Evaluation of a Commercial Visualizing Metal Detector for UXO/Mine Detection: the HILTI Ferroscan System

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Abstract

We will report on first tests of a commercial "imaging metal detector" aimed at trying to assess its potentialities and understand in a broader sense if such systems, possibly in a modified form, could be useful to tackle some aspects of the UXO/mine detection problem. The latter include the detection of shallowly buried Unexploded Ordnance (UXO) (e.g. in Laos) or non minimum-metal mines such as the Russian PMN and PMN2.

1) Introduction

Metal detectors used in humanitarian demining applications have become more and more refined and sensitive over the years, and it has been often said that these devices have reached their limits. In fact there are a number of other technical fields in which metal detectors are used with profit to deliver additional information on the object under study, such as for example its depth, size or identity, albeit often for specific cases only (such as rebars embedded in concrete). Some systems capable of delivering a 2D "image" of buried metallic objects are under study or already commercially available, such as Ferroscan which has been developed for civil engineering applications.

In this report we will try to assess the potentialities of a commercial "imaging metal detector", to understand if such systems, possibly in a modified form, could be useful to tackle some aspects of the UXO/mine detection problem along the lines proposed in [Ebl96][1]. In fact, given that spatial resolution and depth penetration constitute conflicting requirements, we do not expect them to be applicable to humanitarian demining "as is".

Results could be a priori expected for "larger" metallic objects of regular size which have to be differentiated from metallic debris often consisting of small metallic pieces scattered around. Examples are non minimum-metal mines such as the Russian PMN or PMN2, or shallowly buried Unexploded Ordnance (UXO) such as "bomblets" which still plague some areas (e.g. Laos). Minimum metal mines seem much less likely to profit from such a system alone, in the sense that an image of a pointlike object would be of help to the deminer, but in itself probably insufficient to take a yes/no decision.

2) Imaging Metal Detectors

"Conventional" metal detectors can be used to generate bidimensional images of buried metallic objects, but up to now only a few (limited) practical implementations – which could be interesting for us – have been carried out.

2.1) UXO Detection

Concerning the detection and imaging of larger objects, such as UXO, we are aware of the following developments:

- ODIS (Ordnance Detection and Identification System) is a vehicular system conceived to provide the user with quantitative information (relying on database supported inversion) on shallowly buried ordnance and to deliver unprocessed images (not deconvolved) [Bor96] [ODIS96]. The latter are very useful to spatially localize the single objects, which is essential in a real-time constrained vehicular operation, but do probably not allow by themselves to distinguish one object from another, except for "large" objects, i.e. of size comparable to the detector's dimensions. Further developments might have taken place since this information was published.
- Studies are being carried out on a "nearfield holographic" data processing technique aimed at reconstructing the magnetic field distribution in the horizontal plane at various depths in the ground, to localize and possibly resolve near-surface buried metallic objects [Guo96].

[1] "First generation equipment [] could provide the deminer with a visual image of shape and size of the metal signature."

- Arrays of metal detectors have also been built, such as the Schiebel VAMIDS system. Figure 1 shows an image corresponding to data taken on a dirt road at DRES [Fee96]. Each of the 9 wide strips represents the full width of the array as the detector moves along the road at uniform speed. Strongly positive signals are white, strongly negative signals are black. A number of mines are detected, as well as a number of nuisance items and false alarms (courtesy Dr. John McFee, Defence Research Establishment Suffield (DRES), Defence Research and Development Branch, Canada). Note that VAMIDS is not really an imaging detector.

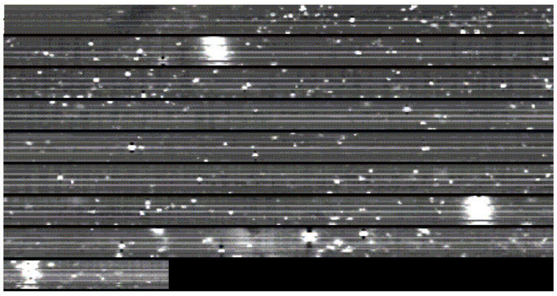

Figure 1: Schiebel VAMIDS "image" (McFee, DRES [Fee96])

2.2) NDT Applications

Smaller objects, closer to what might be interesting for us, are the focus of some Non Destructive Testing (NDT) applications, such as the detection of rebars in concrete. The latter are mostly made of steel, with diameter between 6mm and 50mm, and usually located up to a maximum depth of 18cm.

Metal detectors used in such applications are much smaller than the ones employed for landmine detection, therefore more accurate at shallow depths (increased spatial resolution) but lacking in depth of penetration, given that the detection range is strongly related to the coil dimensions.

