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Instrumented Prodder: results from the tests under controlled conditions

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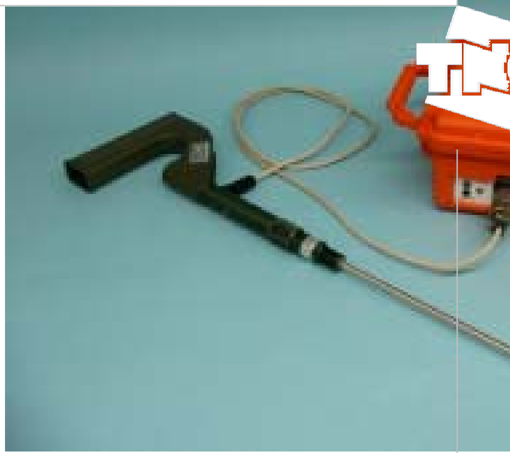
Netherlands Organisation for Applied Scientific Research (TNO)

MANAGEMENTSUMMARY

Instrumented Prodder: results from the tests under controlled conditions



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Problem formulation

The prodder is still one of the most important tool in both humanitarian and military demining operations. In Canada some years ago an instrumented prodder was brought on the market that gives its operator information on the material (plastic/wood; metal; stone) under contact with the prodder. Because the reliability of the material identification feature of this instrumented prodder was too low, this product was taken off the market and work was started on an improved version. This improved version was tested in September 2002 by the Canadian Center for Mine Action Technology (CCMAT). The results were promising, but it was also noticed that further development of the device was necessary before it could be used in demining operations.
By order of the Netherlands Ministry of Defence and with consent of CCMAT, TNO-FEL has taken the lead in the further development of the instrumented prodder. In the first phase of this development project, the performance of the current version of the device is determined under controlled conditions. In order to direct this development to a device that can be used optimally in demining operations, it is important to have knowledge of these operations and the circumstances in which they take place and to know the requirements from the users for these devices.

Task description

A usergroup has been formed with representatives from both humanitarian and military demining organisations. This usergroup was involved in the definition of the demining scenarios in which an instrumented prodder can be used and the draw up of the user requirements for such kind of a device. Via a discussion panel on Internet other persons with experience in demining were asked their opinion on the contribution of a prodder with material identification feature to safer or faster detection of landmines.
Two samples of the current version of the instrumented prodder were made available by CCMAT for tests under controlled condition to determine its performance. A test plan was drawn up with input from the usergroup. The tests were performed at the test facility at TNO-FEL. The material identification feature of the prodder was tested on seven different test target from wood, plastic, metal and stone, buried in six different soil types. This feature requires that the prodder is inserted into the soil with a force that is in a certain range. During the tests it was checked that the forced used was indeed in this range. Three different angles (30°, 60° and 90°) were used to insert the prodder into the soil. In the analysis of the results of the tests the dependence of the performance of the instrumented prodder of the parameters mentioned before were studied.

Results and conclusions

From the discussion with the usergroup and other persons with experience in demining it is concluded that the application of an instrumented prodder will be limited, but that in certain operations it may have a beneficial value. From the test results it is concluded that material identification of buried objects

with the technology applied in the instrumented prodder is possible. The use of the instrumented prodder is limited to the softer soil types, just as the conventional prodder. The performance of the current version of the instrumented prodder is affected by the stickiness of the soil: in sticky soil, such as clay, the material identification by the prodder is unreliable. The test experience with the instrumented prodder has led to a number of proposals for improvements. Three options for continuation of the instrumented prodder development are given. These options are the development of the prodder as a tool for detection (in accordance with the original project plan), the development as a tool that can be used during excavation of a detected, suspected object or as a training tool for deminers. The first two options have the largest technical risk, while the applicability of the resulting devices appears to be limited.

The technical risk of the last option is limited, since the material identification feature will not be implemented. This training tool gives only an alarm when the deminer under training uses a prodding force that is too large for safe demining. The Netherlands Ministry of Defence has decided to stop the sponsoring of this development, because of the disappointing results of the current version of the Instrumented Prodder, the technical risk of the development and the expected limited use of the instrumented prodder in demining operations. The Netherlands Ministry of Defence expects that the Instrumented Prodder (after completion of the development path) will not be accepted by deminers and sees no surplus value of this device in both humanitarian and military demining operations. Moreover, other alternative (mechanical) demining tools are foreseen in the near future.

PROGRAM	**PROJECT**
Program manager -	Project manager Kap N.C. Netten, OTC Genie/Kenniscentrum
Program leader -	Project leader Dr. A.J. Schoolderman, TNO-FEL
Program title -	Project title Smart Prodder product ontwikkelingstraject, Fase A
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Abbreviations

ADP	Accelerated Demining Programme
CCMAT	Canadian Center for Mine Action Technology
ITEP	International Test and Evaluation Programme on humanitarian demining
NGO	Non-governmental organisation
RNLA	Royal Netherlands Army
TNO	Netherlands Organisation for Applied Scientific Research
TNO-FEL	TNO Physics and Electronics Laboratory
TNO-PML	TNO Prins Maurits Laboratory
UXO	Unexploded ordnance

1. Introduction

1.1 History

The prodder is one of the most important tools for a deminer involved in humanitarian demining operations. An overview of the development and the use of the prodder in demining can be found in [1]. Developed in Canada, an 'Instrumented Prodder' was an attempt to improve on the basic prodding tool. This device is a prodder for the detection of landmines, which gives an indication of the type of material (metal, plastic/wood or stone) in contact with the probe tip. This indication aids the operator in classification and identification of the buried object. The first version of the Instrumented Prodder, called 'SmartProbe', was manufactured in small numbers by the Canadian company, DEW Engineering and Development Ltd., under licence from the Canadian Department of National Defence. After extensive field testing, it was concluded that the SmartProbe 'did not function as advertised' [2], [3].

The advantage of a force feedback signal during demining by manual prodding has been stressed by Gasser [4], [5]. Deminers appear not to be aware that the force that they exert on the prodder is in many cases higher (sometimes even orders of magnitude higher) than the force required to detonate many types of anti-personnel mines. This is of concern especially in countries in which the soil is hard, as prodding on anti-personnel mines is a major cause of demining accidents. The force feedback signal that warns the operator of excess force being applied may contribute to increased safety. Funded by CCMAT, the Canadian company, HF Research Inc., initiated a redesign of the Instrumented Prodder and produced a 'technology demonstrator' that is equipped with a force feedback system, in addition to the material indication[1] feature.

The current technology demonstrator version has been subject to a blind test executed in September 2001 in Canada [6]. In this test more than 1000 buried objects (defused mines as well as mine-like objects such as wood, plastic, and stones) were subject to detection by five operators. Though the detection performance of this technology demonstrator version is clearly better than that of the SmartProbe, further development may be necessary to bring the device up to a level that is acceptable to the humanitarian demining community.

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[1] Strictly speaking, this feature classifies the material into three classes, i.e. wood/plastic, metal and stone, and thus should be called a 'material classification feature'. Identification implies that the exact material is given. However, in this report this feature will be denoted as material identification.

It is expected that in certain demining operations the Instrumented Prodder will be very suitable to Non-Governmental Organisations (NGOs) due to its simple operation and small maintenance burden. If the material indication and force feedback functions well and are reliable, the training of local deminers for the operation of the Instrumented Prodder should be only a small addition to their regular training.

In August 2002 the Dutch Ministry of Defence asked TNO-FEL to start the project ’Smart prodder product development path’ in order to guide further development of the technology demonstrator version of the Instrumented Prodder towards a device suitable for use in demining operations. (The name ’Smart prodder’ was abandoned early in the project in order to prevent confusion with the DEW SmartProbe.) This project is one of the six projects for the development of equipment and techniques suitable for humanitarian demining that was funded by the Ministry of Defence. All six projects are being performed at TNO (both TNO-FEL and TNO-PML) or at Technical Universities in the Netherlands.

1.2 Project overview

The objective of the project ’Smart prodder product development path’ is the guidance of the product development path of the Instrumented Prodder. The project aims at the ultimate introduction of the Instrumented Prodder by one or more NGOs. For this purpose a number of activities are being undertaken that cover both the technical and commercial aspects.

One of the activities consists of tests and evaluations of the different versions of the Instrumented Prodder that will become available during the development path. Another important activity is the exploration of possible product development paths. In all activities both the RNLA and one or more NGO's are being involved in order to guarantee the commitment of the end-users. It is essential that, after successful development, NGOs will actually use the Instrumented Prodder. By involving NGOs from the start of the development path and the evaluation, they will gain clear insight at an early stage.

The project ’Smart prodder product development path’ consists of two phases:
Phase A consists of the following work packages:

1 A usergroup formed under the guidance of TNO-FEL. The RNLA (Royal Engineers), one or more NGOs and possibly CCMAT will be represented in this usergroup. The usergroup will be involved in the Instrumented Prodder development during the entire project and served as a sounding board for TNO-FEL. The first task of the usergroup will be writing of a scenario description for the deployment of the Instrumented Prodder. This will be the basis for the formulation of the user requirements.

2 The two technology demonstrator samples of the Instrumented Prodder (that have been made available by CCMAT) will be tested under controlled laboratory conditions in order to determine the detection performance in an objective way. A test plan will be written in which, as far as possible, attention is also given to testing against the user requirements formulated by the usergroup. For evaluation under laboratory conditions on the test lanes of TNO-FEL, the measurement platform will be modified in such a way that the force exerted on the Instrumented Prodder to move it into the soil can be controlled. Inert mines and 'false alarm' objects made of various materials will be buried in the test lanes. The results of these tests under laboratory conditions will be analysed and discussed with CCMAT and HF Inc.

3 The possibilities for further steps in the product development path of the Instrumented Prodder will be investigated in work package 3 that runs parallel to work package 2. To this end further development and finally production in Canada will be discussed with CCMAT and HF Inc, in close consultation with RNLA. Development and production in the Netherlands is also an option and TNO-FEL will play a key role in this. In the latter case, there will be consultation with the Canadian government on the Instrumented Prodder licence.

A status report will be written after completion of the work packages 1-3. This report will be discussed with the usergroup and the RNLA will be advised on continuation of the product development path of the Instrumented Prodder ('Go / No go' for phase A of the project ’Smart prodder product development path’). This advice will be based on the expected chances for final production of the Instrumented Prodder.

After the advice for a ’Go’ or ’No go’ by TNO-FEL, it is expected that the RNLA will take the decision: after a ’No go’ the project will be stopped. If the RNLA decides for a ’Go’, the project will continue with work package 4.

4 If the project is continued (after a decision for a ’Go’), the technology demonstrator version of the smart prodder will be evaluated under simulated operational conditions in work package 4. A test plan will be written after consultation with the usergroup. A test site at the Miner Training Center of the Royal Engineers at Reek (NL) will be prepared. The analysed test results will be discussed with the usergroup, CCMAT and HF Inc.

5 The activities of work package 3 will be continued in work package 5. Interpretation will depend on the results of work package 3. The selection of location for further development of the Instrumented Prodder in Canada or the Netherlands is essential.

After the completion of work packages 4 and 5, a second status report will be written and discussed with the usergroup. This status report will serve as the final report of phase A of the project ’Smart prodder product development path’ and will contain a recommendation with respect to continuation of the development path. In addition to the technical aspects, the opportunities for application by NGOs and possibilities for the production and its related funding will play a key role in this recommendation. The status report will also give a detailed outline of the way to proceed with the development path in phase B of the project.

The Ministry of Defence has put forward the possibility of sponsoring fully or partially series production of the Instrumented Prodder by the Dutch government, e.g., the guaranteed purchase of a limited number of Instrumented Prodders for the benefit of an NGO. TNO-FEL will explore this possibility actively together with the representative of the Ministry of Defence.

The work to be performed in phase B of the project ’Smart prodder product development path’ will depend on the developments in phase A. However, a number of activities in phase B can already be anticipated. After the completion of a prototype version of the Instrumented Prodder, a field trial will be performed in a country with an actual landmine threat. The location of this field trial will be determined in consultation with potential users of the Instrumented Prodder and members of the usergroup will attend these field trials. A test period of approx. 2 weeks is foreseen. The maturity of the prototype will partially determine the composition of the test team. TNO, CCMAT or the manufacturer can bring in technical assistance. After modifications (if necessary) of this prototype, resulting from these field trial experiences, the production of the first series can be started.

Support by the Ministry of Defence
The Dutch Ministry of Defence is playing an important role in the development of the Instrumented Prodder. The RNLA is represented in the usergroup that serves also as a sounding board for the project manager. The RNLA will contribute in the process of the formulation of the user requirements for the Instrumented Prodder. Support has been requested from the Ministry of Defence for the availability and preparation of a test site at the Miner Training Center of the Royal Engineers at Reek (NL).

International collaboration
Collaboration with CCMAT, Canada, is important for this project. CCMAT has already provided TNO-FEL with the two existing Instrumented Prodder samples for the tests in phase A. The results of the tests will be made available for CCMAT. As mentioned above, a representative of CCMAT has become a member of the usergroup.
The collaboration with CCMAT has been placed under quadrilateral collaboration (Canada, UK, Sweden, the Netherlands) in the area of demining. The project is also placed under the umbrella of the ‘International Test and Evaluation Programme on humanitarian demining’ (ITEP).

Collaboration with potential end-users (NGOs) is essential for the success of the project. It may be possible to extend international collaboration via contacts with these NGOs.

Result

The result of phase A of the project ’Smart prodder product development path’ is a recommendation for the continuation or otherwise of the development of the Instrumented Prodder to a version ready for serial production. It will be outlined in detail how this product development path can be modelled in phase B of the project. The roles of the players (TNO-FEL, RNLA, NGOs and if necessary CCMAT and HF Inc) will be indicated. This recommendation will be based on the results of the tests performed in phase A. In these tests the Instrumented Prodder will also be tested against the user requirements as formulated by the usergroup.

The present report is the first status report written under the framework of the project ’Smart prodder product development path, phase A’. The tests under controlled conditions of the technology demonstrator version of the Instrumented Prodder are the main topic of this report. However, in Chapter 2 the establishment of the usergroup as well as discussions with the demining community on the utility of a device such as the Instrumented Prodder in demining operations are reported.

The characteristics of the technology demonstrator version of the Instrumented Prodder and set-up of the tests under controlled conditions are described in Chapter 3. The results of the tests are given in Chapter 4. Finally, in Chapter 5 an assessment of the test results is reported, as well as information on the utility of the Instrumented Prodder obtained from the discussions with the usergroup and the demining community. Chapter 5 concludes with a number of options for the continuation of the product development path of the Instrumented Prodder. The main conclusions are summarised in Chapter 6.

2. Usergroup and discussions with end-users

In order to obtain information from potential end-users of the Instrumented Prodder, a usergroup has been established and the development and use of the Instrumented Prodder have been brought under discussion with the demining community. In this chapter the establishment of the usergroup, communication with that group prior to the tests of the Instrumented Prodder under controlled conditions and the discussion with the demining community are reported. In Chapter 5 the discussion with the usergroup of the results of and experiences in the tests under controlled conditions is reported.

2.1 Usergroup

The goal of establishing the usergroup was to form a sounding board for the project team. Preferably, the usergroup consists of representatives from both the humanitarian demining community and the Royal Netherlands Army. The intention was to find persons with experience in demining, e.g., from involvement in demining operations. For that reason, a number of NGOs have been contacted. It appeared that some of the contacted NGOs had objections with respect to the utility of the Instrumented Prodder in humanitarian demining. This issue will be discussed in Section 2.2.

On 27 November 2002, Phil Straw from the NGO Halo Trust visited TNO-FEL to discuss, amongst other things, the involvement of this NGO in the Instrumented Prodder product development path. After explanation of the project and the Instrumented Prodder, Phil Straw commented that Halo Trust uses metal detectors for primary detection. The conventional prodder is used to probe approaching mines from the side and this prodder is only 20 cm long. Identification of material is regarded as less important, since the deminer will remove the object anyway, since all metal, as indicated by the metal detector, should be removed from the area to be demined.

