

APPLICATION OF MAGNETOVISION FOR DETECTION OF DANGEROUS OBJECTS

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Abstract:

Paper presents application of magnetovision in weak magnetic fields for public security systems. Measurement system was developed to study the magnetic field vector distributions. The measurements of the Earth's field disturbances caused by ferromagnetic objects were carried out. The ability for passive detection of selected dangerous objects and determine their location was demonstrated.

Keywords: magnetovision, magnetoresistive sensors, magnetic imaging

1. Introduction

Magnetovision utilizes the measurement of the distribution of magnetic field induction in a particular plane or in space and presenting it with a 2D image (for the plane) or 3D (for space). The name "magnetovision" comes from an analogy with thermal imaging, because the color in the magnetovision image corresponds to the magnetic flux density or the value of the magnetic field strength at a given point. It is also possible to obtain monochrome image in the form of isolines.

The most suitable sensors for magnetovision are thin-film magnetoresistive sensors. They exhibit high sensitivity and have small size – typically 1x1 mm [3]. Resolution of images depends directly on the number of measurement points per meter. The typical imaging device is a two-dimensional XY scanning system with Hall effect or magnetoresistive sensor [4], moving on the meandering path of a specific, usually rectangular area. In the case of a XY system with a single sensor, critical constraint affecting the measurement time is the number of lines along which the probe moves.

Magnetovision studies carried out previously were focused on the ability to measure stress in the ferromagnetic materials, in relation to the inverse magnetostrictive (Villari) effect [5]. By measuring the intensity of the magnetic field at the surface of samples subjected to mechanical stresses, good correlation of the magnetovision images and the stress distribution inside the test piece was obtained. This phenomenon opens the new possibilities for non-destructive testing of the fatigue processes under cyclic mechanical stresses, also in the high frequency range. In case of Villari effect, external magnetic field was not applied [6].

This paper presents an application of magnetovision method for passive detection of dangerous metal objects. This method enables obtaining magnetovision

images of unknown objects from a greater distance and on a larger surface area, required the development of new methods for measuring and processing the results. The application of passive magnetovision system is important, because the active metal detectors can provoke a reaction of the specially constructed detonators. This applies particularly to the newer generation of landmines, reacting to the presence of active detectors, which represents a direct threat to minesweeper's life [1, 2].

2. Methodology and subject of research

For the study an XY scanning system was designed and built, with a single, tri-axial magnetoresistive Honeywell HMR2300 sensor. It is shown schematically in Figure 1. In this system, the distribution of the magnetic induction vectors in the plane of measurement was measured. On the base of these measurements, the magnetovision image of magnetic field distribution was calculated.

Although the magnetic flux density is a vector quantity, in existing magnetovision systems this fact was omitted. Application of tri-axial sensor enabled to obtain images of the magnetic induction in the three axes XYZ system, which resulted in the information about the magnetic induction vector value and its direction with respect to each measurement point. During the measurements, no additional magnetizing fields have been applied. As a result only background disturbances were measured, mainly disturbances of the natural Earth's magnetic field. Scanning probe system transits along parallel lines with a given interval, setting the measuring plane.

The testing area of 200x200 mm was adopted, with 11 parallel measurement lines. On each line there were 100 measurement points. These parameters were selected based on the desired resolution and measurement time. The results were calculated in Matlab, assigning them to individual measurement lines. Then obtained 100x10 matrix with results was interpolated to 100x100 points, which allowed for a clear picture.

Since the magnetoresistive sensor measures only the value of the three components of the flux density vector at a point in which it is physically located, a problem appeared in separation of distortion generated by a sample object from the background. The simplest laboratory solution is the differential measurement by measurement without the test object and subtracting the result from the measurement with an object. This method gives the best results, allowing precise separation of magnetic induction distribution of the background and the object, which allows for

low-level noise in the magnetovision image. However, this method is possible only in certain conditions, where it is possible to make measurements with an object and without, in the same plane. For this reason, a method of differential measurement was developed, minimizing the impact of the background to the measurement result, including both the Earth's magnetic field as well as the other sources.