Single sensors have normally to be scanned on the area of interest, which can be time consuming and decrease data quality. Multi-sensor systems such as Ferroscan can ease the task, at the price of higher cost and somewhat increased complexity. Example of developments include the following:

- The University of Kassel has been working on an imaging inductive rebar locator, which uses IR sensors for accurate position measurements (0.5 mm) on a 2D grid of lines [Ger96] [Ric95]. Priority is now on data analysis and sensor optimization[2] more than on imaging aspects (although, concerning the latter, interest in a high resolution tracking system remains).

- The University of Manchester is working on an inductive rebar locator and on image processing (enhancement) techniques, such as deconvolution (Figure 2c,d) using an accurately modelled response function, to sharpen the response. This might require the knowledge of the object's depth. Their laboratory prototype uses a high resolution positioning frame and a sensor which is physically much smaller than a "conventional" metal detector (Figure 2a), to improve spatial resolution [Gay94] [Gay95]. The development of a multi-array sensor with a new sensor head[3] is currently being pursued.

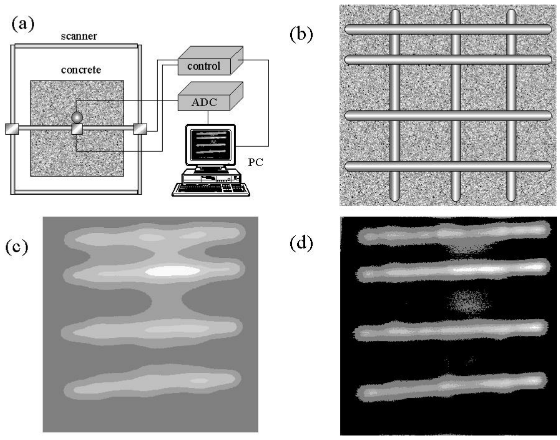

Figure 2: Prototype high resolution imaging metal det. (F. Gaydecki, Manchester [Gay95])

- The Ferroscan system, developed by the HILTI Corporation, which will be detailed below.

Such systems can indeed exploit the fact that rebars are shallowly placed regular structures composed of ferromagnetic objects, usually lying in a plane, whereas the humanitarian demining world is obviously much more complex (small and irregular objects, ground inhomogeneities, etc.).

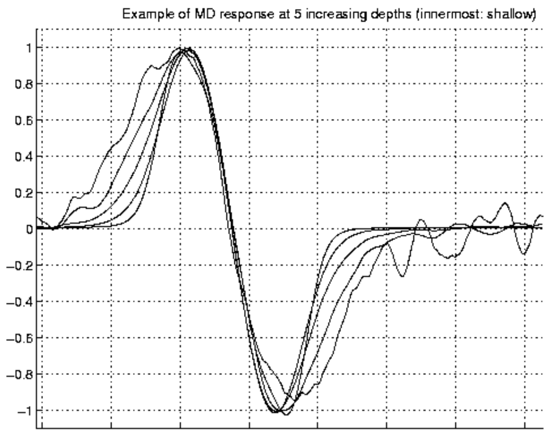

Figure 3: Normalized response at increasing depths (general trend, differ. sensor, line scan)

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[2] W. Ricken, *Private Communication*, Sept. 1997.

[3] F. Gaydecki, *Private Communication*, June & Sept.´97.

As a last point note that the response curve of a sensor depends on its intrinsic resolution as well as on the object's depth, and will tend to broaden with increasing depth (Figure 3), which can considerably affect the images if left untreated.

3) The Ferroscan System

Ferroscan, manufactured by the HILTI Corporation (Schaan, Liechtenstein), has appeared on the market at the beginning of the `90s and is targeted at the visualization of steel rebars in concrete.

3.1) System Components

The heart of the system is represented by the RS 10 multisensor scanner (Figure 4, right), of size 230x140x140 mm and weight 1 kg, which is able to scan a width of 15cm.

Results are displayed on the RV 10 monitor (Figure 4, left), of size 270x200x80 mm and weight 2.2 kg (accumulators included). Its backlight LCD works on 320x240 pixels using 9 grey levels. The monitor can be interfaced to a PC via a standard serial RS 232 interface to download the acquired data, with a maximum of 42 raw data files, each one corresponding to a full acquisition. A PC version of the data processing software running on the monitor's 16 bit microprocessor is also available [HIL1].

Figure 4: Ferroscan RV 10 monitor (left) and RS 10 scanner (right) (ruler length: 30 cm)

3.2) Scanning Procedure

The maximum area which can be covered and analyzed in a single image is 60x60 cm and has to be crossed horizontally and vertically, for a total of eight scans (four in each direction, see Figure 5). Up to 42 images can be stored.

This because the system, due to its differential nature, is not able to find objects located parallel to the scanning direction. The latter is in fact strictly true only for rebars somewhat longer than the scan, in the sense that any object shorter than the scan length will produce at least a signal at its beginning and at its end; this will have some interesting implications on the objects of interest to us. Note that diagonally lying objects are displayed with slightly worsened resolution (fuzzier image).

