field is an extremely important question in landmine detection. Devices supported by ODA and other funds should not be thrust upon users, but should actually be useful in the field. On-site testing and evaluation are necessary before workers in the field will accept new equipment.

This section will describe on-site testing and evaluation of ALIS conducted by Tohoku University in Kabul, the capital of Afghanistan, in December 2004. The testing and evaluation were performed by JICS as ODA, part of the Afghanistan Research Project for Developing Mine Clearance-related Equipment. In addition

Figure 8 : Detection results for SAR-GPR (Tohoku University) (Testing at JST in Sakaide, Japan)



to ALIS, another vehicle-mounted single-sensor landmine detector was also tested.

Tests were carried out in two locations in Kabul. The first was a JICS test site in the Central Demolition Site (CDS), a facility for disposing of landmines and unexploded shells by detonating them. Part of the detection testing was carried out with real but deactivated landmines that could not explode because their detonators had been removed. The site where real landmines were buried was under 24-hour guard. The second location was Bibi Mahro Hill, where actual demining was being carried out.

At the CDS, two kinds of antipersonnel mines commonly found in Afghanistan, the Type 72 and the PMN-2, were buried in different soil conditions and depths for calibration tests to evaluate detection performance. The soil at the CDS is relatively homogenous, but it still has enough irregularities to cause considerable clutter. This testing showed that the limit for landmine detection with metal detectors was a depth of about 15 cm, while GPR was able to detect landmines to a depth of about 20 cm. In addition, while metal fragments caused metal detectors to react, they did not show up clearly on GPR images, demonstrating that landmines and fragments can be distinguished from each other. Figure 4 shows a deactivated PMN-2 landmine buried at a depth of 10 cm. Both the metal detector and GPR provide a clear image. Next, blind tests where the type and position of the buried objects were not revealed in advance were performed under conditions close to those of actual landmine detection work. These tests showed that ALIS responses to metal fragments and landmines were clearly different, so that they could be distinguished from one another in practical use. At the CDS, JICS also performed testing and evaluation of mechanical clearance methods at the same time as the landmine detection tests.

Next, testing under conditions very close to actual demining was carried out at Bibi Mahro Hill, where NGOs were performing demining work. Bibi Mahro Hill is a small hill overlooking the city of Kabul and Kabul Airport. In the 1980s, the former Soviet Army had a missile base there. The soil there is extremely irregular. The ground is covered with vegetation, and the soil contains a lot of gravel and many pieces of wood and metal. In addition, as can be seen in Figures 2 and 3, the ground is sloping. The landmines were buried in straight lines to keep intruders out of the base, but over the ensuing 20 years, almost all the mines have shifted along with the ground due to rain and other natural forces. They are now scattered at random, sometimes even resting on top of the vegetation. Areas where demining is complete and those that have yet to be cleared are demarcated by stones painted red and white so that demining workers can distinguish safe areas. During the testing, this author witnessed a child chase a dog into the demining work area. The child left the area unharmed, but the incident drove home once again the danger of minefields located next to residential areas.

For safety reasons, mock landmines in the shape of the PMN-2's plastic casing with injected TNT were buried along with metal fragments in an area known to be clear of landmines. ALIS testing and evaluation were then carried out. Figure 9 (a) shows metal detector images. Figure 9 (a) shows several metal detector responses, while Figure 9 (b) shows that there was only one response in the GPR image. This enabled the single landmine to be distinguished from several metal fragments in that location.

True evaluation of landmine detection sensors is impossible unless testing takes place with actual landmines in ground where real detection is underway. In Japan, it is extremely difficult to accurately reproduce soil in terms not only of soil components, but also of moisture and temperature, and to replicate work environments. In addition, there are many problems with mock landmines. Although the shapes and internal structures of landmines are public knowledge, the actual internal structures are very difficult to reproduce. This problem also confronts Europe and the USA. There is no better evaluation method than the use of real landmines. This testing and evaluation can only be realized through international cooperation.

Following testing and evaluation in Afghanistan, ALIS demonstration tests were carried out in Italy and Sweden in order to undergo ITEP evaluation. In addition, validation tests were carried out in affected countries such as Croatia and Egypt. In these tests, ALIS operation was explained to technical staff from United Nations institutions, demining workers. They provided a wealth of advice regarding improvements needed for use in real-world demining. These validation tests are extremely important in order to generate reliable feedback that can then be used to develop even better systems.

The JST project is thus planning and implementing testing in affected countries during FY 2005 to verify research results.