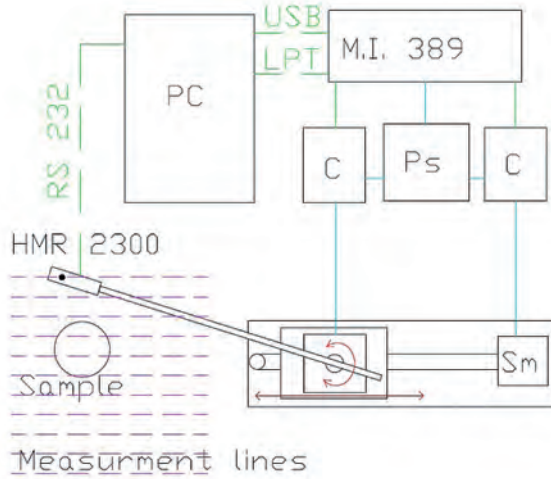


Fig. 1. Schematic block diagram of the measuring system: HMR 2300 – magneto-resistive sensor, Sample – investigated object, Sm – stepper motors, C – motor controllers, MI 3.8.9 – trajectory generator, Ps – power supply, PC – computer

In its simplest form, a differential measurement is the measurement in two planes:

P_1 – at the height x above the test object, and

P_2 – at the height $x + a$, where:

x – the distance approximately known between the object and the plane of measurement P_1 ,

a – the distance approximately known between the plane of measurement P_1 and the plane of measurement P_2 .

Distribution of flux density lines near a ferromagnetic object placed in the Earth's magnetic field is similar to a bar magnet field distribution. In particular, the magnetic flux density can be described as a dipole magnetic field characterized by a magnetic dipole moment \vec{m} . Induction of the magnetic field on the axis of the magnet, in a vacuum, at a distance x from its center is expressed by the formula:

$$\vec{B} = \frac{\mu_0}{2\pi x^3} \vec{m} = C \frac{1}{x^3} \quad (1)$$

Where:

\vec{m} – magnetic dipole moment (A/m^2)

$\mu_0 = 4\pi \cdot 10^{-7} \frac{H}{m}$ – magnetic permeability of vacuum

$C = \frac{\mu_0}{2\pi} \vec{m}$ – induction replacement constant (Am^3)

Since the value of the flux density B is reduced in proportion to the cube of the distance from the source, if $a \approx x$, distortion \vec{B}_1 caused by the object in the first measurement plane will be up to 8 times greater than the \vec{B}_2 in the second plane. If, however, other sources

of magnetic field are at a significantly greater distance $y \gg x$ from the first measurement plane, their influence \vec{B}_B on the value of magnetic induction in the planes P_1 and P_2 will be similar. Therefore:

$$\vec{B}_{P1} = \vec{B}_1 + \vec{B}_{B1} \quad (2)$$

$$\vec{B}_{P2} = \vec{B}_2 + \vec{B}_{B2} \quad (3)$$

Where:

\vec{B}_{P1} – result of flux density measurement in plane P_1 ,

\vec{B}_{P2} – result of flux density measurement in plane P_2 .

$\vec{B}_{B1}, \vec{B}_{B2}$ – Background magnetic induction values in P_1, P_2 planes.

Assuming:

$$\vec{B}_{B1} \approx \vec{B}_{B2}$$

$$\vec{B}_1 > \vec{B}_2$$

Then:

$$\vec{B}_{P1} - \vec{B}_{P2} \approx \vec{B}_1 \quad (4)$$

As a result it is therefore possible to get a rough magnetovision image of the sample located a short distance from the sensor by subtracting the results of a measurement in the plane P_2 from the results in the plane P_1 . Differential two-plane measurement gives the absolute value of the difference in magnetic induction value between the measurement planes.