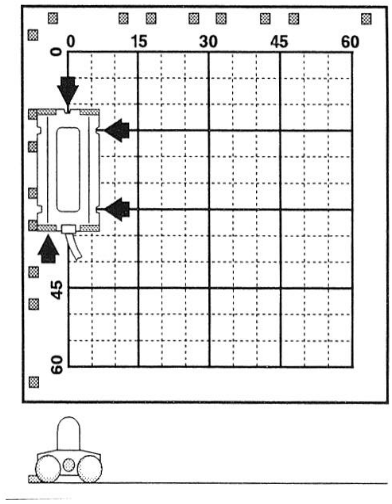

Figure 5: Ferroscan scanning procedure, lengths in cm (from [HIL2])

The maximum scanning speed is 0.5 m/s, which looks quite sufficient for hand-held operation; a complete scan is therefore obtained rather quickly. Note that the area of interest can be smaller if necessary, but only sections containing both horizontal and vertical data are actually displayed and analysed [HIL2].

The distance is measured along the track by odometry, using an optical encoder, given that the surface used is almost always flat. One set of two wheels is placed at each end of the scanner, the four wheels moving together to guarantee displacements as parallel as possible along the scanning direction.

3.3) Technical Details

From the Ferroscan patent [HIL4] we know that the system is of multisensor and differential nature, basically measuring (an approximation of) the horizontal gradient, along the scanning direction, of the vertical component of the induced magnetic field.

Given that such a system is targeted primarily at steel objects it can be built, in principle, either using a permanent magnet or an electromagnet as in conventional metal detectors used for humanitarian demining, in both cases spanning the scanner width. Corresponding sensors include field plates such as magnetically controlled resistors, or more conventional copper coils. A two dimensional arrangement of the sensors is in principle possible.

3.4) Data Processing

The sensor is obviously the central part of the system, but simple and elegant real-time data processing represents an important contribution to system performance too.

Using a differential sensor eases rebar localization, which can be obtained for example by looking for zero crossings in the received signals, or by further differentiation. The differentiated signal curves can then be used to produce, starting from the horizontal and vertical scans, a composite bidimensional grey-scale image such as Figure 6 [HIL4].

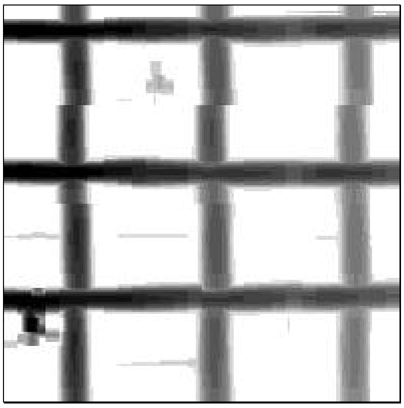

Figure 6: Ferroscan grey scale image (all depths, 60x60 cm)

The latter can then be further processed to look at different depth slices, as depicted in Figure 7 (but always starting from 0, e.g. 0 to 20mm or 0 to 35mm etc.), using a simple and efficient menu driven interface and pushbuttons at the side of the screen [HIL3]. Note that these images are binary (black/white). These impressive processing steps rely probably in a clever way on the characteristics of the rebars´response, which depends much more on its depth than on its size; as such they are not very likely, in their present form, to be generalized easily to other metallic objects.

It is well known that the signals received by metal detectors decay very rapidly with distance, spanning several orders of magnitude. Representing with a few grey levels an image of rebars at different depths requires therefore some form of nonlinear transformation to preserve the system dynamics. This has again implications on the visualization of objects of interest to us, especially small isolated ones. Adequate filtering is also necessary, especially for weak signals.

Note that we do have full access to the system's raw data thanks to the collaboration of HILTI, but we do not know the exact details of the algorithm implemented in Ferroscan. We have therefore tried to reproduce it as simply as possible along the basic lines described above for the purposes of this study.

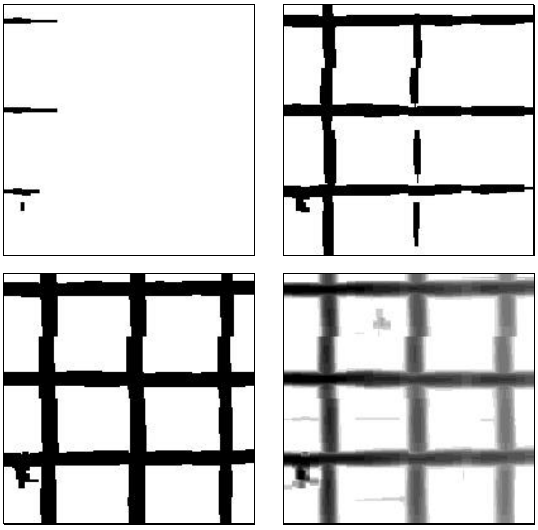

Figure 7: Ferroscan B/W images at increasing depth range (0-20mm, 0-35mm, 0-50mm, 0-max)

3.5) Data Analysis

Rebars of 6mm diameter can be displayed nominally down to 130mm, and those of 36mm down to 180mm. Indication of their depth and size is given only when reliable, which happens for somewhat smaller values of depth. Sensor resolution is such that two rebars should be distinguishable when their distance *d* is greater than their depth (cover) *T* (*d/T‡1*).

