Instrumented Prodder: Preliminary Results of the Technology Demonstrator Evaluation
A.J. Schoolderman\textsuperscript{1}, S.G.M. van Dijk\textsuperscript{1}, D. Deurloo\textsuperscript{1}, K. Russell\textsuperscript{2}

\textsuperscript{1} TNO-FEL  
P.O. Box 96864  
2509 JG The Hague  
The Netherlands  
schoolderman@fel.tno.nl

\textsuperscript{2} CCMAT  
Box 4000, Station Main  
Medicine Hat, Alberta  
Canada T1A 8K6  
Kevin.Russell@drdc-rddc.gc.ca

Abstract
A prodder for mine detection has been enhanced with sensors and electronics in order to provide the operator with information on the force exerted during the prodding operation and on the type of material that is in contact with the tip of the prodder. The performance of a technology demonstrator version of this Instrumented Prodder is tested under laboratory conditions, as a start of a product development path. For these tests seven different types of objects (inert PMN mines and mine-like objects from stone, PVC, wood and metal) were buried in test lanes with six soil types with different hardness and moisture content. The Instrumented Prodder was inserted into the soil in such a way that it was possible to adjust the exerted force.

From the test results it is concluded that material identification of buried objects by an instrumented prodder is feasible. The low reliability of the material identification feature of the technology demonstrator as found in the tests is likely due to incorrect measurement of the contact force between the prodder’s tip and the buried object.

1. Introduction
The prodder is one of the most important tools for a deminer involved in humanitarian demining operations. In [1] the history of the conventional prodder and improvements on this device are discussed. Developed in Canada, an 'Instrumented Prodder' is an attempt to improve on the basic prodding tool. This device is a prodder which gives an indication of the type of material (metal, plastic/wood or stone) under contact with the probe tip. This indication aids the operator with the classification and identification of the buried object. The first version of the Instrumented Prodder, called 'SmartProbe', was manufactured in a small number by the Canadian company, DEW Engineering and Development Ltd., under a 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] and DEW discontinued the product line.

The advantage of a force feedback indicator during 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 where the soil is hard as prodding on anti-personnel mines is a major cause of demining accidents. A force feedback signal which warns the operator of excess force being applied, may lead to safer prodding. Funded by the Canadian Centre for Mine Action Technology (CCMAT), HF Research Inc. (a Canadian company) initiated a redesign of the Instrumented Prodder and produced a 'technology demonstrator' which is equipped with a force feedback system in addition to the case material identification 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 interrogated 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.

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

The current product development project at TNO-FEL has started with the description of the scenarios in which the Instrumented Prodder may be used and the development of user requirements, based on input from a Users’ Group (see section 2). Based on these scenarios and user requirements, a test plan was developed for the current technology demonstrator version under controlled conditions as described in section 3. The test set-up,
including the force applying mechanism, the targets used in these tests, test procedure and the test results are presented in section 4. In section 5, an outlook of the work in the remainder of the current project is presented, as well as the continuation of the project development path to a market-ready device.

2. Scenarios and User Requirements
As a first step in the current product development, the scenarios for demining operations in which an Instrumented Prodder may be applied, are established. The starting point was the description of the 12 demining scenarios provided in a recent report by the Geneva International Center for Humanitarian Demining [7]. The use of the Instrumented Prodder will be limited to scenarios with soft to medium soil hardness. However, due to the force feedback mechanism, it is possible that the Instrumented Prodder may be used more safely in medium-hard soil than the conventional prodder.

Special attention was given to the question of the surplus value of the Instrumented Prodder in demining operations, assuming that this device performs well and reliable. In current humanitarian demining operations the conventional prodder is often used in conjunction with a metal detector. Normally, when the latter indicates the presence of metal, the operator uses the prodder to obtain information on the depth, size, shape and orientation of the (metal-containing) object before attempting to safely excavate the object. In most cases the additional information from the Instrumented Prodder concerning the type of material of the object’s surface will not be of much use for the deminer. He will instead rely exclusively on the metal detector’s alarm and proceed to excavate the object in order to remove the metal part that gave the alarm. A similar situation applies for the case where the Instrumented Prodder is used in conjunction with a demining dog. However, in conditions where a metal detector can’t be used and other demining equipment, like dogs, is not readily available, the Instrumented Prodder may lead to faster and safer demining. One can think of demining near houses or other structures with reinforced concrete, near railways, under powerlines, etc.

With input from the Users’ Group, the user requirements for an Instrumented Prodder can be summarized as follows. The emphasis lies on robustness and on the user interface. It is required that the Instrumented Prodder can also be used as a conventional prodder in operations where the force feedback and material indication are not considered advantageous.

3. Technology Demonstrator
The current version of the Instrumented Prodder can be regarded as a 'technology demonstrator'. The feasibility of a prodder with force feedback and material indication can be demonstrated with this version. However the device as constructed in this version is not intended nor suitable for field testing under less than perfect conditions.