8 Future prospects

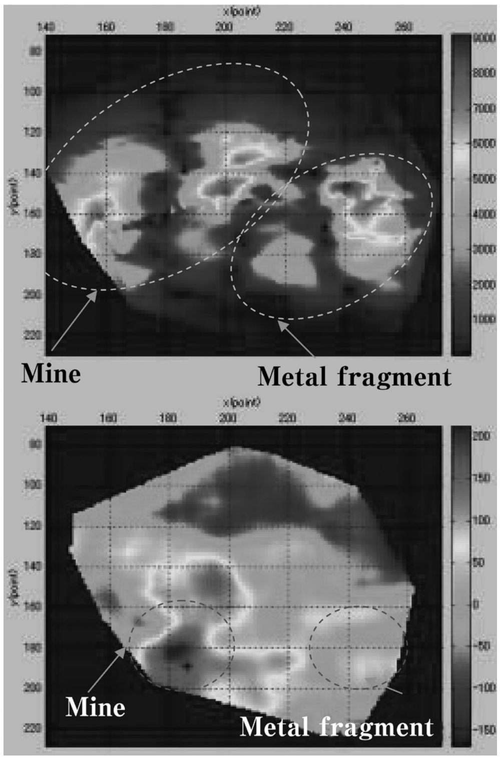
Landmine detection technology is the technology that one hopes will become unnecessary within a few years as demining work proceeds. In the meantime, however, there is a strong demand for equipment with greater reliability, efficiency, and operability, as well as lower prices. The provision and operation of landmine detection equipment is largely dependent on ODA and other funds, so ordinary corporations find its commercialization problematic. Therefore, development by non-profit universities and public research institutions as an act of international contribution has been preferable.

Worldwide, ground penetrating radar development projects run by universities and public research institutions have largely been completed and some of their results are now moving towards application following field testing and evaluation.

In addition, this is a time when research results can be applied not only to landmine detection, but also to other applications requiring new sensor technologies. Therefore, leading research groups that have carried out landmine detection research in Japan, the USA and European countries are planning to build a research network. This continued research means that landmine detection technology may also be able to make major international technological contributions to environmental monitoring as well as in other areas.

Furthermore, because landmine detection technology is shallow ground measurement technology used in extremely difficult environments, the technical development standards are very high. There are potential applications of underground measurement technology currently being studied that will help to safeguard society. These applications include lifeline maintenance engineering for gas and water pipelines, communications and electrical cables, addressing soil pollution and other environmental problems, disaster prevention, and other safety measures. The advanced technology obtained through work on landmine detection can thus provide many opportunities to contribute to safety in various applied fields.

Figure 9 : ALIS output images from Bibi Mahro Hill



This report examined humanitarian landmine detection technology in the area of public research and development for a highly specific purpose. In addition to meeting its original goals, the accumulated results of this technical development should be disseminated to general-purpose and applied fields. The research conducted in this field can become a model for the widespread application of research and development results throughout society.

References

[1] Japan Science and Technology Agency,

http://www.jst.go.jp/kisoken/jirai/index.html
[2] Website of the International Campaign to Ban Landmines, http://www.icbl.org/
[3] Website of the United Nations Electronic Mine Information Network, http://www.mineaction.org/index.cfm
[4] D. Daniels, "GPR for landmine detection, and Invited review paper," Proc. Tenth Inter. Conf. on Ground Penetrating Radar, IEEE Catalog No. 04EX855, 2004.
[5] Website of CyTerra Corp., http://www.cyterracorp.com/CY-minedet-fr-HSTAMIDS.htm
[6] ERA Technology Ltd., http://www.era.co.uk/
[7] Website for demining detection technology, http://www.itep.ws/
[8] Website on humanitarian demining, http://www.gichd.ch/
[9] Ministry of Foreign Affairs related website, http://www.mofa.go.jp/mofaj/gaiko/oda/seisaku/bunya/jirai/jirai.html
[10] M. Sato, Y. Hamada, X. Feng, F. Kong, Z. Zeng, G. Fang, "GPR using an array antenna for landmine detection," Near Surface Geophysics, 2, pp. 3-9, 2004.
[11] X. Feng and M. Sato, "Pre-stack migration applied to GPR for landmine detection," Inverse problems, 20, pp 1-17, 2004.
[12] X. Feng, J. Fujiwara, Z. Zhou., T. Kobayashi and M. Sato, "Imaging algorithm of a Hand-held GPR MD sensor (ALIS)," Proc. Detection and remediation technologies for mines and minelike targets X, March 2005.
[13] X. Feng, Z. Zhou., T. Kobayashi, T. Savelyev, J. Fujiwara and M. Sato, "Estimation of ground surface topography and velocity models by SAR-GPR and its application to landmine detection," Proc. Detection and remediation technologies for mines and minelike targets X, March 2005.

Information on mine detection technology

[i] The Demining Technology Information Forum (DTIF): http://maic.jmu.edu/dtif/
[ii] The European Commission's Joint Research Centre (JRC), Sensors and Cybersecurity Unit (SERAC): http://serac.jrc.it/tethud/
[iii] The European Union, EUDEM database: http://www.eudem.vub.ac.be.
[iv] Action for Research and Information Support (ARIS): http://demining.jrc.it/aris/
[v] The Nordic Demining Research Forum (NDRF): http://www.ndrf.dk/
[vi] The United States Humanitarian Demining Research and Development Technology Program: http://www.humanitariandemining.org/
[vii] The United States Unexploded Ordnance Center of Excellence (UXOCOE): http://www.uxocoe.brtrc.com/
[viii] The Canadian Centre for Mine Action Technologies (CCMAT): http://www.ccmat.gc.ca/
[ix] The James Madison University (JMU), Mine Action Information Center (MAIC): http://maic.jmu.edu/
[x] MgM: http://www.landmine.org,
[xi] Norwegian People's Aid (NPA): http://www.angola.npaid.org/
[xii] HALO Trust: http://www.halotrust.org.
[xiii] Nobuhiro Shimoi, "Technology that aims to eradicate landmines: the state of humanitarian landmine detection and removal", Morikita Shuppan Co., Ltd., 2002

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