Note that processing is tuned to ferromagnetic objects; non ferromagnetic ones, e.g. aluminium or copper, do also produce signals, which can however not be evaluated. The corresponding images look somewhat like “negatives” of the expected ones. This does usually not represent a problem given that the analysis of such objects is not the primary goal of the system, and that they appear rarely in the context in which Ferroscan is used.

Note also that the magnetic field induced in the bar, or any other (linear) structure, radiates from its ends in all directions and is often detected in more than one sensor, which contributes to making the final image fuzzier [HIL3]. This effect complements the one described in §3.2.

4) Tests in the “Sandbox”

A number of objects, mostly of the UXO type (and ferromagnetic), were tested in our “sandbox” at different depths. For this purpose we put a wooden plate directly on the flattened sand surface and moved the sensor over the plate in much the same way as would be done while scanning a standard wall (as described before). We do obviously NOT suggest here that this experimental practice is applicable “as is” to the detection of ordnance or landmines. On the contrary, as for other detectors which have to be scanned in a precise way over the object of interest, an adequate tracking system would have to be given careful attention and its implementation is far from trivial, but its development was not the aim of the present study.

The objects under analysis include (see the corresponding images on the following pages):

- *Small submunition*, steel (ferromagnetic), slight ellipsoidal shape (31mm x 36mm), 63 grams, internally prefragmented;
- *BLU 26 "bomblet"* (blue coloured, probably the training version), round (65mm diameter), 430 grams. Its body is likely to be non ferromagnetic (e.g. aluminium), containing ferromagnetic shrapnel. Note that this might be different from the live (all steel?) version[4]. Large quantities of similar UXO are still found in Laos for example
- *Mortar shell*: of total length 30cm, its top half is steel (ferromagnetic), while the bottom half is aluminium.
- *20mm Projectile*: cylindrical, 20mm diameter at the basis, 14mm length, steel (ferromagnetic) with an aluminium tip.
- *"Rocket"*: cylindrical, aluminium, 32-33cm length.
- *PMN* "like" AP[5] (origin: Cambodia): a "classical" AP, diameter 11cm, height 5, with cover retaining ring (ferromagnetic!) placed at about 1.5cm from the top (height 5mm, thickness about 2mm, double i.e. bent twice). This mine has *usually* a steel striker composed essentially of two cylinders joined one to the other, the first of 19mm length and 9mm diameter, the second of 39mm length and 5mm diameter. This striker is located horizontally somewhat above the bottom. The one in our possession had in fact a slightly smaller, non ferromagnetic (alloy?) striker.
- *Debris*: a steel screw (ferromagnetic), about 20mm long, head 7mm wide, and a large metallic piece of irregular shape (twisted), 10mm large and about 3-4mm thick, probably made of copper (reddish colour).

5) Discussion

As hinted at before, a wooden plate was placed between the sensor and the sand (thickness 1.6cm or 1.9cm, indicated with "+1.6cm" and "+1.9cm" respectively). This thickness has therefore to be added to the depth indicated for each object, measured from its top, to obtain the actual distance from the sensor. "Flush" means (with the top) just underneath the surface level.

Each image is presented as the standard Ferroscan picture (compression of the intensity's dynamic range by default) and as obtained by us using a linear scale. The latter might be more appropriated to reproduce with greater accuracy an (isolated) object's shape.

The objects are represented up to a depth which gives roughly, *with the current hardware and data processing*, reasonable images, but which has not to be taken as a precise indication of the actual sensor performances. Note also that the data has been acquired with two different sensors, with the second one possibly more noisy. All images are taken on the full 60x60cm except for the first ones.

Some of the interesting features of the images presented include the following:

- *Small submunition*: image size 30x30cm.
- *BLU 26 "bomblet"*: its mixed nature (ferromagnetic and non material embedded in the same object) is probably at the origin of some of the complex image details displayed.
- *Mortar shell*: notice the "negative image" (void) corresponding to the bottom non ferromagnetic part, due to the processing algorithm tuned to enhance ferromagnetic objects and suppress non ferromagnetic ones.
- *20mm Projectile*: was lying diagonally along the axis NW-SE, which as expected somewhat degrades image quality. Note that a rebar of the same size would be visible, if orthogonal to one of the scanning directions, down to 160mm.
- *"Rocket"*: this large ferromagnetic object produces again a "negative image" (void).
- *PMN:* the cover retaining ring is clearly visible, with the darker spot probably corresponding to the area around the pin used to secure the ring (see the front of the corresponding picture).
- *Debris*: notice again the halo of the ferromagnetic object (lower right) and the bizarre shape of the screw (upper left) in the original image. The latter is due to some of the technical and physical features described in the previous paragraphs, enhanced by the compression of the intensity's dynamic range necessary to visualize clearly all objects.