According to Straw, there could be a use for the Instrumented Prodder in a military context. In the UK army the prodder is the primary sensor and a metal detector is used for confirmation. Shrapnel causes a metal detector alarm that is for the operator often indistinguishable from an alarm caused by a mine that contains metal. Additional information on the material on the outside of the unknown object (mine or shrapnel) from the Instrumented Prodder may avoid checking shrapnel.

In the opinion of Straw it is not likely that the Instrumented Prodder, nor an upgraded version, will be used in Halo Trust's operations, since Straw expects that in a time frame of 2-3 years from now better detectors and detection techniques will be available. Hence, in his opinion the outcome of the project ’Smart prodder product development’ will come too late on the market.

In December 2002, Andy Frizzell, Chief Technical Advisor of the Accelerated Demining Programme (ADP) in Mozambique, and Jacky D'Almeida, Programme Director of ADP, were contacted by e-mail to invite them to become a member of the usergroup. After two reminders, they replied in January 2003 that ADP had decided against becoming involved in the Instrumented Prodder project for two reasons. Firstly, because ADP was very busy with a "long term trail and testing of a mini-flail and a potential commitment to a GPR trial evaluation process" and, secondly, because ADP was of the opinion that the demining community "is trying to move away from a heavy reliance on manual demining. ADP has reservations regarding the ability of the Instrumented Prodder to enhance the way ADP undertakes humanitarian clearance".

In December 2002, Martin Auracher, director of the demining organisation Demira, was informed about the Instrumented Prodder, asked about his opinion on the utility of the device for demining and invited to become a member of the usergroup. Demira is primarily active in the Balkan region and Auracher accepted the invitation.

In January 2003, the British NGO MAG was contacted to invite them to make a representative available for the usergroup. This contact was made possible partly due to individuals involved in ITEP. However, no response form MAG was received.

CCMAT, the initiator of the Instrumented Prodder development, found that John Kirby was willing to become a member of the usergroup. Kirby has a lot of experience in both military and humanitarian demining and has worked since February 2003 as senior technical advisor in Congo for Handicap International Belgium.

After invitation, Russel Gasser became a member of the usergroup. At present Gasser is working as a project officer for Humanitarian Demining RTD for the European Commission, but his involvement in the usergroup is in a private capacity.

As a representative of the military demining community, warrant officer Willem Fleury became member of the usergroup. Warrant officer Fleury is a demining instructor at the Training Centre of the Miners School of the Royal Engineers of the RNLA.

The usergroup, therefore, consists of the following persons.
M. Auracher (Demira),
J. Kirby (Handicap International Belgium),
Dr. R. Gasser (private capacity),
Warrant-officer W. Fleury (Royal Engineers, RNLA).

2.2 Discussions with the demining community

The NGO 'Menschen gegen Minen' (MgM, People against mines) has a free forum on Internet that can be used by deminers, researchers, etc., to discuss all topics related to demining and UXO disposal. More than 1000 persons are on the mailing list of the MgM Forum.

In February 2003 a question was asked on the status of the DEW SmartProbe. After a few replies were posted on experiences with this device (in most cases from hearsay), the Instrumented Prodder project team posted a short message saying that the device had been redesigned and that a technology version is under test. The text of this message is as follows:

The information on the 'intelligent prodder' (or Smart Prodder) that is mentioned in the previous messages on this topic is outdated. All these messages refer to the product by the Canadian company Dew (the Dew SmartProbe). This device has been tested (amongst others) by the NVESD.

Due to the results of these tests, the device was redesigned by the company HF Inc (also from Canada), sponsored by CCMAT (located at DRES, now DRDC Suffield). This redesign has resulted in a 'technology demonstrator' that has been tested in a limited field test by CCMAT. The results were quite promissing and were presented by Kevin Russell (DRDC Suffield) at the last UXO/Countermine Forum.

The technology demonstrator version of the Instrumented Prodder (we speak now of the Instrumented Prodder in stead of Smart Prodder, to prevent confusion with the Dew SmartProde) will be tested under laboratory conditions in April in the Netherlands and in the fall under simulated field conditions as a first step in a product development path. These tests will be set up and executed by TNO-FEL in the framework of a project funded by the RNLA. A usersgroup is formed to get input, comments etc from deminers with field experience. We intend to present the results of the first tests at the EUDEM2SCOT 2003 conference in September in Brussels.

Hope to have you updated now on the Instrumented Prodder.
Regards,
Project team

A number of people responded to this message. They commented on the absence in the message of any mention of new functionalities in the Instrumented Prodder with respect to the DEW SmartProbe and on its blast resistance. Andy Smith, a well-known independent demining consultant, sent the following message:

You have not explained how the functionality [of the Instrumented Prodder] varies from the Dew SmartProbe, but that is not the reason for my concern. Perhaps you have added a value that I cannot guess?

I hope that the development path could be STOPPED if necessary because prodding and digging hand-tools that are not blast-resistant have been the direct cause of many severe injuries, amputations and some deminer deaths.

Many demining accidents that are deemed "unavoidable" occur while prodding or excavating. If your prodder ever gets into wide service, a deminer WILL initiate a mine with it before too long. A complex probe is likely to have many components and so will be liable to separate and/or shatter in a blast unless you have taken great care to design to avoid this. Does your testing include tests to ensure that it will not break-up and cause the user severe injury when he inadvertently initiates 240g TNT? If you want to include such tests, I can advise - but you may like to go off-line to avoid boring others.

In a later message, after the project team had described the functionality of the load sensor of the Instrumented Prodder, Andy Smith replied:

On safety, I repeat, if your prod gets into use - it WILL initiate a mine sooner or later. You really CANNOT add blast-resistant characteristics as an afterthought. The design limitations needed to achieve blast resistance are so fundamental that you must go back and redesign the whole thing again.

He also gave some information on how the prodder is frequently used:

It is a very fortunate deminer who has nice soft soil to prod about in. In the real world, ground hardness dictates that varied forces are required in order to penetrate the ground. This is often done "two-handed" - and excavation tools around the world include probes, bayonets, pick-axes, hoes, spades, shovels, and a variety of trowels. Any tool that set a "limit" to what was safe in terms of the force applied, has very limited practical utility, if any.

In most circumstances where the ground is hard or compacted, deminers do not prod to "feel" for a mine. They prod to loosen the ground and frequently MUST use a force that would initiate most mines to do this. They then excavate the loosened ground and work forward with a prodding action to loosen more ground again. What makes this safe is that they start back from the detector reading, dig down and then forward so that they would expose the side of a laterally placed mine.

They never intend to prod onto the top of it. If mines are known to have moved or to have been placed in an anti-prod orientation on their side - the excavation process can be painfully slow but it works at least 99.99% of the time.

In those luxurious circumstances where mines are placed in soft or sandy ground, a prod can be used to feel forward - but the deminer is "feeling" for the side of the mine not for the pressure-plate.

Bob Keeley brought the issue of productivity increase into the discussion:

[…] your response would have also been so much more powerful if you were able to say something like "In (simulated) field conditions our time and motion study suggests that a deminer can achieve between X and Y% increase in productivity given the following conditions..." which would at least give us something to chew on! The absence of ANY reference to productivity suggests that it hasnt been thought as being of very much importance.

The discussions came to an early end after the following message was posted by the project team:

In the contributions to the discussion on the Instrumented Prodder up till now we don't find a response on the point that the Instrumented Prodder may be useful in some demining scenario's ("when blast-resistant", Andy [Smith] will add; we have not forgotten that issue). Think of scenario's where
1a) or very much metal clutter is present so that metal detectors in general can't be used because of the large number of false alarms,
1b) or the soil contains a huge percentage of magnetite so that the metal detector of the demining organization involved in this operation can't be used,
2) the soil is not that hard,
3) from information on the mine threat (by experience or from intelligence) one knows that only mines with plastic/bakelite casing are present.
We would like to see some input on this point, preferably also by others than those already involved in the discussion. From personal mail that we received parallel to this discussion (but clearly triggered by this discussion), we conclude that there are at least some 'supporters'. Andy asked already for mails to the forum from anyone that supports the idea of the Instrumented Prodder (in some scenario's, we add).

Bob [Keeley] asked for a statement on the expected productivity increase due to the Instrumented Prodder. We agree that it would be nice if we could provide that information. However, after the development and validation of a model (what Bob calls "time and motion study in (simulated field) conditions"), we would have to feed the model with values for its parameters describing (amongst other things) the prodder's 'intrinsic' performance. Those values are not known yet for the Instrumented Prodder (probably even not all parameters!).

We hope to get an understanding of these things from the tests under controlled conditions as scheduled for April. In brief: it is much too early to answer this question.

We will certainly include all points from the discussion here on MgM forum in the report on the project that will be written medio July, and discuss them with our sponsors. But the discussion is not yet closed …

Regards,
The project team.

As indicated in the message above, some readers of the MgM Forum preferred to contact the project team directly, thus avoiding a discussion on the Forum. One of these, James Trevelyan, a well-known professor at a university in Australia, advised us to "*visit a demining group in Croatia or Bosnia where metal contamination issues are significant and demining costs are high in some areas*". The possibilities for such a visit have been discussed with Martin Auracher from the demining organisation Demira and one of the members of the usersgroup. However, it was decided first to get a better impression of the performance of the Instrumented Prodder by execution of the tests as intended in the project.

Summarizing, the following topics should be considered at an appropriate moment along the product development path of the Instrumented Prodder.
- How can the Instrumented Prodder be designed so that it is blast resistant?
- What is the productivity increase that can be achieved in a demining operation by using the Instrumented Prodder?
- In which demining scenarios has an optimal performing Instrumented Prodder a surplus value?

The last topic will be considered again in Chapter 5.

3. Tests under controlled conditions

The tests under controlled conditions of the technology demonstrator version of the Instrumented Prodder were performed in April 2003 at the outdoor test facility of TNO-FEL, The Hague, The Netherlands. This version of the Instrumented Prodder and the set-up of the tests are described in this chapter and the results of the tests are discussed in Chapter 4.

3.1 Technology demonstrator of the Instrumented Prodder

The current version of the Instrumented Prodder, as designed by HF Research Inc. under contract to CCMAT, can be regarded as a 'technology demonstrator'. With this version, the feasibility of the concept of a prodder with force feedback and material indication can be demonstrated, but the device in this version is not intended or suitable for field testing under less controlled conditions. Since improvements of the technology demonstrator are not part of the objective of the current project, only a short description of the working principle of the technology demonstrator is given here. However, some ideas for improvements that occurred during the preparations and execution of the tests are described in section 4.3.

The current version of the Instrumented Prodder has two integrated sensors: a load cell and a piezoelectric crystal. The load cell is used to measure the force exerted on the prodder’s needle when it is inserted into the soil. The implemented load cell is an Entran ELFM subminiature load cell with a force range up to 25 N (specified over-range limit: 50 N). The piezoelectric crystal sends ultrasonic pulses with a frequency of 100 kHz through the prodder's shaft and receives back the reflected pulses. Combining the phase change of the transmitted and reflected pulses and the contact force between the prodder’s tip and the material buried, the material in contact with the tip can be identified by the 2-parameter material recognition algorithm implemented in the electronics. This algorithm is described in [6].

The electronics to drive the piezoelectric crystal and to process the phase change and load cell signals are housed in a plastic box, together with the power supply batteries. The prodder is tethered to this box by a cable (see Figure 1). The electronics box is equipped with a RS232 connector for digital recording of the load cell output and the material identification signal (the so-called ’decision signal’). The present technology demonstrator does not have an audio output, hence it is necessary to use it with a laptop or palmtop computer, equipped with suitable software, in order to visualise the decision signal and, if desired, the load cell reading.

Figure 1: Technology demonstrator version of the Instrumented Prodder

3.2 Objective of the tests under controlled conditions

The objective of the tests under controlled conditions was to assess the material identification feature of the technology demonstrator version of the Instrumented Prodder for objects buried in soils with different properties (sand; clay; peat; iron-containing, medium hard soil; forest soil and grassland). Objects of stone (brick, concrete), wood, metal (steel, aluminium) and plastic (PVC, inert PMN mines) were used as test targets. The execution of the tests under controlled conditions implies that the force used to penetrate the prodder into the soil is controlled, as well as the angle of the prodder with the soil surface (the prodding angle). The ‘decision signal’ and the force as measured by the load cell of the Instrumented Prodder were recorded digitally during the tests for future processing.

3.3 Test set-up

The set-up for the tests under controlled conditions is described comprehensively in the test plan (Appendix B), which also describes the test procedure and looks forward to the analysis method.

In this section the most important issues laid down in the test plan are reported, as well as a few deviations from the test plan that occurred during execution of the tests.

3.3.1 Equipment

Instrumented Prodder

Two identical samples of the Instrumented Prodder (technology demonstrator version) were available for the tests. The three main parts of each sample, i.e., the part consisting of the needle and the piezoelectric crystal, the part containing the load cell and the electronics box, were all marked with the letter ‘A’ or ‘B’ . In this report the same designation is used.

Test lanes

The tests were executed at the outdoor test facility of TNO-FEL. This test facility consists of six test lanes with a length of 10 m, width of 3 m and depth of 1.5 m. The six lanes contain one of the following materials: sand, clay, peat, iron-containing soil (ferruginous soil), woodland soil (forest soil) or a grass layer (Figure 2). At the test facility an XY positioning frame is present which enables the measurement platform, on which the prodder under test is mounted, to be positioned manually on the intended prodding location prior to each prodding action. Additional information on the test lanes .

Figure 2: TNO-FEL outdoor test facility consisting of 6 test lanes and an XY-positioning frame

Mounting and force control

In order to control the angle of the prodder to the soil surface, a mounting frame was designed. This mounting frame consisted of an aluminium plate and an extension part for the Instrumented Prodder (Figure 3). The aluminium plate was fixed on the measurement bridge with four screws.

The Instrumented Prodder was screwed on the extension part after the handle of the prodder had been removed. The extension part was attached to the mounting plate on a pivot, so that the angle of the Instrumented Prodder with respect to the soil surface can be changed. Screw holes in the aluminium plate facilitate fixing the prodder at prodding angles of 30°, 60° and 90° with respect to the soil surface. These three prodding angles were used in the actual tests (see Section 3.3.3).

To exert a force on the prodder to penetrate the soil, initially a DC motor was used. Since the material-identification algorithm implemented in the Instrumented Prodder is designed to perform optimally for contact forces in the range of 2 to 11 N (see [6]), a motor was selected that could apply a maximum force of 15 N. This motor was driven by a power supply with current limitation. A calibration table was used to set the current for the chosen force.
However, during preliminary tests it became clear that forces larger than 15 N were required to insert the Instrumented Prodder in most soil types present in the six test lanes. For that reason the motor was replaced by a manually operated spindle with a gearwheel (Figure 4). The manually exerted force was shown on the monitor of a laptop computer (see the following sub-section) in real time, so that the operator could control this force. Forces up to 35 N were used.

Figure 3: Instrumented Prodder mounted on the measurement platform

Figure 4: Instrumented Prodder under test with the manually operated spindle

Interface

To read out the decision signal and the load cell signal of the Instrumented Prodder, dedicated software, a DOS program which runs on a laptop computer (Toshiba 430CDT was used) has been developed. The laptop was connected to a RS-232 output connector on the electronics box of the Instrumented Prodder via a serial extension cable.

The operation of the Instrumented Prodder was controlled via three input commands. By sending a character to the input port, the prodder can be set into the three modes of operation as described in Table 1.

Table 1: Input control characters

Character	*Mode of operation*
“c”	Calibrate. This command will calibrate the system in air without contact with another object.
“i”	Initiate. This command will send the load cell offset to the output of the serial port.
“t”	Trigger. This command will make the Instrumented Prodder operational by activating the prodder’s sensors, and makes the output data available on the RS 232 output bus.

The data available on the output of the RS 232 port is given in Table 2.