A similar method to compensate for the impact of background on the measurement result is the gradient measurement used in astrophysics and geology (e.g. in gravity gradiometer). In the generalization it is based on the measurement of the magnetic field or gravity values at different levels and the field gradient designation on that basis. Use of this method also yields good results, but the images obtained are distinctly different than those obtained by the differential method. They allow to distinguish between positive and negative areas of magnetic disturbance relative to the Earth's field.

3. The experimental results

Measurements were carried out on a test stand setup described in previous chapter. The following ferromagnetic samples were used for testing:

Sample 1 – steel cylinder, 80 mm diameter and 20 mm height,

Sample 2 – steel cylinder 71 mm diameter and 35 mm height,

Sample 3 – Swiss army knife, 120 mm long (closed).

Distance between measurement planes was set to $a = 50$ mm.

Figure 2 shows a picture of the three-dimensional distribution of magnetic induction vectors at the measuring points for Sample 1. Absolute values were obtained by differential measurement in a single plane with the influence of the background removed. Distance of the sample from the plane of the measurement was $x = 50$ mm.

Figure 3 shows an magnetovision image obtained by differential bi-plane measurement within 50 mm of the second sample. Minimization of the background impact on the result is clearly visible.

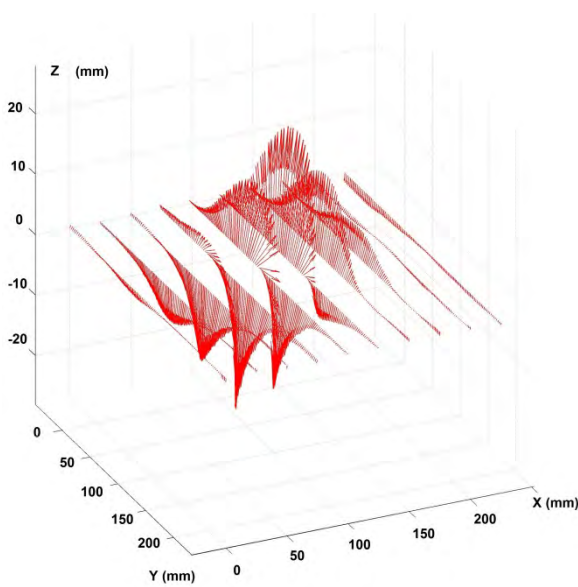


Fig. 2. Distribution of magnetic induction vectors along the measurement lines, Sample 1. Background magnetic field was removed

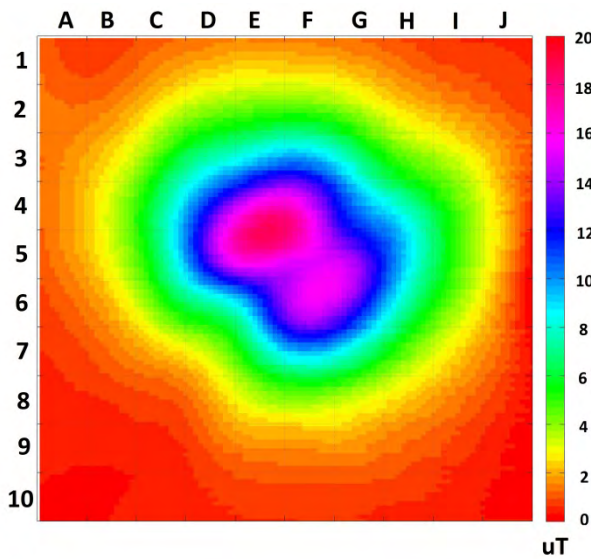


Fig. 3. Image of the Sample 2 – steel cylinder, biplane differential measurement. Influence of the background is minimized

In the Figure 4 the gradient measurement results of the Sample 1, with removing the influence of background magnetic field are shown. It should be emphasized, that the results exhibit a distinct difference between the positive and negative areas of magnetic disturbance.