Note that in general an object's image gets larger with increasing depth, as expected.

[4] Lyn Haywood, Miltra Eng., *Private Communication.*
[5] It could be a Chinese Type 58 copy (Lyn Haywood, *Private Communication).*

6) Concluding Remarks

The Ferroscan system is one of the few commercially available metal detector, if not the only one, capable of providing the user with visual information of the objects under study, in addition to "traditional" indications on depth and diameter. The Ferroscan images are indeed a precious aid in localizing and interpreting the underlying metallic structure, without pretending to deliver a true representation of it. This task has been solved by employing multisensor hardware and, as far as we have been able to judge, simple and elegant data processing software. Imaging has also been "eased" by the fact that the nature of the problem is rather well defined a priori, i.e. mostly cylindrical parallel ferromagnetic objects placed horizontally in standard patterns at shallow depth.

Our preliminary tests were targeted at applying this existing system "as is" to the localization, and possibly visualization, of shallowly buried UXO, mostly ferromagnetic, and possibly some APs with relevant metal content (e.g. PMN). The size of such objects can vary rather widely, and they often do come isolated, placed at random.

The multisensor arrangement is practical to scan quickly a large area. On the other hand using more than one sensor, and the differential arrangement itself, have some side effects for the visualization of smaller isolated (ferromagnetic) objects, for which the system was indeed not intended, and in presence of edges. And the increased spatial resolution comes obviously at the price of decreased depth, to nobody's surprise.

The images obtained confirm nevertheless that this approach is potentially interesting, especially if one has to look for ferromagnetic objects, and, once more, that the task we face remains a formidable one. Improvements on the range and sensor directivity could come from the data processing side, for very weak signals for example, and from the sensors, where it has been suggested to use smaller probes, e.g. magnetoresistive or miniature fluxgate elements[6] [Czi96], or to alter the coil geometry [Gay94].

Ultimately, feedback has to come from the people in the field, the end users of the equipment and those more directly concerned with its performances.

[6] Which obviously have to provide the required sensitivity and work at the required frequencies, not at DC as standard magnetometers.

Acknowledgments

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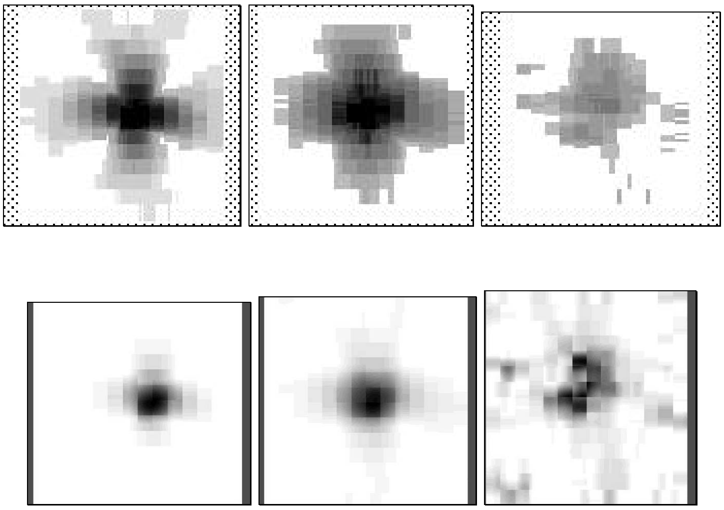
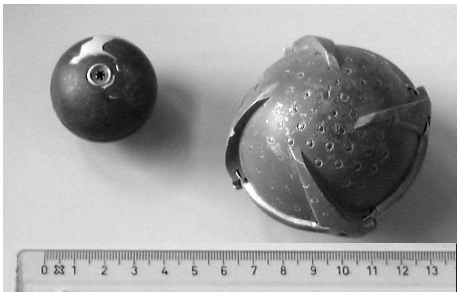
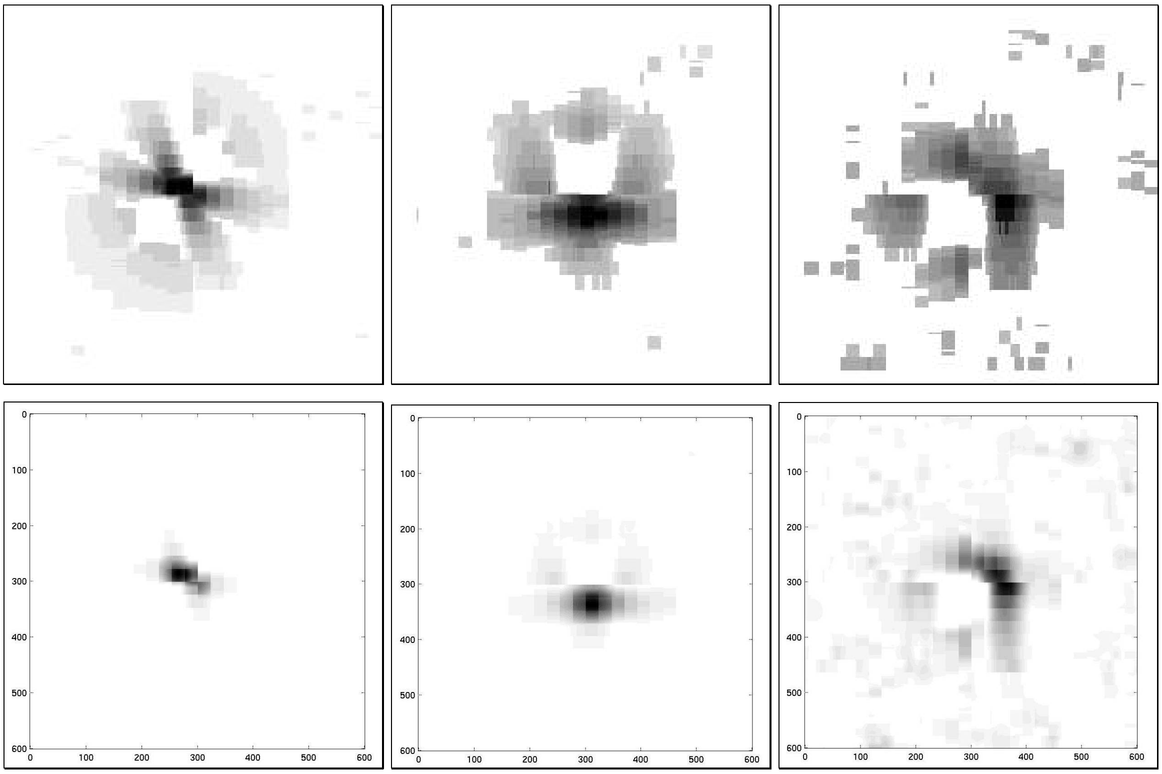