Table 2: Output data

Data	*Indication*
PF	Load cell reading. This reading can be transformed to the actual force (in Newton) by using a simple formula (subtraction of the load cell offset, followed by a multiplication with a factor: F = c(PF – offset))
A	'Accuracy' (in some documents called the 'minimum error'). This figure is, according to the manufacturer, "essentially a measure of relative phase shift" of the received ultrasonic waves and is the solution of the algorithm implemented in the prodder's electronics.
M	Material. "0" = rock, "1" = metal, "2" = plastic/wood.

All output comes as a 4-character string, in which leading zeros are inserted if needed. The continuous data stream returned after triggering is made up of three (3) 4 character strings, separated by a "|", for example "0123|0022|0001". The first four characters represent the load cell reading, the second four represent the calculated minimum error. The last four characters represent the material determination.

The interface of the dedicated communication programme is shown in Figure 5, and Figure 6 shows the interface during an actual measurement.

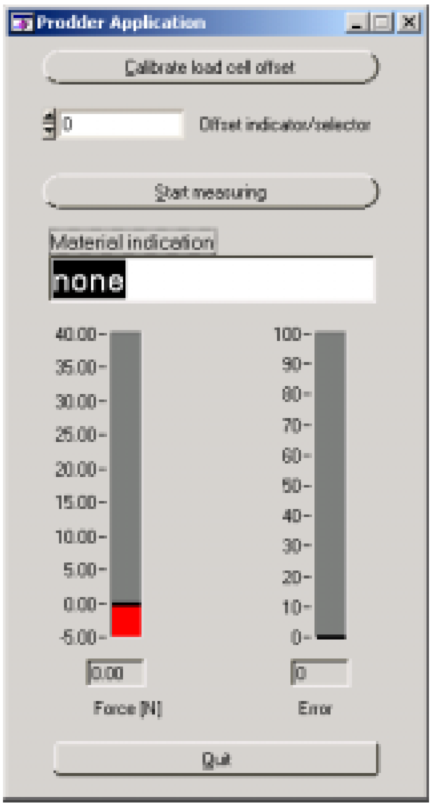

Figure 5: User interface of the communication programme

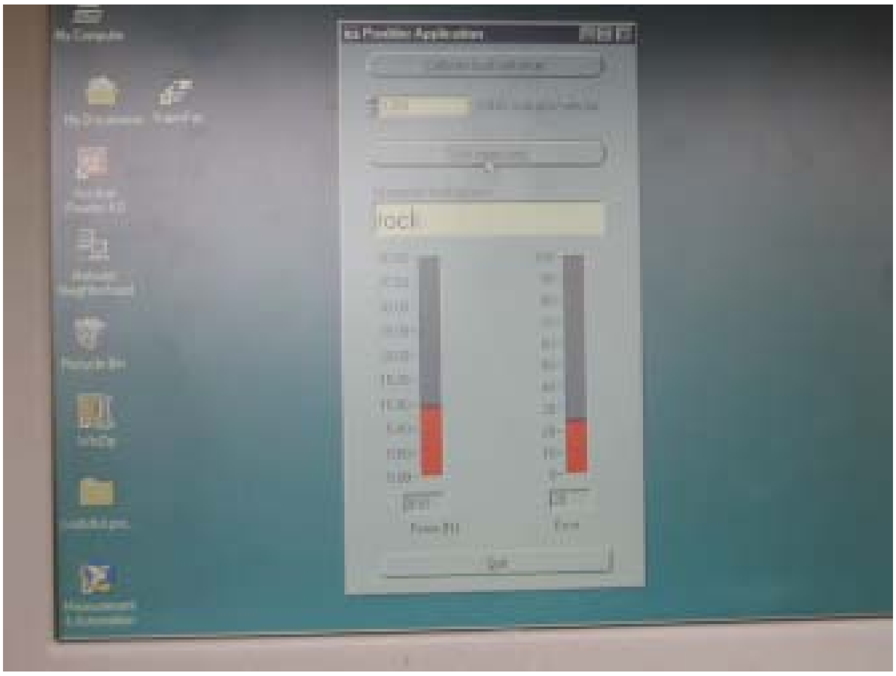

Figure 6: User interface during a measurement

Environmental characterisation

The soil hardness of and the moisture content in the top layer (the first 15 cm) of the six test lanes were measured. For the soil hardness measurements a Dutch Cone Penetrometer was used (Figure 7). The moisture content was measured with a Time Domain Reflectometer (TDR).

Figure 7: Use of the Dutch Cone Reflectometer on one of the test lanes

3.3.2 Test targets

In order to test the material identification of the Instrumented Prodder, seven different types of test targets were used. Two targets types were made of stone (concrete and brick) and two were made of metal (steel and aluminium). The three remaining target types were made of wood (fir) and plastic (PVC and inert PMN mines). The dimensions and shapes of all used targets were approximately the same. Table 3 contains detail information on the test targets and figure 8 shows these targets.

One sample of each target type was buried in each test lane. The targets were placed for convenience in a straight line with intermediate distances of 50 cm in each lane. The test targets were buried at a depth of 50 mm under the soil surface, measured to the top of the test object. The soil surface in each test lane was leveled after burial of the targets.

A hole was drilled in the top-center of each test target except for the PMN. The position of each buried test target was indicated above the soil surface via a marker (skewer) placed in this hole.

Table 3: Target types

No.	*Material*	*Shape and dimensions*	*Remarks*
1	PMN (inert)	Cylindrical, with protrusions Ø: 125 mm; h: 55 mm	PMN not present in the sand or clay lanes
2	Concrete	Cylindrical Ø: 100 mm; h: 55 mm	
3	Brick (cobble)	'Pillow-shaped' Ø: 100 h: 55 mm	
4	Aluminium	Cylindrical Ø: 100 mm; h: 55 mm	
5	PVC	Cylindrical Ø: 100 mm; h: 55 mm	
6	Wood (fir)	Cylindrical Ø: 100 mm; h: 55 mm	
7	Steel	Cylindrical Ø: 100 mm; h: 55 mm	

Figure 8: Seven different target types. From left to right: inert PMN, concrete, brick, aluminium, PVC, wood, steel.

3.3.3 Test Procedure

The test procedure consisted of the following steps.

- The Instrumented Prodder was assembled according to the test plan (see Appendix B).
- The measurement bridge and platform were positioned over the test target at the position suitable for prodding at the selected prodding angle (see test plan for detailed information on position). Three measurements were done for one prodding angle for each test target: one at the center of the target and two 4 cm out of the center (one measurement on each side of the center).
- The Instrumented Prodder and the laptop computer were switched on.
- The Instrumented Prodder was calibrated according to the procedure given in the test plan.
- The extension part of the mounting frame was adjusted for the selected prodding angle.
- The environmental information (soil hardness and moisture content) was recorded.
- The prodder was inserted into the soil by spinning the spindle manually while monitoring the exerted force on the monitor of the laptop computer.
- The time of the test, the ’material indication’ reading, the ’accuracy of indication’ reading and the ’load cell force’ reading on the laptop were recorded.
- The Instrumented Prodder was pulled back out of the soil.
- Whenever necessary (visual inspection), the Instrumented Prodder’s needle was cleaned with a dry cloth.

All test data was laid down on test cards as shown in the test plan. The digital output signal from the Instrumented Prodder under test was recorded for each test run, consisting of the prodding actions at one prodding angle and in one test lane, and the calibration prior to this run.

4. Results of the tests under controlled conditions

In this chapter the results of the tests under controlled conditions of the technology demonstrator version of the Instrumented Prodder and analysis of the results are reported. In addition, experiences with the technology demonstrator version are described.

As will be explained in Section 4.3.1, only one of the two available samples of the Instrumented Prodder (sample B) could be tested on all six test lanes. Consequently, only a well-founded assessment of the material identification performance of this sample is possible. For this reason, only the results of sample B are given in this chapter.

4.1 Test conditions

The tests of technology demonstrator sample B were performed from 14 to 16 April 2003, starting at 8h30 and stopping the tests at 16h00. The weather was fair during these days with no rain and temperatures during daytime around 20° C.

The moisture contents of the top layer of the six test lanes during the test period are given in Table 4. The hardness of the soil top layers was measured with a Dutch Cone Penetrometer. The average values and the standard deviation are given in Table 4. The clay, ferruginous, woodland soil and grassland soil can be considered as relatively difficult to penetrate. The high value for the standard deviation of the hardness in the lane with ferruginous soil is probably caused by the presence of many solid lumps of this soil type with typical dimensions of 2-3 cm. Sand and peat are relatively soft soils.

Table 4: Test lane soil conditions

Soil type	Sand	Clay	Peat	Ferruginous	Woodland	Grassland
Moisture content	4.4%	32%	29%	10%	15%	6%
Average hardness (Pa)	52	102	65	109	93	92
Standard deviation hardness (Pa)	8.5	20	16	39	5.5	18

4.2 Test results

Tables 5–10 show the test results for all soil types and all target types and for prodding angles of 30°, 60° and 90° and fixed load cell readings of 5 and 10 N. The load cell readings were monitored by the operator at the moment that he felt confident that the prodder's tip was in contact with the buried target.

In these tables, incorrect material identification (plastic: P; rock: R or metal: M) by the Instrumented Prodder are marked by a grey tint. When the prodder's tip could not make contact with the buried target, because the exerted force was too low, this is denoted in the tables with a dash. Contact of the prodder's tip with the buried object is called a 'hit'.

The results are given for each soil type in Tables 11-17. The percentages for the correct and incorrect material identifications are calculated relative to the number of hits.

The results of the tests are discussed in Chapter 5.

Table 5: Test results for a prodding angle of 30° and 5 N load cell reading

target	P/R/M	location	Sand	Clay	Peat	Ferruginous	Forestsoil	Grass	# hits	correct number	identification percentage
	P	+40	NA	NA	P	P	R	P			
PMN	P	center	NA	NA	P	P	P	P	12	10	83%
	P	-40	NA	NA	P	P	P	M			
	R	+40	R	-	M	M	P	M			
Concrete	R	center	R	-	P	R	R	P	16	8	50%
	R	-40	R	R	P	R	R	P			
	R	+40	M	M	-	M	-	-			
Brick	R	center	R	R	P	P	R	P	15	5	33%
	R	-40	R	P	P	M	R	P			
	M	+40	R	-	-	R	P	P			
Aluminium	M	center	R	P	M	M	R	P	16	5	31%
	M	-40	M	R	M	M	R	P			
	P	+40	R	-	-	P	R	P			
PVC	P	center	R	R	P	P	P	P	14	9	64%
	P	-40	R	-	P	-	P	P			
	P	+40	-	-	P	P	P	P			
Wood	P	center	P	P	P	P	R	P	16	13	81%
	P	-40	P	R	P	P	P	R			
	M	+40	-	-	-	R	M	M			
Steel	M	center	M	M	M	M	M	M	15	12	80%
	M	-40	R	M	M	M	M	P			

Table 6: Test results for a prodding angle of 30° and 10 N load cell reading

target	P/R/M	location	Sand	Clay	Peat	Ferruginous	Forestsoil	Grass	# hits	correct number	identification percentage
	P	+40	NA	NA	P	R	P	P			
PMN	P	center	NA	NA	P	P	P	P	12	9	75%
	P	-40	NA	NA	P	R	P	M			
	R	+40	R	-	M	M	R	R			
Concrete	R	center	R	R	R	M	R	R	16	12	75%
	R	-40	R	R	-	M	R	R			
	R	+40	M	M	-	M	-	-			
Brick	R	center	R	R	R	M	R	R	14	7	50%
	R	-40	M	R	M	M	-	R			
	M	+40	R	-	-	R	M	R			
Aluminium	M	center	M	P	M	M	R	P	16	9	56%
	M	-40	M	P	M	M	M	M			
	P	+40	R	-	-	P	P	P			
PVC	P	center	R	R	P	P	P	P	14	10	71%
	P	-40	R	-	P	-	P	P			
	P	+40	-	-	P	P	P	P			
Wood	P	center	P	P	P	P	P	R	16	13	81%
	P	-40	P	R	P	P	P	R			
	M	+40	-	-	-	M	M	M			
Steel	M	center	M	R	M	M	M	M	15	13	87%
	M	-40	M	R	M	M	M	M			

Table 7: Test results for a prodding angle of 60° and 5 N load cell reading

target	P/R/M		Sand	Clay	Peat	Ferruginous	Forestsoil	Grass	# hits	correct number	identification percentage
	P	+40	NA	NA	P	M	P	P			
PMN	P	center	NA	NA	P	R	P	P	12	9	75%
	P	-40	NA	NA	P	M	P	P			
	R	+40	M	R	-	R	R	R			
Concrete	R	center	M	R	R	M	R	R	16	10	63%
	R	-40	M	M	P	-	R	R			
	R	+40	M	M	P	P	M	P			
Brick	R	center	M	M	P	R	R	R	18	5	28%
	R	-40	M	M	P	R	R	M			
	M	+40	M	R	-	-	M	M			
Aluminium	M	center	M	R	M	R	R	M	16	11	69%
	M	-40	M	M	R	M	M	M			
	P	+40	R	R	-	P	P	P			
PVC	P	center	R	R	-	P	P	P	15	8	53%
	P	-40	R	R	-	M	P	P			
	P	+40	R	R	-	P	P	-			
Wood	P	center	R	R	P	R	P	-	13	7	54%
	P	-40	R	P	P	-	P	-			
	M	+40	-	R	-	M	M	M			
Steel	M	center	M	R	-	R	R	M	13	8	62%
	M	-40	R	M	-	-	M	M			

Table 8: Test results for a prodding angle of 60° and 10 N load cell reading

target	P/R/M		Sand	Clay	Peat	Ferruginous	Forestsoil	Grass	# hits	correct number	identification percentage
	P	+40	NA	NA	P	M	P	P			
PMN	P	center	NA	NA	P	R	P	P	12	9	75%
	P	-40	NA	NA	P	M	P	P			
	R	+40	M	R	-	R	R	R			
Concrete	R	center	M	R	P	M	R	R	16	11	69%
	R	-40	M	R	P	-	R	R			
	R	+40	M	M	R	R	R	R			
Brick	R	center	M	M	P	R	R	R	18	11	61%
	R	-40	M	R	P	R	R	R			
	M	+40	M	R	-	-	M	M			
Aluminium	M	center	M	M	M	R	M	M	16	12	75%
	M	-40	M	M	R	R	M	M			
	P	+40	R	P	-	P	P	P			
PVC	P	center	R	P	-	P	P	P	15	10	67%
	P	-40	R	R	-	M	P	P			
	P	+40	R	R	-	R	P	-			
Wood	P	center	R	P	P	R	P	-	13	7	54%
	P	-40	R	P	P	-	P	-			
	M	+40	M	R	-	R	M	M			
Steel	M	center	M	M	-	R	R	M	14	9	64%
	M	-40	M	R	-	-	M	M			

Table 9: Test results for a prodding angle of 90° and 5 N load cell reading

target	P/R/M	location	Sand	Clay	Peat	Ferruginous	Forestsoil	Grass	# hits	correct number	identification percentage
	P	+40	NA	NA	P	P	P	P			
PMN	P	center	NA	NA	P	R	P	P	12	10	83%
	P	-40	NA	NA	P	R	P	P			
	R	+40	R	R	R	M	R	R			
Concrete	R	center	R	M	R	M	P	R	18	13	72%
	R	-40	R	R	M	R	R	R			
	R	+40	M	M	P	M	R	M			
Brick	R	center	M	M	P	M	R	M	18	4	22%
	R	-40	R	M	M	M	R	M			
	M	+40	M	M	M	-	M	R			
Aluminium	M	center	R	M	M	P	M	M	17	14	82%
	M	-40	M	M	M	M	M	M			
	P	+40	P	R	P	P	P	P			
PVC	P	center	P	R	P	P	P	P	18	15	83%
	P	-40	P	P	P	R	P	P			
	P	+40	P	R	P	P	P	P			
Wood	P	center	P	R	P	R	P	P	18	13	72%
	P	-40	R	R	P	P	P	P			
	M	+40	M	M	M	P	M	M			
Steel	M	center	M	M	M	M	M	M	18	17	94%
	M	-40	M	M	M	M	M	M			