The Instrumented Prodder has two integrated sensors, a load cell to measure the force exerted by the operator and a piezoelectric crystal for sending and receiving ultrasonic pulses through the prodder’s shaft. Combining the transmitted and reflected pulses, the material under contact with the tip of the prodder can be identified. The prodder is tethered by a cable to a box that houses the power supply (batteries) and electronics for signal processing (see Figure 1). The box is equipped with a RS232 connector for digital recording of the load cell output and the material identification signal (“decision signal”). The present technology demonstration version is not equipped with an audio output. Two samples were available for testing.

![Figure 1 Technology demonstrator version of the Instrumented Prodder](image)

4. Tests under Controlled Conditions
The technology demonstrator version of the Instrumented Prodder was tested under controlled conditions to assess its capability of identifying the casing material of buried objects. The objects were buried in several soils with varying properties. Prior to the execution of the tests, a test plan was written. The test plan described the test facility, test objects, test procedure and additional measurements. The force used to push the prodder into the soil was controlled, as well as the angle of the prodder with the soil surface. The decision signal of the Instrumented Prodder was assessed and recorded by an operator during the tests.

4.1. Test Set-up
The tests were executed at the outdoor test facility of TNO-FEL in The Hague, The Netherlands. 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 sand, clay, peat, iron-containing soil (ferruginous soil), woodland soil and a grass layer, respectively. Figure 2 shows a picture of the test facility. On the test facility a xy-positioning frame is present (see Figure 2). Additional information on the test lanes can be found in [8].

During the test period (April 14 - 16, 2003), the hardness and the moisture content of the top layer (up to 10 cm deep) of the six lanes were measured with a penetrometer and a Time Domain Reflectometer (TDR). The results of these measurements are given in Table 1, together with other relevant data of these soils.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Sand</th>
<th>Clay</th>
<th>Peat</th>
<th>Ferruginous</th>
<th>Woodland</th>
<th>Grassland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness (Pa)</td>
<td>52</td>
<td>102</td>
<td>65</td>
<td>109</td>
<td>93</td>
<td>92</td>
</tr>
<tr>
<td>Moisture content</td>
<td>4.4%</td>
<td>32%</td>
<td>29%</td>
<td>10%</td>
<td>15%</td>
<td>6%</td>
</tr>
<tr>
<td>Dry matter</td>
<td>1525</td>
<td>1422</td>
<td>943</td>
<td>1686</td>
<td>1411</td>
<td>n.a.</td>
</tr>
<tr>
<td>density (kg/m³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic matter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n.a.</td>
</tr>
<tr>
<td>content</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lutum content</td>
<td>&lt; 1%</td>
<td>3%</td>
<td>35%</td>
<td>2%</td>
<td>5%</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

The Instrumented Prodder was mounted on the measurement platform of the xy-positioning frame in such a way that it could be forced into the soil at the angles of 30°, 60° and 90°. 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 [5]), a DC 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 larger forces 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 (see Figure 3). During insertion, the exerted force on the prodder was shown on the display of a laptop computer using a locally created program. The program also created a log file in which the measured force and the result of the material identification algorithm (i.e. the decision signal) were recorded. The same laptop computer was also used to operate the Instrumented Prodder where control characters were sent to the prodder to set the various modes of operation: calibration of the load cell in air; correction for the load cell’s offset; and starting the material identification algorithm.

### 4.2. Test Objects

In order to assess the material identification feature of the Instrumented Prodder, seven different types of objects were buried in each of the six test lanes at a depth of 5 cm (i.e. the distance of the top of the object to the soil surface). These objects are:

- Inert PMN mines (fuzes removed and the explosive replaced by silicon rubber RTV3110 from Dow Corning);
- Solid cylinders of pouring concrete (10 cm diameter, 5.5 cm height), with a smooth surface;
- Bricks with a rough surface (sides of 11 cm, 6 cm height);
- Solid aluminium cylinders with a diameter of 10 cm and height of 5.5 cm;
- Solid PVC cylinders with a diameter of 10 cm and height of 5.5 cm;
- Solid cylinders (10 cm diameter, 5.5 cm height) from fir;
- Solid steel cylinders (10 cm diameter, 5.5 cm height).

Because only four inert PMN mines were available, no inert PMNs were buried in the lanes with sand and clay.

Figure 4 shows samples of the seven object types. The test objects were buried along a straight line parallel to the long sides of the lanes and at intermediate distances of 50 cm. All objects were buried in such a way that the axis of the cylinder was oriented vertically. The positions of the buried objects were indicated with a marker (skewer) to facilitate the determination of the prodding positions.