***Small submunition* (upper left of picture). TOP row: original FS images. BOTTOM row: linear scale.**

Depth from left to right: flush(+1.9cm), 5cm(+1.9cm), 9cm(+1.9cm) . Image size 30x30cm.

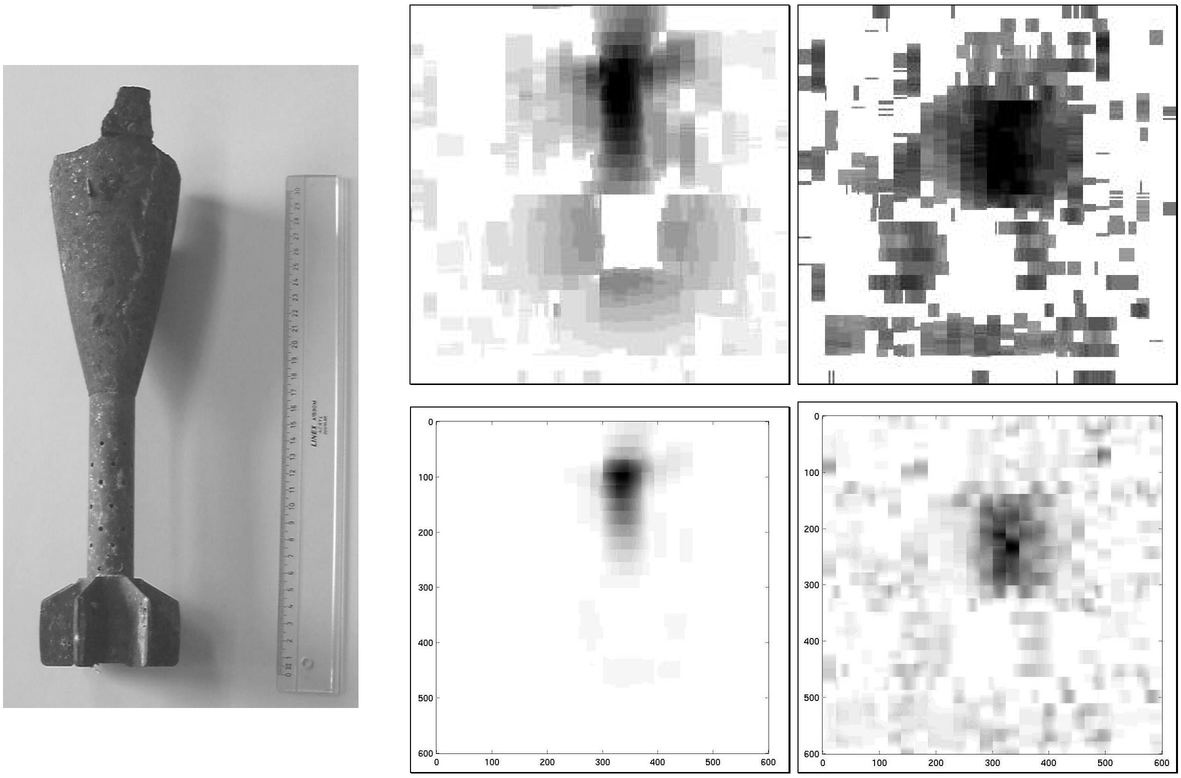


Visible ruler length: 13cm



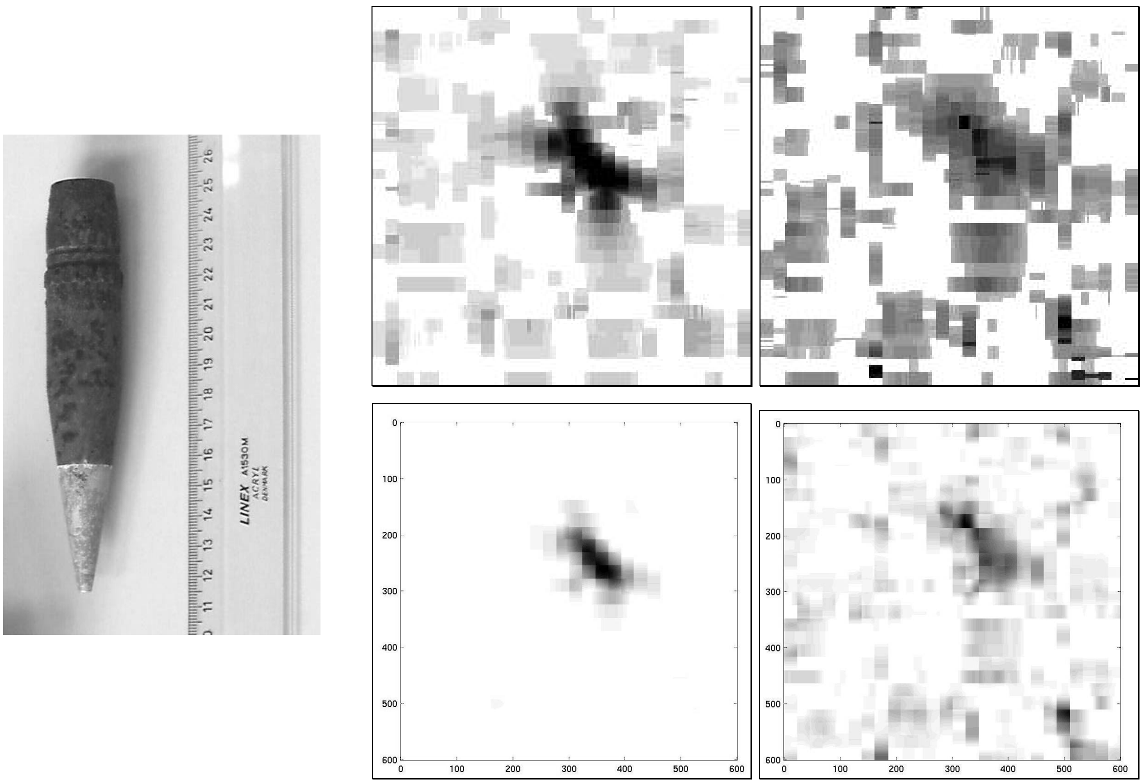
***BLU26 "bomblet"* (lower right of picture). TOP row: original FS images. BOTTOM row: linear scale.**

Depth from left to right: flush(+1.9cm), 3cm(+1.9cm), 5cm(+1.9cm). Image size 60x60cm.