Table 10: Test results for a prodding angle of 90° and 10 N load cell reading

target	P/R/M	location	Sand	Clay	Peat	Ferruginous	Forestsoil	Grass	# hits	correct number	identification percentage
	P	+40	NA	NA	P	P	P	P			
PMN	P	center	NA	NA	P	R	P	P	12	10	83%
	P	-40	NA	NA	P	R	P	P			
	R	+40	R	R	P	M	R	R			
Concrete	R	center	R	M	P	M	R	R	18	11	61%
	R	-40	R	M	R	M	R	R			
	R	+40	R	M	R	M	R	M			
Brick	R	center	M	M	R	M	R	M	18	9	50%
	R	-40	R	M	R	M	R	R			
	M	+40	M	M	M	-	M	R			
Aluminium	M	center	M	M	M	M	M	R	17	15	88%
	M	-40	M	M	M	M	M	M			
	P	+40	P	R	P	R	P	P			
PVC	P	center	P	R	P	R	P	P	18	12	67%
	P	-40	P	R	P	R	P	P			
	P	+40	P	R	P	P	P	P			
Wood	P	center	P	R	P	R	P	P	18	14	78%
	P	-40	P	R	P	P	P	P			
	M	+40	M	M	M	P	M	M			
Steel	M	center	M	M	M	M	R	M	18	16	89%
	M	-40	M	M	M	M	M	M			

Table 11: Test results in the lane with sand

Prodding angle	Load cell reading	Numbers	Percentage
30	5 N	Hits: 16 (of 18)	89%
		Correct identification: 9	56%
		Incorrect identification: 7	44%
	10 N	Hits: 16 (of 18)	89%
		Correct identification: 10	63%
		Incorrect identification: 6	37%
60	5 N	Hits: 17 (of 18)	94%
		Correct identification: 4	24%
		Incorrect identification: 13	76%
	10 N	Hits: 18 (of 18)	100%
		Correct identification: 6	33%
		Incorrect identification: 12	67%
90	5 N	Hits: 18 (of 18)	100%
		Correct identification: 14	78%
		Incorrect identification: 4	22%
	10 N	Hits: 18 (of 18)	100%
		Correct identification: 17	94%
		Incorrect identification: 1	6%

Sand	
Results for all prodding angles and load cell readings totalled	
Hits	103 (of 108)
Correct identification	60 (58%)
Incorrect identification	43 (42%)

Table 12: Test results in the lane with clay

Prodding angle	Load cell reading	Numbers	Percentage
30	5 N	Hits: 11 (of 18)	61%
		Correct identification: 5	45%
		Incorrect identification:6	55%
	10 N	Hits: 12 (of 18)	67%
		Correct identification: 5	42%
		Incorrect identification:7	58%
60	5 N	Hits: 18 (of 18)	100%
		Correct identification: 5	28%
		Incorrect identification:13	72%
	10 N	Hits: 18 (of 18)	100%
		Correct identification: 11	61%
		Incorrect identification:7	39%
90	5 N	Hits: 18 (of 18)	100%
		Correct identification: 9	50%
		Incorrect identification:9	50%
	10 N	Hits: 18 (of 18)	100%
		Correct identification: 7	38%
		Incorrect identification:11	62%

Clay	
Results for all prodding angles and load cell readings totalled	
Hits	95 (of 108)
Correct identification	42 (44%)
Incorrect identification	53 (56%)

Table 13: Test results in the lane with peat

Prodding angle	Load cell reading	Numbers	Percentage
30	5 N	Hits: 17 (of 21)	81%
		Correct identification: 12	71%
		Incorrect identification: 5	29%
	10 N	Hits: 16 (of 21)	76%
		Correct identification: 14	88%
		Incorrect identification: 2	12%
60	5 N	Hits: 12 (of 21)	57%
		Correct identification: 7	58%
		Incorrect identification: 5	42%
	10 N	Hits: 12 (of 21)	57%
		Correct identification: 7	58%
		Incorrect identification: 5	42%
90	5 N	Hits: 21 (of 21)	100%
		Correct identification: 17	81%
		Incorrect identification: 4	19%
	10 N	Hits: 21 (of 21)	100%
		Correct identification: 19	90%
		Incorrect identification: 2	10%

Peat	
Results for all prodding angles and load cell readings totalled	
Hits	99 (of 126)
Correct identification	76 (77%)
Incorrect identification	23 (23%)

Table 14: Test results in the lane with ferruginous soil

Prodding angle	Load cell reading	Numbers	Percentage
30	5 N	Hits: 20 (of 21)	95%
		Correct identification: 14	70%
		Incorrect identification: 6	30%
	10 N	Hits: 20 (of 21)	95%
		Correct identification: 11	55%
		Incorrect identification: 9	45%
60	5 N	Hits: 17 (of 21)	81%
		Correct identification: 8	47%
		Incorrect identification: 9	53%
	10 N	Hits: 17 (of 21)	81%
		Correct identification: 6	35%
		Incorrect identification: 11	65%
90	5 N	Hits: 20 (of 21)	95%
		Correct identification: 9	45%
		Incorrect identification: 11	55%
	10 N	Hits: 20 (of 21)	95%
		Correct identification: 7	35%
		Incorrect identification: 13	65%

Ferruginous soil	
Results for all prodding angles and load cell readings totalled	
Hits	114 (of 126)
Correct identification	55 (48%)
Incorrect identification	59 (52%)

Table 15: Test results in the lane with forest soil

Prodding angle	Load cell reading	Numbers	Percentage
30	5 N	Hits: 20 (of 21)	95%
		Correct identification: 13	65%
		Incorrect identification: 7	35%
	10 N	Hits: 19 (of 21)	90%
		Correct identification: 18	95%
		Incorrect identification: 1	5%
60	5 N	Hits: 21 (of 21)	100%
		Correct identification: 18	86%
		Incorrect identification: 3	14%
	10 N	Hits: 21 (of 21)	100%
		Correct identification: 20	95%
		Incorrect identification: 1	5%
90	5 N	Hits: 21 (of 21)	100%
		Correct identification: 20	95%
		Incorrect identification: 1	5%
	10 N	Hits: 21 (of 21)	100%
		Correct identification: 20	95%
		Incorrect identification: 1	5%

Forest soil	
Results for all prodding angles and load cell readings totalled	
Hits	123 (of 126)
Correct identification	109 (89%)
Incorrect identification	14 (11%)

Table 16: Test results in the lane with grass

Prodding angle	Load cell reading	Numbers	Percentage
30	5 N	Hits: 20 (of 21)	95%
		Correct identification: 9	45%
		Incorrect identification: 11	55%
	10 N	Hits: 20 (of 21)	95%
		Correct identification: 15	75%
		Incorrect identification: 5	25%
60	5 N	Hits: 18 (of 21)	86%
		Correct identification: 16	89%
		Incorrect identification: 2	11%
	10 N	Hits: 18 (of 21)	86%
		Correct identification: 18	100%
		Incorrect identification: 0	0%
90	5 N	Hits: 21 (of 21)	100%
		Correct identification: 17	81%
		Incorrect identification: 4	19%
	10 N	Hits: 21 (of 21)	100%
		Correct identification: 17	81%
		Incorrect identification: 4	4%

Grass	
Results for all prodding angles and load cell readings totalled	
Hits	118 (of 126)
Correct identification	92 (78%)
Incorrect identification	26 (22%)

4.2.1 Influence of the prodding angle

The test results per prodding angle are given in Tables 17-19 for determining the influence of the prodding angle on the performance of the Instrumented Prodder. The results of all soil types and the load readings of 5 N and 10 N have been combined. In addition, the test objects have been classified in the material classes Rock, Metal and Plastic (includes wood).

From these results it can be concluded that the Instrumented Prodder performs better for a prodding angle of 90°, since the number of incorrect material identifications for metal objects increases for prodding angles of 30° and 60°.

Table 17: Results for a prodding angle of 90° (soil types and load readings combined)

90deg, 5+10 N

			identif.		
		Hits	Rock	Metal	Plastic
object	Rock	72	51%	42%	7%
	Metal	70	7%	89%	4%
	Plastic	72	25%	0%	75%

Table 18: Results for a prodding angle of 60° (soil types and load readings combined)

60 deg, 5+10 N

			identif.		
		Hits	Rock	Metal	Plastic
object	Rock	68	54%	31%	15%
	Metal	60	32%	67%	0%
	Plastic	56	39%	36%	57%

Table 19: Results for a prodding angle of 30° (soil types and load readings combined)

30 deg, 5+10N

			identif.		
		Hits	Rock	Metal	Plastic
object	Rock	61	52%	12%	36%
	Metal	62	22%	63%	15%
	Plastic	60	25%	0%	75%

4.2.2 Influence of soil hardness

According to Table 4, the hardness of the soils in the test lanes can be grouped as ‘Soft soils’ (sand and peat), ‘Medium hard soils’ (woodland and grassland) and ‘Hard soils’ (clay and ferruginous soil). The test results are given per soil hardness group in Tables 20-22 for determining the influence of the soil hardness on the performance of the Instrumented Prodder,. The results for all prodding angles and load cell readings have been added together.

From these results no clear conclusions can be drawn on the influence of the soil hardness on the Instrumented Prodder’s performance. In contrast to expectations, the number of hits is least in the soft soils, although the percentage of hits is in all three soil hardness groups around 90%. Hard soils have the highest percentage of incorrect material identification, but unexpectedly the lowest percentage of incorrect material identification is in the medium hard soils.

Table 20: Results for soft soils

Soft soils: Sand and Peat	
Hits	202 (of 234), i.e. 86%
Correct identification	136 (67%)
Incorrect identification	66 (33%)

Table 21: Results for medium hard soils

Medium hard soils: Woodland and Grassland	
Hits	241 (of 252), i.e. 96%
Correct identification	201 (83%)
Incorrect identification	40 (17%)

Table 22: Results for hard soils

Hard soils: Clay and Ferruginous soil	
Hits	209 (of 234), i.e. 89%
Correct identification	97 (46%)
Incorrect identification	112 (54%)

4.2.3 Influence of center and off-center prodding

In the tests of the Instrumented Prodder, three measurements were performed for each test object for one prodding angle: one at the centre of the object and two 4 cm from the centre (on each side of the centre). In order to study the influence of centre and off-centre prodding on the performance of the Instrumented Prodder, the hit percentages and the percentages of incorrect material identifications are given in Table 23, in which all results for different soil types and load cell readings have been added together.

These results confirm the expectation that off-centre prodding has a larger chance of missing the object. This is especially clear for prodding angles of 30° and 60°, for which the path of the prodder's needle through the soil is longer than for prodding at an angle of 90°. This can be regarded as an artifact of the test set-up and does not give information on the performance of the Instrumented Prodder. However, the slightly increased percentage of incorrect material identification for prodding angles of 30° and 60° for off-center prodding in comparison to prodding at the center of the object suggests that the angle of the needle's tip with the object may influence the performance of the material identification feature.

Table 23: Percentages of hits and incorrect identification for center and off-center proddings

	Prodding angle:	*90°*	*30° and 60°*
Center prodding	Hit percentage	100%	96%
	Incorrect identification	35%	33%
Off-center prodding	Hit percentage	99%	82%
	Incorrect identification	23%	39%

4.3 Experience with the technology demonstrators

During the preparation and execution of the tests, experience was gained in using technology demonstrator version of the Instrumented Prodder. Although the technology demonstrator version is not intended or suitable for field tests or field use, experience with this version can be used in the process for improving the technology demonstrator and for development towards a device ready for use in the field. We discuss these experiences in the following and some improvements to the prodder are proposed.

4.3.1 Mechanical construction

The piezoelectric crystal that sends and receives the ultrasonic acoustic waves is glued on the end of the prodder’s needle and it is located in the cylindrical casing. A rubber ring is located around the needle where it enters this casing (Figure 9). When the needle of the instrumented prodder is bent too far, the piezoelectric crystal will break off the needle due to the lateral force (Figure 9). This was the cause of an accident that occurred during the tests which made one of the Instrumented Prodders unusable.

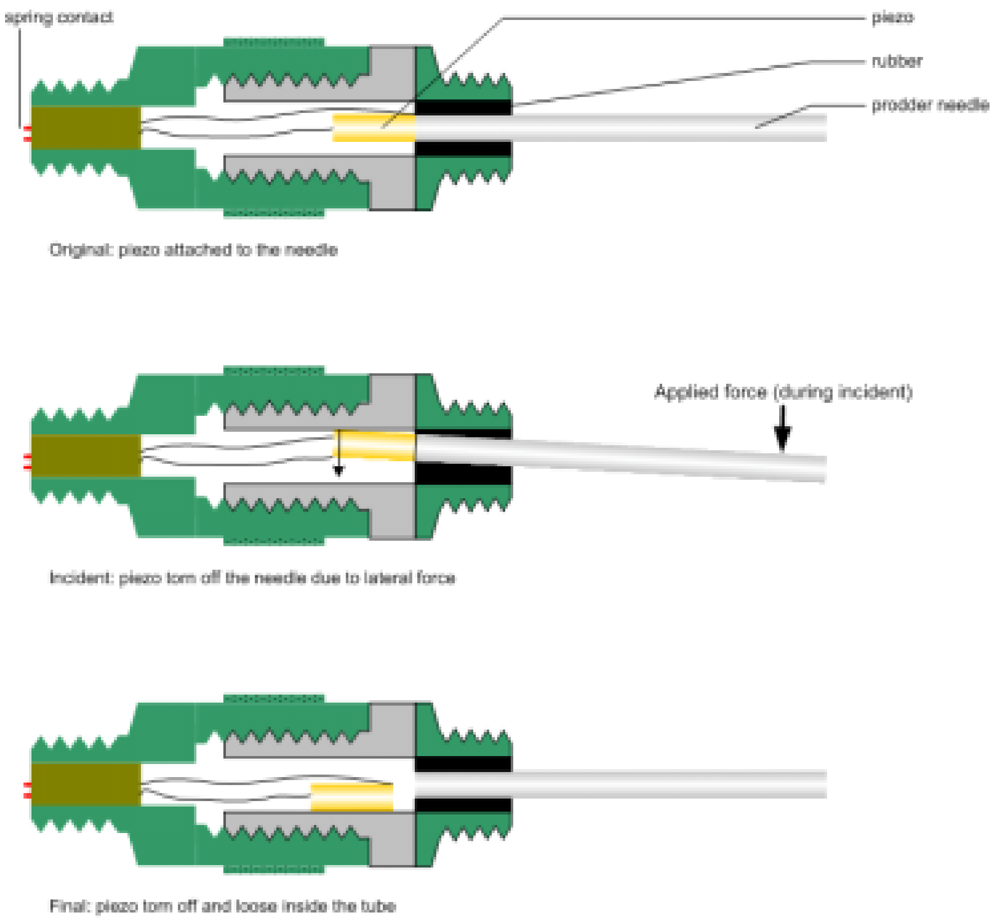

Figure 9: Schematic diagram of the piezoelectric crystal breaking off the needle

This can be prevented by one of the following mechanical modifications.

1. Making the inner space of the casing wider, so that the needle can bend further before the piezoelectric crystal makes contact with the inner wall.
2. Making the rubber longer, so that the needle will bend less.

These modifications are illustrated in Figure 10.