4.3. Test Procedure

The test procedure consisted of a number of steps for a prodding action on a single test object which can be summarized as follows:

1. After calibration of the load cell and correction for the load cell’s offset, the measurement platform with the mounted Instrumented Prodder was moved manually to the prodding position. This position (relative to the test object) depended on the chosen prodding angle. Angles of 30°, 60° and 90° were used.
2. The prodder was forced into the soil under the chosen angle with a force up to 25 N by spinning the gearwheel manually. The actual force was indicated in real-time on a laptop’s display present on the measurement platform. Hence the operator was able to control the force by hand.
3. When the operator was confident that the prodder’s tip was in contact with the buried object, he lowered the force to 10 N, recorded the material indication from the laptop’s display, lowered the force to 5 N and again read off the material indication.
4. If necessary, the needle of the prodder was cleaned with a cloth after the shaft was removed from the ground.

In addition, the output of the load cell and the decision signal were recorded digitally during all prodding actions for future analysis.

Figure 5 shows the Instrumented Prodder under test. On each buried object, 3 prodding actions were performed: one on the center of the object and two 4 cm out of the center. In total 288 prodding actions were performed; 96 per prodding angle.

4.4. Test Results

For the tests, two samples of the Instrumented Prodder’s technology demonstration version were available. However, due to technical problems, the tests on all six lanes and for all three prodding angles (30°, 60° and 90°) were fully completed by only one of the prodders. Only the results of the sample that went through the complete test are reported here.

In Table 2 the results for the material identification of the Instrumented Prodder per soil type are shown. The results for the three prodding angles and the two ‘contact forces’ (5 and 10 N) are tallied up in this table.

From Table 2 it is clear that the material identification feature of the Instrumented Prodder’s technology demonstration version is not functioning reliably under all test conditions. There appears to be no correlation between the hardness of the soil considered (see Table 1) and the material identification performance. In 68 prodding actions, the prodder’s tip did not make contact with the buried object. This happened only twice for the 90° prodding angle.
Table 3 shows the test results for peat and woodland soil when prodding with an angle of 90°. The results for the ‘contact forces’ of 5 and 10 N are tallied up in this table.

### Table 2 Test results

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Object/Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metal</td>
</tr>
<tr>
<td></td>
<td>correct</td>
</tr>
<tr>
<td>Sand</td>
<td>27</td>
</tr>
<tr>
<td>Clay</td>
<td>6</td>
</tr>
<tr>
<td>Peat</td>
<td>22</td>
</tr>
<tr>
<td>Ferroginous</td>
<td>19</td>
</tr>
<tr>
<td>Woodland</td>
<td>6</td>
</tr>
<tr>
<td>Grassland</td>
<td>4</td>
</tr>
</tbody>
</table>

The results shown in Table 3 indicate that material identification of buried objects is feasible with the technology implemented in the Instrumented Prodder. However, comparison of the test results for the different soil types and prodding angles clearly show that the performance of the material identification feature of the technology demonstrator depends strongly on the test conditions. The technology demonstrator performs unreliable for prodding angles of 30° and 60° and in sand, clay, ferroginous soil and grassland. This suggests that the performance is degraded when the prodder’s needle is inserted deeply into the soil in order to make contact with the buried object. It also appears that performance is reduced when the device is used in sticky soil. This behaviour may be explained by the notion that the load cell measures not only the force on the prodder’s tip (due to the soil to be penetrated or the object that is contacted), but also the friction force on the inserted part of the needle. This friction force may dominate the load cell output when the needle is far enough in the soil and the soil is sticky. Since the load cell output is essential for the material identification algorithm, a significant friction force contribution to the load cell output will result in an incorrect material identification. Another possibility to consider is that the ultrasonic pulses may be attenuated by material that sticks to the prodder’s shaft. This may lower the signal to noise ratio and confuse the identification algorithm.

5. Conclusion

The material identification performance of the Instrumented Prodder’s technology demonstrator has been assessed by tests conducted under controlled conditions. The results of these tests show that material identification of buried objects is feasible with the implemented technology. The large percentage of incorrect material identifications in four of the six soil types used in the tests and for prodding angles that necessitate deeper insertion of the prodder’s needle for contact with the buried object, are probably due to friction forces on the prodder’s needle and possible signal attenuation. To increase the reliability of the material identification feature to the level that is necessary for operational use of the Instrumented Prodder, the mechanical design and the implementation of the sensor used to measure the applied force should be reconsidered. If this reliability level is reached, design aspects like robustness and user interface should be looked at in close collaboration with potential end users in order to proceed with the product development. Besides further technical development of the Instrumented Prodder, it is essential to define the added value of such a system to the current demining tool box, the scenarios in which it can be used successfully, and the performance limitations.

Acknowledgments

The authors would like to thank the Royal Netherlands Army for funding the project, the Canadian Centre for Mine Action Technology and HF Inc for support and the members of the Users’ Group for valuable input and comment.

6. References

8330-3301-8.