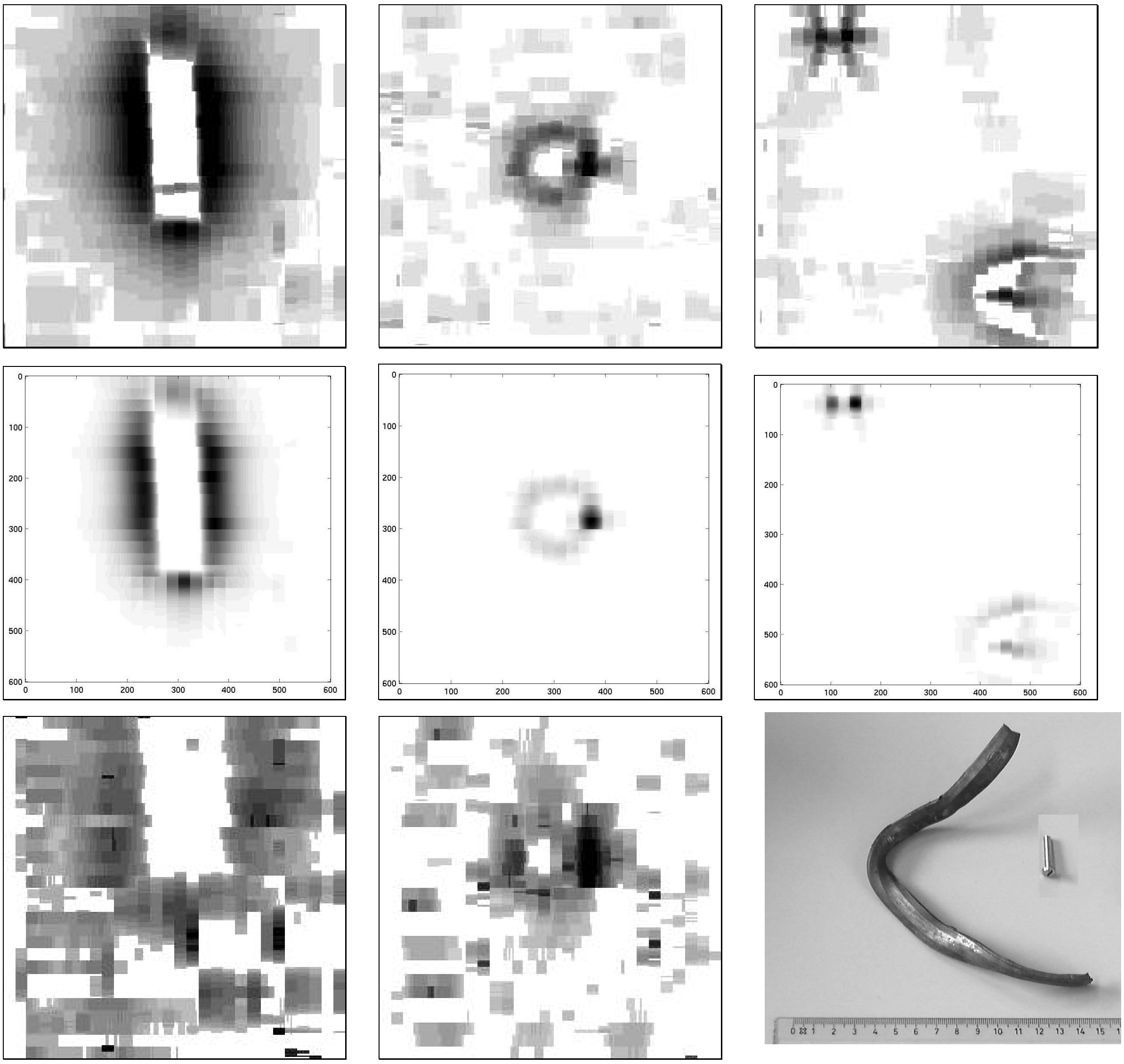
(UXO) ***Mortar shell*** **(ruler length: 30cm). TOP row: original FS images. BOTTOM row: linear scale.**

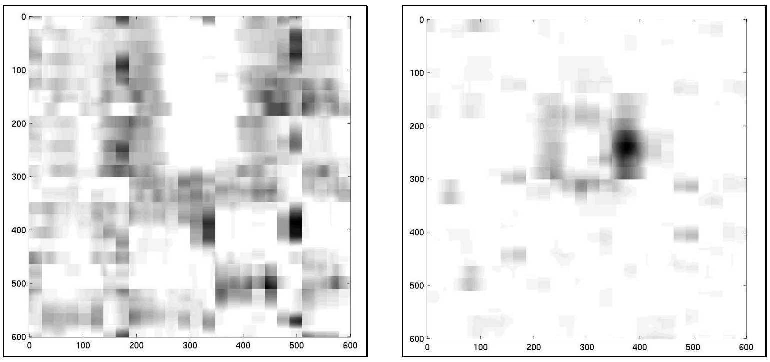
Depth (of the uppermost parts) from left to right: 1-2cm(+1.6cm), 10-12cm(+1.6cm). Image size 60x60cm.



(UXO) ***20mm projectile*** **(visible ruler length: 14cm). TOP: original FS images. BOTTOM: linear scale.**

Depth from left to right: flush (+1.6cm), 6cm(+1.6cm). Image size 60x60cm.





🡅 Right column: *debris* (large copper, steel screw). Flush (+1.6cm)

TOP: original Ferroscan image
BOTTOM: linear scale
Visible ruler length: 15cm

🡅Central column: *PMN AP mine*
TOP: flush (+1.6cm)
BOTTOM: at 3cm(+1.6cm)
(each original & in linear scale)
Corresponding picture 🡆

🡅 Left column: (UXO) *Rocket*, TOP: flush (+1.6cm)

BOTTOM: at 8cm(+1.6cm) (each original & in linear scale)