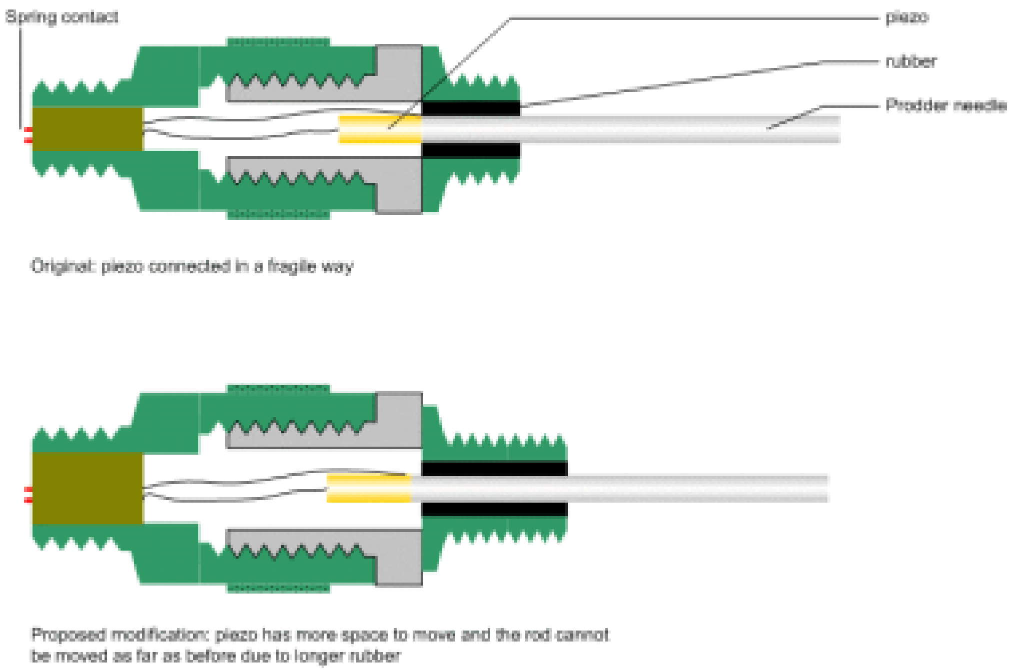

Figure 10: Suggested mechanical modifications

It is expected that the second option for modification (extending the rubber) will result in a small increase in the damping of the acoustic vibrations. However, most sound will propagate through the needle in a longitudinal direction and the acoustic impedance difference of the needle's material and rubber will keep all waves inside the needle.

During the measurements an increase in the force indication was observed from 0 N to about 1 N. All intermediate forces were indicated as 0 N. This may be caused by friction between the sliding parts of the piezoelectric crystal casing and the load cell casing (see Figure 11). Another possibility is that it is caused by non-linear behaviour of the load cell.

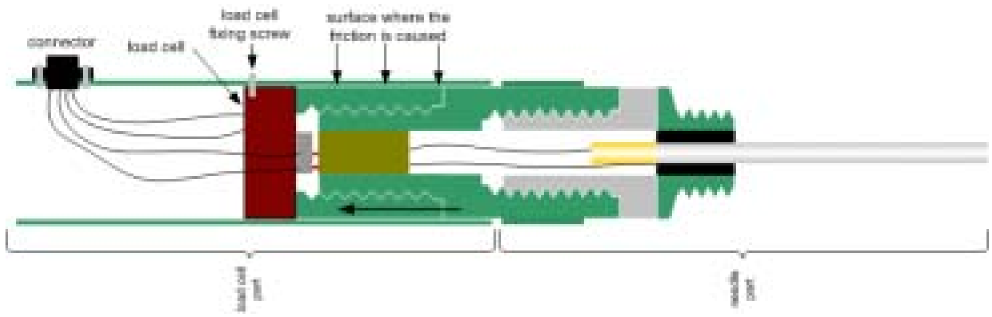

Figure 11: Cross section of the two casing parts of the prodder. The arrow denotes the applied force on the load cell.

Erratic results were observed during one measurement. After inspection we concluded that this behaviour was caused by a faulty spring contact resulting in an unreliable electronic connection between the piezoelectric crystal and the electronics box.

4.3.2 Range of operation of the load cell

The operational range of the load cell (1 to 11 Newton) is very low. In most soils it will be impossible to use the prodder when forces within this range are applied. During the tests it was found that the prodder did not penetrate any type of the six soil types using a force of 10 Newton at an angle of 30°. Forces of about 35 Newton for the relatively soft soils (sand, woodland, grassland) and even higher forces for clay were necessary to insert the prodder. For the latter, the necessary penetration forces were not measured, because of possible damage to the load cell. For the ferruginous soil, large differences in penetration force were observed, due to the presence of hard lumps in this soil.

It is necessary to protect the load cell against overload, because this can easily occur, will damage the load cell and can cause unreliable force indications and material identifications. This protection can be achieved either mechanically or via software. Mechanical force limitation is preferable because it may be more reliable. The advantage of a software solution is that it does not require redesign of the mechanical parts of the prodder. It can be achieved by continuously measuring the applied force and generating an alarm when the force is approaching the overload limit. However, the software solution has a number of disadvantages:

- When the Instrumented Prodder is switched off, the software will not give an overload alarm and the load cell can be damaged.
- If the Instrumented Prodder falls by accident on its needle’s tip, it will not be protected against overload.
- The method of measuring the force with the same load cell as the one to protect against overload is in principle not very safe.
- Slight damage to the load cell may result in an invalid force indication without the operator being notified.

4.3.3 Stickiness of the soil

The contact force between the needle’s tip and the buried object is a crucial parameter for the material identification feature of the Instrumented Prodder. However, the load cell to measure this force is placed inside the grip and not at the tip of the needle (Figure 12).

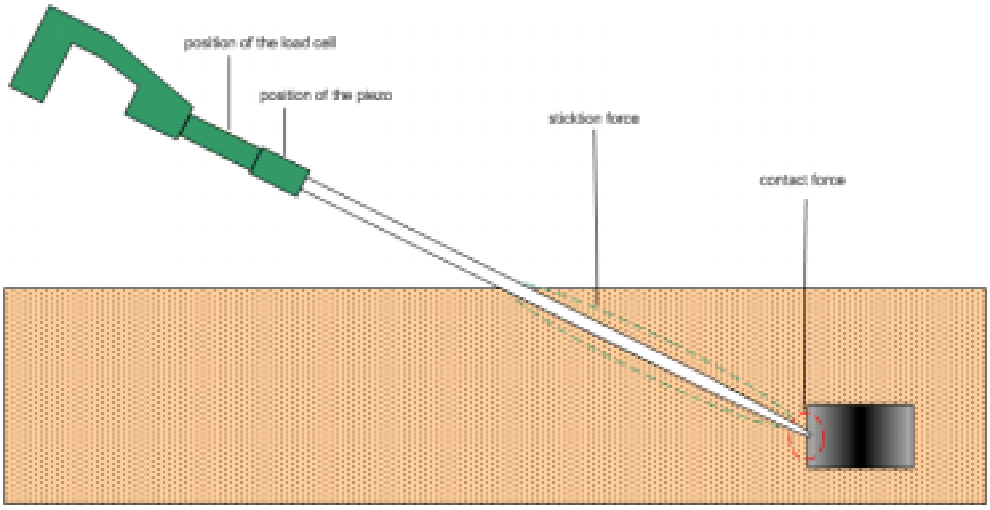

Figure 12: Instrumented Prodder making contact with a buried object

For relatively deeper buried objects this force measurement principle may not be valid, because the stickiness of the soil leads to forces between the needle and the soil that can be large in comparison with the contact force. This will result in a bias in the force measurement, which will yield in a wrong material identification.

Tables 24 and 25 show test results for the material identification feature of the Instrumented Prodder in sticky soil (clay) and in the two least sticky soils (peat and forest soil), respectively. Comparison of these results shows that the material identification feature does give more reliable results in the least sticky soils.

Table 24: Test results for material identification feature in sticky soil (clay).

clay		identif.		
		Rock	Metal	Plastic
object	Rock	45%	52%	3%
	Metal	31%	59%	9%
	Plastic	73%	0%	27%

Table 25: Test results for material identification feature in the least sticky soils (peat and forest soil).

peat and forest soil		identif.		
		Rock	Metal	Plastic
object	Rock	61%	9%	28%
	Metal	15%	83%	2%
	Plastic	3%	0%	97%

Theoretically, there are two options to solve this problem:

1. move the load cell to the tip of the needle, or
2. reduce the forces due to soil stickiness.

The first option does not seem very realistic, since it is hard to achieve without influencing the principle of ultrasonic material identification.

With regard the reduction of the forces due to soil stickiness, a coating or synthetic layer (e.g., Teflon) on the needle or using a needle with a different cross-section or smaller diameter may help. A disadvantage of a coating or layer is the possibility of wear during use.

5. Discussion

In this chapter the results of the tests under controlled conditions are discussed. In addition, some conclusions have been drawn from the discussions with the demining community on the usefulness and the desirability of the Instrumented Prodder in demining operations in Section 5.2, as mentioned in Chapter 2. Finally, in Section 5.3 the continuation of the product development path for the Instrumented Prodder is discussed.

5.1 Results of the tests under controlled conditions

From the results of the tests under controlled conditions (Chapter 4), the following conclusions can be drawn:

- The current technology demonstrator version of the Instrumented Prodder performs best for a prodding angle of 90°. For smaller prodding angles (60° and 30°), a larger number of incorrect material identifications was observed.
- For a prodding angle of 90°, the Instrumented Prodder correctly identified all but one of the metal and plastic/wood objects in peat and forest soil.
- The material identification feature works slightly better for a load cell reading of 10 N compared to 5 N.
- The material identification feature performs most reliably in forest soil compared to the other five soil types used in the tests.
- The ferruginous soil poses for all considered prodding angles the most problems for the technology demonstrator version of the Instrumented Prodder.

From these results it is clear that the material identification feature of the Instrumented Prodder in its current form, the technology demonstrator version, is not working sufficiently reliably to be able to use it in a wide variety of soil types. The results indicate the following possible causes:

- The prodder’s material identification method may be affected in a negative way by the soil’s stickiness because the best performance of the material identification feature was obtained in soil that is not sticky. The forest soil, and, to a lesser extend, the peat can be characterized as non-sticky and slightly sticky, respectively. The stickiness of the soil leads to a large friction force on the prodder’s needle. Due to this force contribution, the prodder’s load cell reading will not give information on the contact force of the needle’s tip with the buried object. By prodding at angles of 60° and 30° a larger path through the soil must be covered than for a prodding angle of 90 degrees, leading to a larger friction force contribution to the load cell reading. Since the load cell reading is used by the material identification algorithm, this may result in an incorrect material identification.
- No correlation was found between the soil hardness and the prodder’s material identification performance in the tests.

- It is not clear whether the prodder's needle tip makes good contact with the object when the needle makes an angle of 30° or 60° with the object's surface. If in fact the contact is declined for smaller prodding angles, it may affect the material identification performance for objects with a smooth surface (in the tests: the PMNs, concrete, aluminium, PVC and steel cylinders). However, no correlation was found in the test results.
- The ferruginous soil contains many hard lumps of material, with sizes of 2-3 cm. In some cases the operator was not sure whether the needle's tip was actually making contact with the buried object or that such a lump was present between the tip and the object. During a number of insertions of the needle, the needle was clearly deflected by the lumps that were on its path through the soil.

However, the results for the peat and forest soil lanes and prodding at an angle of 90° show that material identification of buried object by the method implemented in the Instrumented Prodder is feasible (Table 26).

Table 26: Results on the lanes with peat and forest soil for prodding at an angle of 90 degrees. Load cell reading: 10 N.

target	Plastic/ Metal/Rock		Peat	Forestsoil	# hits	correct number	identification percentage
	P	+40	P	P			
PMN	P	center	P	P	6	6	100%
	P	-40	P	P			
	R	+40	P	R			
Concrete	R	center	P	R	6	4	67%
	R	-40	R	R			
	R	+40	R	R			
Brick	R	center	R	R	6	6	100%
	R	-40	R	R			
	M	+40	M	M			
Aluminium	M	center	M	M	6	6	100%
	M	-40	M	M			
	P	+40	P	P			
PVC	P	center	P	P	6	6	100%
	P	-40	P	P			
	P	+40	P	P			
Wood	P	center	P	P	6	6	100%
	P	-40	P	P			
	M	+40	M	M			
Steel	M	center	M	R	6	5	83%
	M	-40	M	M			

The tests and their results have yielded insight into the limitations of the technology demonstrator version of the Instrumented Prodder and have led to a number of ideas for improvements, as reported in Section 4.3.

5.2 Utility of the Instrumented Prodder

Apart from the performance of the Instrumented Prodder's technology demonstrator, the usefulness and desirability of the device in a demining operation is an important issue for the continuation or adjustment of the product development path. In order to continue product development of the Instrumented Prodder it is essential to have abundant evidence that this device will lead to safer and/or faster demining operations. Although operational limitations of the Instrumented Prodder are acceptable in certain scenarios, at least one scenario should exist in which the Instrumented Prodder has a beneficial value. In order to focus the discussion on the utility of the Instrumented Prodder, it is assumed here that the Instrumented Prodder performs well, is ruggedized, has a proper user interface, its operator is trained, etc. If this scenario (or these scenarios) is (are) common in demining operations, the Instrumented Prodder may become an important demining tool.

Four different ways of use of the Instrumented Prodder in demining operations can be distinguished:
- as a detection tool in conjunction with other detection tools, such as a metal detector, dogs, etc;
- as a detection tool in a scenario where no other detection tools are usable;
- as a classification tool used during excavation,
- as a training tool to make operators aware of the exerted force.

As an example of the first case, a demining operation is considered in which the Instrumented Prodder will be used after the area is scanned with a metal detector. It is assumed that the metal detector can be used successfully in the demining operation under discussion; it gives an alarm above all mines, but also above pieces of metal that are not mines.
The following situations can occur.
Situation 1:
The metal detector does not give an alarm. In current humanitarian demining operations the prodder is not used when the metal detector is silent. It is not expected that this will change when the Instrumented Prodder is available.
Situation 2:
The metal detector gives an alarm. In current humanitarian demining operations the prodder is used to get an idea about the type of object, orientation, depth, etc. If the Instrumented Prodder is used, information will be obtained on the casing material of the buried object.
Then the following situations can occur.
Situation 2a:
The metal detector gives an alarm and the Instrumented Prodder gives 'metal'. In this situation the deminer will excavate the object. The indication of the Instrumented Prodder can be regarded as confirmation of the metal detector alarm, but it is not decisive for starting the excavation.

Situation 2b:
The metal detector gives an alarm and the Instrumented Prodder gives ‘rock’ or ‘plastic’. What is the deminer supposed to do? In the case of the indication ‘plastic’, the deminer will excavate the object, since many mines have a plastic casing. From discussions with the members of the usergroup it is clear that no deminer will ignore the metal detector’s alarm, even if the Instrumented Prodder gives the indication ‘rock’, and the deminer will excavate the unknown object. Hence the object is always excavated when the metal detector gives an alarm and the Instrumented Prodder will not be used when the metal detector is silent. It is concluded that the Instrumented Prodder has no beneficial value when a well-performing metal detector is available in the demining operation. A similar reasoning can be followed for demining operations in which demining dogs are used and the same conclusion can be drawn.

In some demining operations no other detection tools than the conventional prodder are available or usable. For instance, most (or even all) metal detectors cannot be used for mine detection in the vicinity of houses and buildings with reinforced concrete, near railways or under power lines. Above soils with extreme magnetic properties or with large numbers of ‘false positives’, such as shell fragments, metal detectors are also not usable or are very difficult to use. From the discussions with usergroup members it can be concluded that in these scenarios the material identification feature of the Instrumented Prodder may help the deminer. However, it was stressed by the usergroup that this identification must be absolutely reliable so that the deminer will be and will remain confident of the device.

Some members of the usergroup mentioned that there could well be an application for a device that indicates what material an exposed, or soon to be exposed, corner of a buried object is made from. This device could be used for objects that are still just below the "surface", e.g., the working level that has been exposed during excavation. A small Instrumented Prodder that does this may add value but a good look at operational criteria is needed.

In Section 1.1 the advantage of a force feedback signal during demining by manual prodding has already been mentioned. From research by (amongst others) Gasser [4], [5], it was concluded that deminers are using, at times, forces during prodding that are higher (sometimes even orders of magnitude higher) than the force required to detonate many types of anti-personnel mines. Evidence exists of deminers prodding with enough force to visibly bend the needle of the prodder and this is of concern especially in countries in which the soil is hard. Prodding on anti-personnel mines with too high forces is a major cause of demining accidents. A force feedback signal can be used during training to make the deminers aware of excess force being applied and hence may contribute to increased safety. For this application, the material identification feature as implemented in the Instrumented Prodder, is not used.

From the above it is concluded that no surplus value for the Instrumented Prodder has been identified in operations in which it will be used in conjunction with other detection tools. However, the Instrumented Prodder may have a beneficial value in (humanitarian) demining operations:

(a) when no other detections tools (apart from the conventional prodder) can be used;
(b) to obtain casing material information during excavation;
(c) as a training tool to make deminers aware of the force that they exert during prodding.

For all applications of the Instrumented Prodder it is important to study the operational criteria and the cost-benefits. Moreover, the deminers will only accept the tool for demining when they have been absolutely convinced of its proper functioning.

5.3 Way ahead

Now that the tests under controlled conditions of the Instrumented Prodder and analysis of the test results are completed, and the discussion on the application of the Instrumented Prodder in demining operations has resulted in some conclusions, the continuation of the project ’Smart prodder product development path’ at TNO-FEL must be reconsidered. The following options are listed for discussion with the project officer and sponsor:

(a) Continue development of the Instrumented Prodder as a detection tool that will be used in demining operations for which no other detection tools are available or usable. In this case it is essential to improve the Instrumented Prodder’s material identification performance, since deminers will only accept the tool when it is reliable. In Section 4.3 a few suggestions for improvements of the current technology demonstrator version are described. Moreover, it is important to consider the blast resistance of the design.
(b) Continue the development of the Instrumented Prodder as a tool that can be used for the identification of the casing material of a buried object during excavation. Since the distance that the prodder’s needle must penetrate into the soil is less when the object has been partially excavated, it is expected that the challenge in the development of this ‘excavation tool’ is more manageable than for the option mentioned under the previous entry.
(c) Continue with the development of the Instrumented Prodder as a training tool. In this case the material identification feature will be left out and the focus will be on the development of a reliable force-reading method. Since this tool will not be used in live minefields, requirements on its performance will be less severe.
(d) Terminate the development of the Instrumented Prodder since it has been concluded from the test results that the remaining development effort is quite large whereas the application of the Instrumented Prodder in demining operations is doubtful.

The conclusion of this discussion is that the Netherlands Ministry of Defence will stop the funding of the Instrumented Prodder development, because of the disappointing results of the current version of the Instrumented Prodder, the technical risk of the development and the expected limited use in demining operations of this device. Moreover, other alternative (mechanical) demining tools are foreseen in the near future.

6. Conclusions

In the project ‘Smart prodder product development path, phase A’, two activities have been displayed:

- The usefulness and the desirability of an Instrumented Prodder for demining have been discussed with the demining community and with the members of the usergroup that was formed for this purpose.
- The technology demonstrator version of the Instrumented Prodder was tested under controlled conditions.

A first version of a user-requirements document was drafted and presented to the usergroup for comment and additions. From the discussion on the use of an Instrumented Prodder in demining operations with the demining community it was concluded that such a device will have only a limited area of application, although it may have a beneficial value in certain demining operations.

From the results of these tests it was concluded that material identification of buried objects by the method implemented in the Instrumented Prodder is feasible. However, the use of the Instrumented Prodder is limited by the hardness of the soil (as is the use of the conventional prodder). For certain soil types, the performance of the current version of the Instrumented Prodder is probably reduced by the stickiness of these soils. The experiences with the Instrumented Prodder during the tests have resulted in a number of suggestions for modifications of the prodder’s design in order to improve the performance and to make it more robust.

Apart from the option to stop the product development path of the Instrumented Prodder because of the expected limited area of application, proposals are included for continuation of the project for the development of the Instrumented Prodder as a detection tool, in accordance with the original project plan, as an excavation tool or as a training tool.

The sponsor of the project, the Netherlands Ministry of Defence, decided to stop the funding for the continuation of the Instrumented Prodder development. The reasons for this decision are the disappointing results of the current version of the Instrumented Prodder, the technical risk of the development and the expected limited use of the Instrumented Prodder in demining operations. The Netherlands Ministry of Defence expects that the Instrumented Prodder (after completion of the development path) will not be accepted by deminers and sees no surplus value of this device in both humanitarian and military demining operations. Moreover, it is foreseen that other alternative mechanical tools for the manual prodder will be available in the near future.

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8. Signature

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Appendix A Scenarios and User Requirements for the Instrumented Prodder

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0.1	20-12-2002	Initial document
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A.1 Scope

This document establishes scenarios and user requirements for the Instrumented Prodder.

The Instrumented Prodder is intended to be used for the detection of mines in demining operations. The Instrumented Prodder is an improvement of the conventional prodder, since it assists the operator by providing an indication of both the applied force and the type of material of the detected object. The prodding process can therefore be accelerated without decreasing the safety of operation.

Concise history of the Instrumented Prodder
The prodder is one of the most important tools for a deminer involved in humanitarian demining operations. It is used to obtain information on the exact location, including the depth, of buried objects that are, in most cases, detected with the help of a metal detector or by dogs. The operator of the prodder uses his 'finger-sensitivity' to get an idea about the identity and orientation of the detected object.

In Canada a step forward is made with an 'Instrumented Prodder' that gives an indication of the type of material (metal, plastic or stone) that is touched. This indication helps the operator with the classification and identification of the detected object. Moreover, the Instrumented Prodder is equipped with a force feedback indication, that warns the operator when too much force is applied for proper operation of the device. The force feedback has also the advantage that the operator is warned when the applied force can trigger the fuse of buried mines.

A first version of the Instrumented Prodder, called the 'SmartProbe', was manufactured by the Canadian company Dew under a license of the Canadian Department of National Defence. However, due to disappointing test results, this version was withdrawn from the market and a redesign was started by the Canadian company HF Inc under the guidance of CCMAT.
This redesign has resulted in two (identical) samples of the Instrumented Prodder that can be regarded as 'technology demonstrators'. They are suitable for tests under controlled conditions to assess the intrinsic performance of the applied technology, but will need further development and, if necessary, modifications before series production can be started.

A.2 Related Documents

[1] Mine Action Equipment: Study of Global Operational Needs. Geneva International Centre for Humanitarian Demining, June 2002.

[2] HOM-2000 Scenario's, November 1996, ing de Bruyn Prince-van Kempen (in Dutch).
See also: the Final report of Taskgroup 3 of the AC/323 NATO SCI-046 on Landmine Countermeasures (draft issue, August 2001).

A.3 Demining Scenarios

Scenario characteristics

In this document the 12 demining scenarios in accordance with ref. 1 of section A.2, are used to evaluate the applicability of the Instrumented Prodder. These 12 scenarios adequately represent the full range of environmental and operational settings within which mine action is conducted.

In 1996, nine scenarios for (humanitarian) demining were developed in the framework of the Dutch HOM-2000 project, ref. 2 of section A.2. These scenarios can be summarized as follows.

1: Hot/dry, routes.
2: Hot/dry, terrain.
3: Hot/dry, built-up areas.
4: Hot/wet, routes.
5: Hot/wet, terrain.
6: Hot/wet, built-up areas.
7: Intermediate cold, routes.
8: Intermediate cold, terrain.
9: Intermediate cold, built-up areas.

The relation of the 12 scenarios of ref. 1 of section A.2 with the nine HOM-2000 scenarios is established here.

Grassland

Open flat or rolling land.
Soil is medium.
In relation to ref. 2, the scenario 'grassland' generally corresponds with HOM-2000 scenario 5 (hot/humid terrain) and scenario 8 (tempered/cold terrain).

Use of the conventional prodder is possible. However, increased pressure is required which reduces safety of the prodding operation.
Use of the Instrumented Prodder may be possible. It offers the advantage of the force feedback to the operator that increases safety of the prodding operation.

Woodland

Characteristics of heavily wooded land.
Soil is soft.
In relation to ref. 2, the scenario 'woodland' corresponds with HOM-2000 scenario 5 (hot/humid terrain) and scenario 8 (tempered/cold terrain).

Use of conventional prodder is possible. Use of the Instrumented Prodder may be possible.

Hillside
Characteristics of open hillside.
Soil is medium.
In relation to ref. 2, the scenario 'hillside' corresponds with HOM-2000 scenario 2 (dry/hot terrain), scenario 5 (hot/humid terrain) and scenario 8 (tempered/cold terrain).

Use of the conventional prodder is possible. However, increased pressure is required which reduces safety.
Use of the Instrumented Prodder may be possible. It offers the advantage of the force feedback to the operator that increases safety of the prodding operation.

Routes
Un-metalled roads and tracks, including 10 meter on either side.
Soil is hard.
In relation to ref. 2, the scenario 'routes' corresponds with HOM-2000 scenario 1 (hot/dry routes), 4 (hot/humid routes) and 7 (temperate/cold routes).

It is generally not possible to use the conventional prodder. It is also expected impossible to utilize the Instrumented Prodder.

Infrastructure
Metalled roads and railway tracks, including 10 metres on either side.
Soil is hard.
In relation to ref. 2, the scenario 'infrastructure' corresponds with HOM-2000 scenario 1 (hot/dry routes), 4 (hot/humid routes) and 7 (temperate/cold routes).

It is generally not possible to use the conventional prodder. Also, it is expected impossible to utilize the Instrumented Prodder.

Urban
Large town or city.
Soil is hard.
In relation to ref. 2, the scenario 'urban' corresponds with HOM-2000 scenario 3 (hot/dry built-up areas), 6 (hot/humid built-up areas) and 9 (temperate/cold built-up areas).

It is generally not possible to use the conventional prodder. Also, it is expected impossible to utilize the Instrumented Prodder.

Village
Rural population centre.
Soil is medium.

In relation to ref. 2, the scenario 'village' corresponds with HOM-2000 scenario 3 (hot/dry built-up areas), 6 (hot/humid built-up areas) and 9 (temperate/cold built-up areas).

Use of the conventional prodder is possible. However, increased pressure is required which reduces safety.
Use of the Instrumented Prodder may be possible and offers the advantage of the force feedback to the operator that increases safety.

Mountain
Characteristics of mined area conditions found at high altitude.
Soil is hard.
In relation to ref. 2, the scenario 'mountain' corresponds with HOM-2000 scenario 2 (hot/dry terrain) and 8 (temperate/cold terrain).

It is generally not possible to use the conventional prodder. Also, it is expected impossible to use the Instrumented Prodder.

Desert
Very dry, sandy environment.
Soil is soft.
In relation to ref. 2, the scenario 'desert' corresponds with HOM-2000 scenario 2 (hot/dry terrain).

Use of conventional prodder is possible. Use of the Instrumented Prodder may be possible.

Paddy field
Land allocated for the growing of rice. Generally either under water or completely dried out.
Soil is soft.
In relation to ref. 2, the scenario 'paddy field' corresponds with HOM-2000 scenario 5 (hot/humid terrain).

Use of conventional prodder is possible. Use of the Instrumented Prodder may be possible except when the water level is too high

Semi-arid savannah
Scenario prevalent in the Horn of Africa; dry, generally open and flat, little vegetation.
Soil is hard.
In relation to ref. 2, the scenario 'semi-arid savannah' corresponds with HOM-2000 scenario 2 (hot/dry terrain).

It is generally not possible to use the conventional prodder. Also, it is expected impossible to use the Instrumented Prodder.

Bush
Bush characteristics – significant vegetation and possible rock formations.
Soil is hard.
In relation with ref.2, the scenario 'bush' corresponds with HOM-2000 scenario 5 (hot/humid terrain) and 8 (temperate/cold terrain).

It is generally not possible to use the conventional prodder. Also, it is expected impossible to utilize the Instrumented Prodder.

Suitability of the Instrumented Prodder
In the following scenarios the Instrumented Prodder can be used. This conclusion is based on the presence of soft soil in these scenarios.

- Woodland
- Desert
- Paddy Field

In the scenarios with medium-hard soil (Grassland, Hillside, Village), the safe use of the conventional prodder is limited because higher prodding pressure is required. Since the Instrumented Prodder is equipped with a force feedback indication to the operator, the safe use of the Instrumented Prodder in these scenarios may be feasible.

Even in scenarios of generally hard soil, small areas of medium or soft soil might occur. In these areas the use of the Instrumented Prodder may be feasible.

A.4 User Requirements of the Instrumented Prodder

The Instrumented Prodder shall fulfill the following requirements.

Operational Requirements

Robustness
The construction of the Instrumented Prodder shall be robust enough for long-term operation of the device under severe conditions.
No wires connected to the Instrumented Prodder shall be present during the prodding operation.

Audio signal
The audio signal shall indicate the following parameters.
- Proper operation of the device (e.g. by a 'heartbeat' (short pulses, 'tick')).
- Applied force is in the appropriate force range for proper function of the material indication feature.
- Either type of material (plastic/wood, metal, stone) or safe / hazard.
- Battery status.

The volume level of the audio signal shall be adjustable. However, there shall be a minimum volume-level. It shall not be possible to adjust the volume of the Instrumented Prodder below this level in order to prevent dangerous situations.

Visual indicators
There shall be no visual indicators on the Instrumented Prodder that give indications necessary for properly operating the device.

Weight, handling
The weight of the Instrumented Prodder shall not be more than 300 gr.
The Instrumented Prodding handle shall be comfortable for use and shall not cause Repetitive Strain Injury.

Environmental Requirements

Temperature
The Instrumented Prodder shall function properly in an on-site operating temperature range from –20 ^{0}C to 60 ^{0}C.

Temperature variation (shock)
The Instrumented Prodder shall function properly under an on-site operating temperature variation less than 20 ^{0}C per minute.

Fluid contamination
Contamination of fluids such as may be encountered during the Instrumented Prodder's life cycle, either incidentally, intermittently or regular, shall not lead to degradation of performance.

Solar Radiation (Sunshine)
The heating effect of direct solar radiation shall not increase the temperature of the Instrumented Prodder to such an extent that the device can not be handled with bare hands.
Solar radiation shall have no effect on the performance of the Instrumented Prodder.

Rain
The Instrumented Prodder shall be provided with protective measures and seals to protect against water ingress. Use of the prodder during heavy rain is not foreseen.

Humidity
The operating humidity of the prodder may vary from 10% to 100% without degradation of performance. Use of the prodder in a warm and humid atmosphere shall not degrade performance.

Fungus
Fungus on the Instrumented Prodder shall not degrade performance.

Salt Fog
The influence of salt fog shall not lead to degradation of performance.

Sand and Dust
It is expected that the Instrumented Prodder will be used in extreme sandy and dusty environments. The Instrumented Prodder shall be protected against the influence of sand and dust.

Immersion
It shall be possible to immerse the Instrumented Prodder for a short period of time (5 seconds) without degradation of performance. Underwater prodding with the Instrumented Prodder is not foreseen.

Vibration
The Instrumented Prodder in its protective transport cover shall withstand all vibration levels that can be expected during transportation. Degradation of performance shall not occur.
The Instrumented Prodder shall have no degradation of performance due to vibrations that may occur during use under severe environmental conditions.

Shock
The Instrumented Prodder shall physically and functionally withstand relative infrequent, non-repetitive shocks encountered during handling, transportation and service environment.

Wear
The performance of the Instrumented Prodder shall not degrade due to wear of the prodding needle.

Maintainability
The maintainability of the Instrumented Prodder shall be simple and straightforward.
In-field repair shall be possible, e.g., a simple change of spare parts.
If the Instrumented Prodder consists of different parts that can be disconnected, equivalent parts shall be physically, electrically and functionally interchangeable.
Calibration of the Instrumented Prodder by the operator, if necessary, shall be simple and infrequent.

Appendix B Test plan for the tests under controlled conditions

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Version	:	1.0 (N.B. version as used during the tests)
Date	:	21-03-2003
Written		S.G.M. van Dijk MSc, D. Deurloo, Dr. A.J. Schoolderman TNO Physics and Electronics Laboratory PO Box 96864 2509 JG The Hague The Netherlands
Framework	:	Instrumented Prodder, technology demonstrator evaluation, product development path

Document information	
Subject:	Instrumented Prodder
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Authors:	S.G.M. van Dijk MSc, D. Deurloo, Dr. A.J. Schoolderman
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Document history		
Issue	**Date**	**Description**
1.0	21-03-2003	First Issue

B.1 Scope

Document
This document describes the facilities and procedures for the first tests that will be performed within the framework of the project "Instrumented Prodder Product Development Path, Phase A" at TNO-FEL.
The objective of these tests is to assess the material identification feature of the Instrumented Prodder for objects buried in several soils with different properties (sand, clay, peat, iron-containing, medium hard soil, forest soil and grassland). The tests will be executed under controlled conditions. This implies that the force used to push the prodder into the soil is controlled, as well as the angle of the prodder with the soil surface. The raw signal and the decision signal of the Instrumented Prodder are recorded digitally for future processing.

Instrumented Prodder
The prodder is one of the most important tools for a deminer involved in humanitarian demining operations. It is used to obtain information on the exact location, including the depth, of buried objects that are, in most cases, detected with the help of a metal detector or by dogs. The operator of the prodder uses his 'finger sensitivity' to gain an idea of the identity and orientation of the detected object.

In Canada a step forward is made with an 'Instrumented Prodder' that gives an indication of the type of material (metal, plastic/wood or stone) that is touched. This indication helps the operator with the classification and identification of the detected object. Moreover, the Instrumented Prodder is equipped with a force feedback indication that warns the operator when too much force is applied for proper operation of the device. The force feedback may also contribute to increased safety during prodding, because the operator is warned when the applied force is of a magnitude that can trigger the fuse of buried mines.

A first version of the Instrumented Prodder, called the 'SmartProbe', was manufactured by the Canadian company DEW Engineering and Development Ltd. under a license of the Canadian Department of National Defence. However, due to disappointing test results, this version was withdrawn from the market and a redesign was started by the Canadian company HF Research Inc under the guidance of CCMAT.

This redesign has resulted in two (identical) samples of the Instrumented Prodder that can be regarded as 'technology demonstrators'. They are suitable for tests under controlled conditions to assess the intrinsic performance of the applied technology, but will need further development and probably modifications before series production can be started.

Usergroup
In order to gather useful information for the project from potential end-users, a usergroup has been formed. This usergroup consists of a representative from the Royal Netherlands Army (W.L. Fleury), M. Auracher from the demining organization Demira, J. Kirby, a demining consultant currently working for Handicap International and Dr. R. Gasser (speaking as a private person).

B.2 Documents

[1] Project proposal “Smart Prodder Product development, fase A”, Dr. A.J. Schoolderman.
[2] Scenarios and User Requirements for the Instrumented Prodder, Dr. A.J. Schoolderman, S.G.M. van Dijk MSc, doc. 31580.01.01

B.3 Description of test facilities, equipment and set-up

General
This paragraph gives a description of the test facility and measurement set-up used in the tests to assess the Instrumented Prodder.

Test lanes
An outdoor test facility is situated on the proving ground "Waalsdorp" near TNO Physics and Electronics Laboratory (TNO-FEL) in the Netherlands, (52.11° N latitude, 4.33° E longitude).
In total six test lanes with a different soil type in each lane are available. Figure B.1 gives a schematic drawing of the layout. The dimensions of the test lanes are 10 m x 3 m x 1.5 m for length, width and depth, with a distance of 1 m between them.

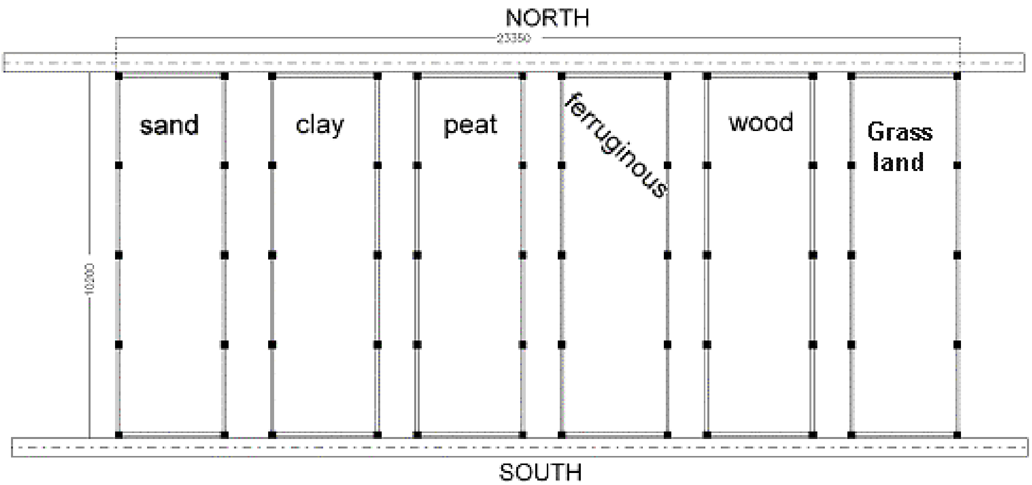

Figure B.1: Layout of the test facility. The dimensions in this drawing are in millimetres. The horizontal bars above and below the 6 lanes give the positions of the measurement platform

The Instrumented Prodder will be tested in all six soil types.

Measurement Bridge and Platform
The test facility is equipped with a measurement bridge (see Figure B.2). It consists of a 17 m long glass fiber enforced polyester tube with a diameter of 0.9 m. The measurement bridge can be moved manually from lane to lane (in the East-West direction) over rails along the North and South sides of the lanes (see Figure B.1). In the East-West direction the measurement bridge can be positioned with steps of 5 cm. The bridge can be fixed in a certain position by using pin holes which are available in the rails. On top of the measurement bridge another set of rails are fixed to the tube which are aligned to be flat within 5 mm over the full 17 m.

A measurement platform which can carry a total load of 600 kg, can move over these rails (automatically, if desired). The position of the measurement platform along the bridge in North-South direction can be measured continuously with a laser distance meter, and logged versus the time. The platform height and angle can be altered in order to approach the surface from different perspectives. The reproducibility of the platform position is 1 cm in all directions.

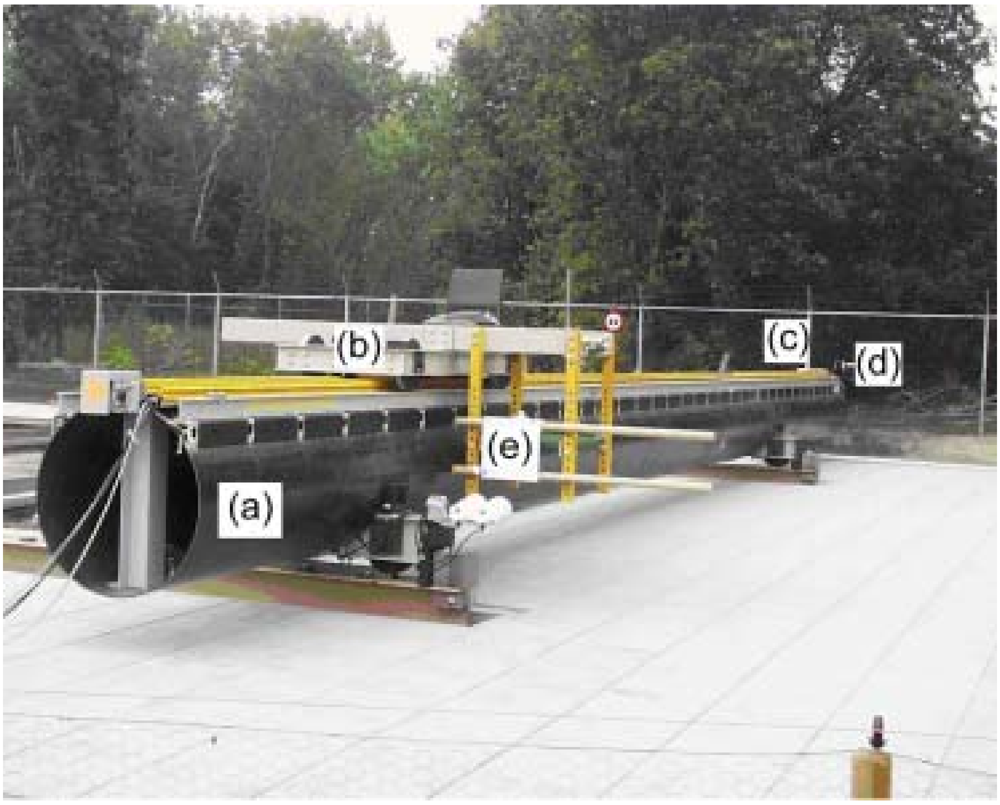

Figure B.2: Measurement bridge (a) with the rails (c) on which the measurement platform (b) and (e) can move.

Soil Types

The test lanes are filled with the following soil types: sandy soil, clay, peat, ferruginous soil, a sandy woodland soil and grassland.
A chemical and physical description, which gives insight of the texture and the structure of the different types of soil, is given in table B.1.

Table B.1: Typical soil characteristics of the first 50 cm from the surface. Iron, organic matter and lutum content are given relative to the dry matter content. The last column gives the typical groundwater level

Soil	Dry matter density (kg/m^3)	Iron content (g/kg)	Organic matter content	Lutum content	Ground-water level
Sand	1525	1.9	< 1%	< 2%	120 cm
Clay	1422	22	3%	27%	120 cm
Peat	943	39	35%	15%	40 cm
Ferruginous	1686	165	2%	60%	120 cm
Woodland	1411	5.3	5%	3%	120 cm
Grassland	NA	NA	NA	NA	120 cm

Characterisation of soil hardness

The soil hardness is characterized by the penetration resistance of a defined cone. This resistance can be measured with a penetrometer, specified by the ASAE, S313.3. The penetrometer which will be used during the tests of the instrumented prodder is the :

Eijkelkamp handpenetrometer, type IB.
S/N: TBD

Characterisation of soil moisture

The moisture content of the soil is recorded with a Time Domain Reflectometer (TDR)

Eijkelkamp TDR 8107, TRIME FM

Test objects

The Instrumented Prodder will be tested in relation to the following test objects.

Table B.2: Characteristics of the testobjects.

No:	Material	Shape	Remarks
1	Metal	Ø: 100 h: 55	
2	Wood	Ø: 100 h: 55	
3	P V C	Ø: 100 h: 55	
4	Aluminium	Ø: 100 h: 55	
5	Brick (cobble)	Ø: 100 h: 55	
6	Concrete	Ø: 100 h: 55	
7	PMN (inert)	Ø: 125 h: 55	No PMN is present in the Sand and Clay test lanes.

A hole is drilled in the top-center of each test object except for the PMN. Through a marker (skewer) placed in this hole the position of each test object is be indicated above the soil surface.

Test object burial position in the test lanes

Burial position of the test objects is done according the scheme, outlined in Figure B.3. The positions of the test objects is identical in each of the six test lanes with the exception of the sand and clay test lane where no PMN is present.
The absolute East-West position of the test objects is given in pin hole numbers. The pin holes are used to fix the measurement bridge.

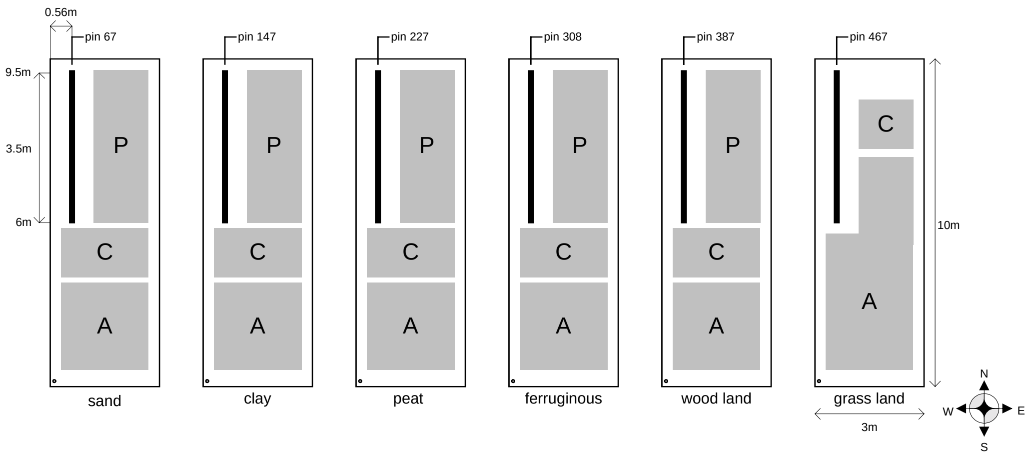

Figure B.3: Position of test objects in test lanes.

The straight thick lines in the north-west zones of all lanes are the prodder test tracks. The coordinates of the test objects are given in table B.3.

Table B.3: Position of test object.

Object	N/S coordinate	E/W coordinate	Depth
1: Spare 1	6000	560	
2: Steel	6500	560	50
3: Wood	7000	560	50
4: PVC	7500	560	50
5: Aluminium	8000	560	50
6:Brick	8500	560	50
7: Concrete	9000	560	50
8: PMN	9500	560	50

The center of each buried test object except the PMNs is indicated through a marker (skewer) in a way that the position of the object below the surface is marked at the soil surface.
The test objects are buried at a depth of 50 mm under the soil surface. This depth is measured to the top of the test object. The soil surface in each test lane is leveled. The surface is not covered against (eventual) rain after burial of the test objects.

Concise description of the Instrumented Prodder (Technology Demonstrator version)
The Instrumented Prodder is a deminer tool, which is derived from the conventional prodder. The Instrumented Prodder is supposed to give a safe/hazard indication of the type of material that is touched with the tip of the prodder needle. The Instrumented Prodder Technology Demonstrator version, which is subjected to the tests described in this document, consists of the following components.

- Prodding needle. This part consists of the actual prodding needle plus two integrated sensors, i.e. a load cell to measure the exerted force and a piezoelectric crystal for sending and receiving ultrasonic pulses through the prodders shaft. Combining the transmitted and reflected pulses, the material under contact with the tip of the prodder can be identified.
- Handgrip. The handgrip serves to ease the operator in handling of the prodder.
- Signal Processing box. The signal processing box is connected to the prodder needle. It contains the power supply (batteries) and electronics for signal processing. The box is equipped with a headphone plug and two RS 232 connectors. The audio signals on the headphone plug are not available. On the RS-232 connectors the signals as described in Table B.6 are available.
- External power supply.

A picture of the Instrumented Prodder technology demonstrator version is given in Figure B.4.

Two samples of the Instrumented Prodder technology demonstrator version are available, each marked A or B. All tests will be executed with both samples of the prodder.

Figure B.4: Picture of the "Instrumented Prodder technology demonstrator" version.

Test installation

The Instrumented Prodder needle will be forced into the ground and retracted from the ground via a spindle that is fixed to the needle. A DC motor drives the spindle. The DC motor is operated through a power supply with current limit and an up/rest/down select switch. With selection of the down position of the switch the needle is driven into the soil and with selection of the up position the needle is retracted from the soil.

The prodder is operated through a laptop computer. Through this computer control characters can be send to the prodder to set the various modes of operation. The controls characters and the corresponding operating modes are listed in table B.5. The data that is gathered from the prodder is displayed and logged into the laptop. A dedicated computer program is written to display the prodders' output parameters and to create a log file in which the parameters are recorded.

Figure B.5: Picture of the test installation.

Prodding force
The applied prodding force can be adjusted by limitation of the motor current through the drive motor.

Table B.4: Motor current versus prodding force.

Prodding Force	Motor Current
10N	TBD
5 N	TBD

The prodding force that shall be applied is specified in the test card given in section B.6.

Prodding angle
The prodding angle is the angle between the prodder needle and surface of the soil when the prodder needle is forced into the ground.
The required prodding angle can be selected through fixing holes that are available in the prodder fixing plate. The required prodding angles are specified in the test procedure. See Figure B.5.

Signal assessment and data recording

The operation of the Instrumented Prodder is be controlled via input commands to the prodder via a standard RS 232 port. By sending a character to the input port, the prodder can be set into the following modes of operation:

Table B.5: Input control characters.

Character	Mode of operation
"c"	Calibrate. This command will calibrate the system in air without contact with another object.
"i"	Initiate. This command will send the load cell offset to the output of the serial port.
"t"	Trigger. This command will make the Instrumented Prodder operational by activating its sensors, and makes the output data available on the RS 232 output bus.

The following data is available on the output of the RS 232 port.

Table B.6: Output data.

Data	Indication
PF	Load cell reading
A	Accuracy (calculated minimum error) The calculated minimum error indicates the accuracy of the material indication. The accuracy is specified as follows: TBD.
M	Material. "0" = rock, "1" = metal, "2" = plastic/wood.

All data is returned as a 4-character string, in which leading zeros are inserted if needed. The continuous data stream returned after triggering is made up of three (3) 4 character strings, separated by a "|", for example "0123|0022|0001". The first four characters represent the load cell reading, the second four represent the calculated minimum error. The last four characters represent the material determination.

B.4 Test procedure

The test procedure consists of the following steps.

A: The test setup shall be assembled according to the procedure below.

B: The measurement bridge and platform as described below shall be positioned over the selected test object. The pin number to fix the measuring bridge is given in the test card (section B.6).

C: The test setup and laptop shall be powered.

D: The Instrumented prodder shall be calibrated according the description given below.

E: The prodding force, which is specified in the corresponding test card, is selected according the description given below.

F: The prodding angle as specified on the test card shall be adjusted.

G: The general recordings (soil hardness and moisture content) on the test card shall be taken.

H: The prodder shall be driven into the soil by selecting the drive switch in the “down” position.

I: The indicated recording time, “material indication”, “accuracy of indication” and “load cell force” on the laptop shall be recorded on the test card.

J: The prodder shall be pulled back.

K: The prodder needle shall be visually cleaned with a dry cloth.

Both available samples of the Instrumented Prodder, marked by "A" and "B", shall be tested.

Instrumented Prodder test assembly

1. The Instrumented Prodder shall be fixed to the load-cell.
2. The prodder plus load-cell shall be attached to the force generating mechanism.
3. The prodder plus force generator shall be assembled to the measurement platform.
4. The prodder plus load-cell shall be connected to the electronics box.
5. The electronics box shall be connected to the laptop through the RS 232 cable.
6. The power supply shall be connected to the electronics box.

Calibration of the Instrumented Prodder.
The Instrumented Prodder shall be calibrated according the following procedure.

1. The prodder shall be positioned vertically to relief load on the load-cell.

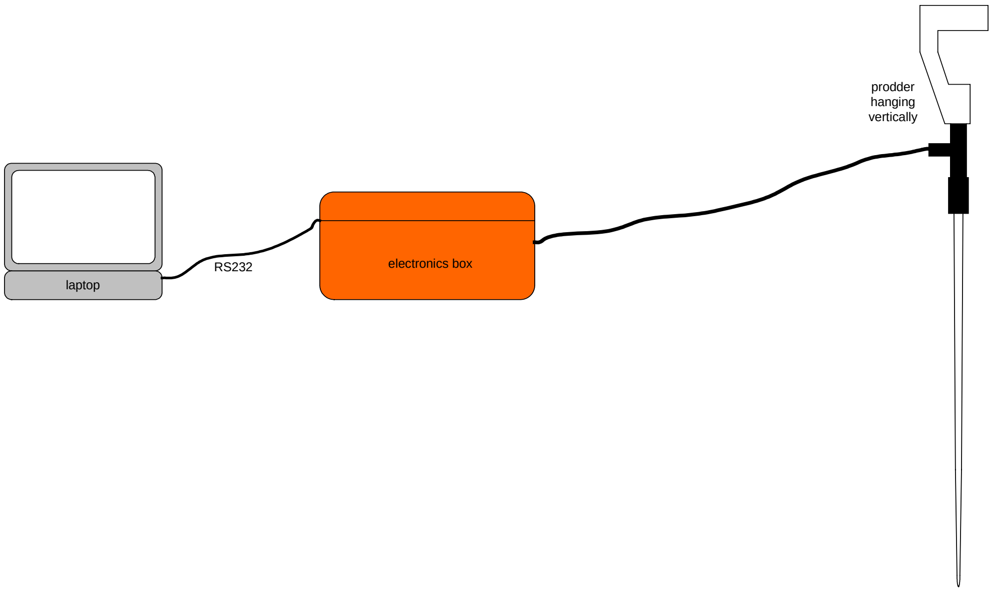

Figure B.6: Calibration setup.

2. The prodder terminal program on the laptop shall be started.
3. The operator shall send a “c” from the terminal program on the laptop through serial (RS232) link to the prodder electronics box.
4. Wait 10 seconds.
5. The indicated offset value shall be recorded on the test card.
6. An “i” shall be send to the prodder electronics to compensate for the calibrated offset.

Measurements
The following measurements shall be taken.

Per test object
On each test object prods shall be done according to the following positions and angles, as outlined in Figure B.7.

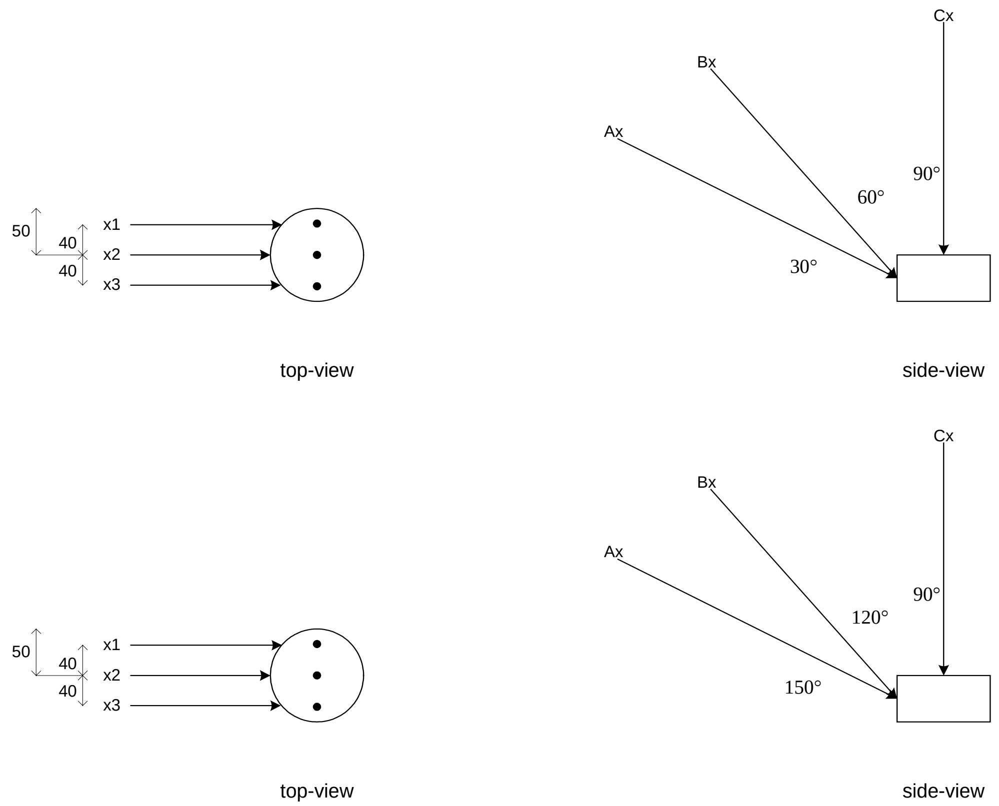

Figure B.7: Positions and prodding approach angles of the test objects. Distances are given in millimeters and angles are given in degrees.

Examples for the positions and angles:
C2 = a prodding straight down at the center-top of the object,
A1 = prodding with an angle of 30° and 40 mm north of the center-side of the object.

Figure B.8 outlines the prodding distances under a prodding angle of 30 degrees.

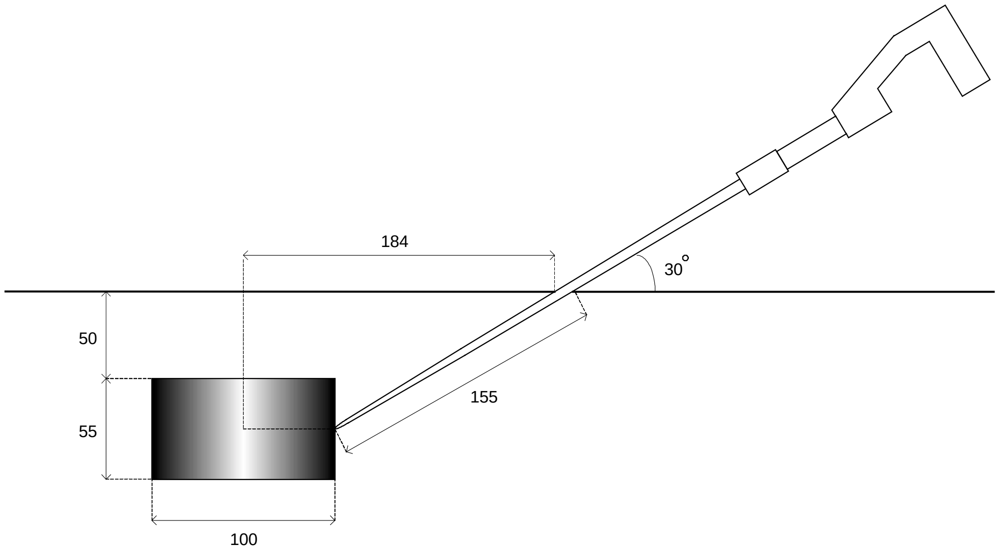

Figure B.8: Side-view of a buried test object and the prodder. Distances are given in millimeters and angles are given in degrees.

For each test object the next matrix applies. Each cell in the matrix contains three values, which are:

– measured prodding force at the load cell: PF,
– accuracy of material indication: A,
– indicated material: M.

Table B.7: Test object prodding.

	angle	force	1 40 mm north PF	A	M	2 center PF	A	M	3 40 mm south PF	A	M
A	30º	10N									
B	60º	10N									
C	90º	5N									
D	120º	5N									
E	150º	5N									

Per Testlane
Per test lane the measurements as specified before shall be executed on each test object. The position of each object is outlined in Figure B.3.

Test lanes
The measurements as specified before shall be executed in all test lanes.

B.5 Preparations for evaluation of the test results

In this chapter the performance evaluation of the Instrumented Prodder Technology Demonstrator is prepared. Through presentation of data that is obtained during the tests in a set of tables, dependencies of the prodders' material indication on prodding angle, prodding force and soil type can be studied.

Material indication versus prodding angle
The material as indicated by the Instrumented Prodder as a function of the prodding angle will be shown in Table B.8. From this table the performance of the prodder under various prodding angles can be obtained.

Table B.8: Material indication versus prodding angle.

		Prodder Indication		
		Rock	Metal	Plastic/Wood
Test object	**Steel** A: 30° B: 60° C: 90°			
	Wood: A:30° B: 60° C: 90°			
	Plastic: A:30° B: 60° C: 90°			
	Aluminium: A:30° B: 60° C: 90°			
	Brick: A:30° B: 60° C: 90°			
	Concrete: A:30° B: 60° C: 90°			
	PMN: A:30° B: 60° C: 90°			
	Spare: A:30° B: 60° C: 90°			

Material indication versus prodding force

The material as indicated by the Instrumented Prodder as a function of the prodding force will be shown in Table B.9. From this table the performance of the prodder by using different prodding forces can be obtained. From the tests it will also become clear if the prodder force operating range will be enough to penetrate the different soil types.

Table B.9: Material indication versus prodding force.

		Prodder Indication		
		Rock	Metal	Plastic/Wood
Test object	**Steel** 10N 5N			
	Wood: 10N 5N			
	Plastic: 10N 5N			
	Aluminium: 10N 5N			
	Brick: 10N 5N			
	Concrete: 10N 5N			
	PMN: 10N 5N			
	Spare: 10N 5N			

Material indication versus soil type.

The material indication by the Instrumented Prodder as a function soil type will be shown in Table B.10. From this table the performance of the prodder for use in different soil types can be obtained.

Table B.10: Material indication versus soil type.

		Prodder Indication		
		Rock	Metal	Plastic/Wood
Test object	**Steel** Sand Clay Peat Ferruginous Wood Grassland			
	Wood: Sand Clay Peat Ferruginous Wood Grassland			
	Plastic: Sand Clay Peat Ferruginous Wood Grassland			
	Aluminium: Sand Clay Peat Ferruginous Wood Grassland			
	Brick: Sand Clay Peat Ferruginous Wood Grassland			

	Concrete: Sand Clay Peat Ferruginous Wood Grassland			
	PMN: Peat Ferruginous Wood Grassland			
	Spare: Sand Clay Peat Ferruginous Wood Grassland			

Safe/Hazard indication assessment

From the data gathered from the Instrumented Prodder, the performance of the safe/hazard indication can be evaluated. The data will be projected in Table B.11. It must be stressed that the tests are not meant to obtain a precise statistical figure of the prodders' performance, but an indication of the feasibility of the applied technology.

Table B.11: Instrumented prodder safe/hazard indication assessment.

		Prodder indication	
		Danger	Safe
Detected Object	Mine:	Normal operation	Hazard
	No mine:	False alarm	Normal operation

B.6 Testcard

Testlane: (Sand/Clay/Peat/Ferruginous/Wood/Grassland)
Test object: (Steel/Wood/PVC/Aluminium/Brick/Concrete/PMN)
General Parameters

	Value	Remark
Testlane:		
Date:		
Time:		
Soil hardness:		
Moisture content:		
Prodder Sample:		

				1 **40 mm off-center North**			Rem.
Position	Angle	Force	Pin no.	PF	A	M	
A	30°	10N	TBD				
B	60°	10N	TBD				
C	90°	5N	TBD				
D	120°	5N	TBD				
E	150°	5N	TBD				

				2 **Center**			Rem.
Position	Angle	Force	Pin no.	PF	A	M	
A	30°	10N	TBD				
B	60°	10N	TBD				
C	90°	5N	TBD				
D	120°	5N	TBD				
E	150°	5N	TBD				

				3 **40 mm off-center South**			Rem.
Position	Angle	Force	Pin no.	PF	A	M	
A	30°	10N	TBD				
B	60°	10N	TBD				
C	90°	5N	TBD				
D	120°	5N	TBD				
E	150°	5N	TBD				

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Instrumented Prodder: results from the tests under controlled conditions

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

The prodder is one of the most important tools in demining operations. In Canada an instrumented prodder is developed that gives an indication of the type of material (metal, plastic/wood, or stone) under contact with the probe tip. From discussions with experienced deminers it is concluded that an instrumented prodder will have only a limited area of application, but that it may have a surplus value in certain demining operations. The performance of the material identification feature of this prodder is tested for 6 soil types and 7 different buried objects of metal, plastic, wood and stone. The force to insert the prodder into the soil was monitored and the prodder was used under 3 different angles with the soil surface. From the results it is concluded that material identification is feasible with the technique implemented in the instrumented prodder, but that the use of this prodder is limited by the hardness of the soil. The performance is probably reduced in sticky soils. Suggestions to improve the prodder's performance are included. Apart from continuation of the development of the instrumented prodder as a detection tool, development as a excavation tool or as a training tool for deminers is proposed.

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