The Figure 5 shows image obtained by a one-time measuring just 50 mm from the second sample, at different angular positions relative to the plane of measurement. For such a small distance effect of the background becomes negligible. Sample was rotated around the axis perpendicular to the plane of measurement, allowing the visualization of the impact of sample position relative to the Earth’s magnetic field

on the resulting image. It should be noted that the position of the specimen is clearly visible, what creates new possibilities of development of security systems.

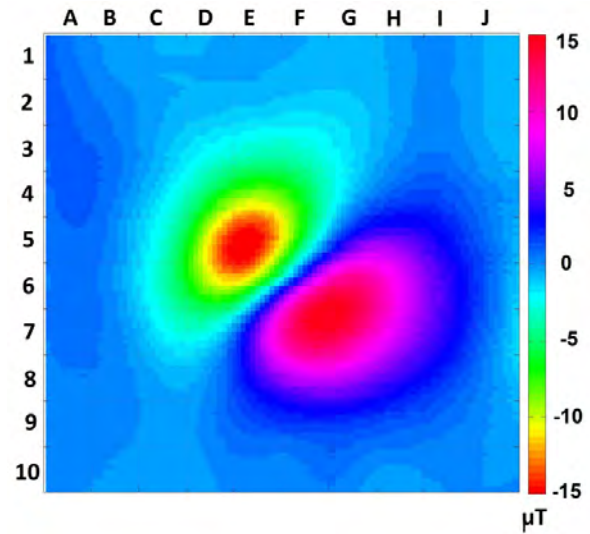


Fig. 4. Gradient measurement of the Sample 1, with removing the influence of the background field

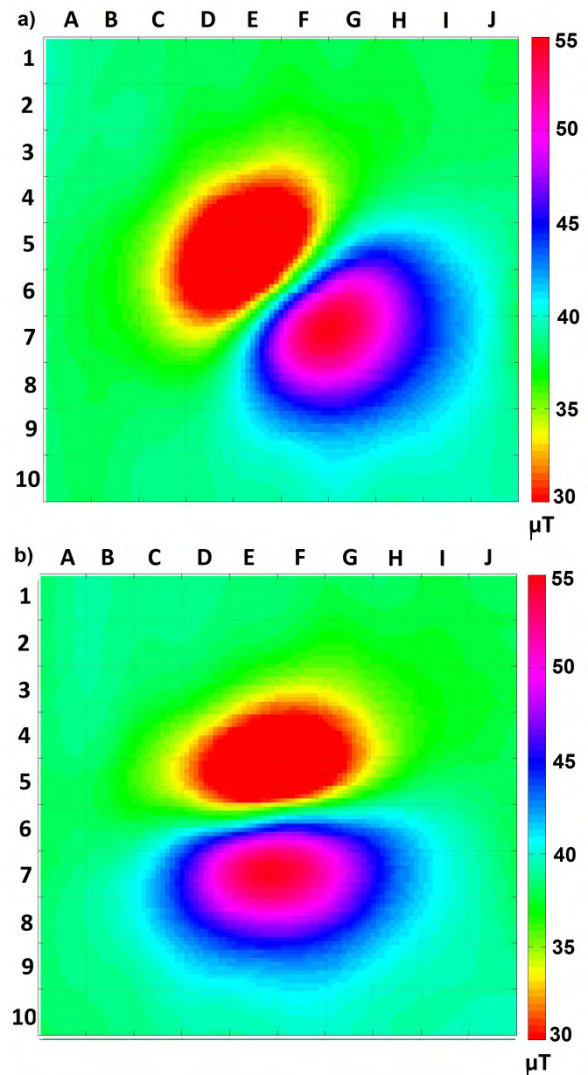


Fig. 5. Sample 1 (steel cylinder), single measurement, without background subtraction. Sample rotated by an angle: a) -0° , b) -45° , relative to the Earth’s field

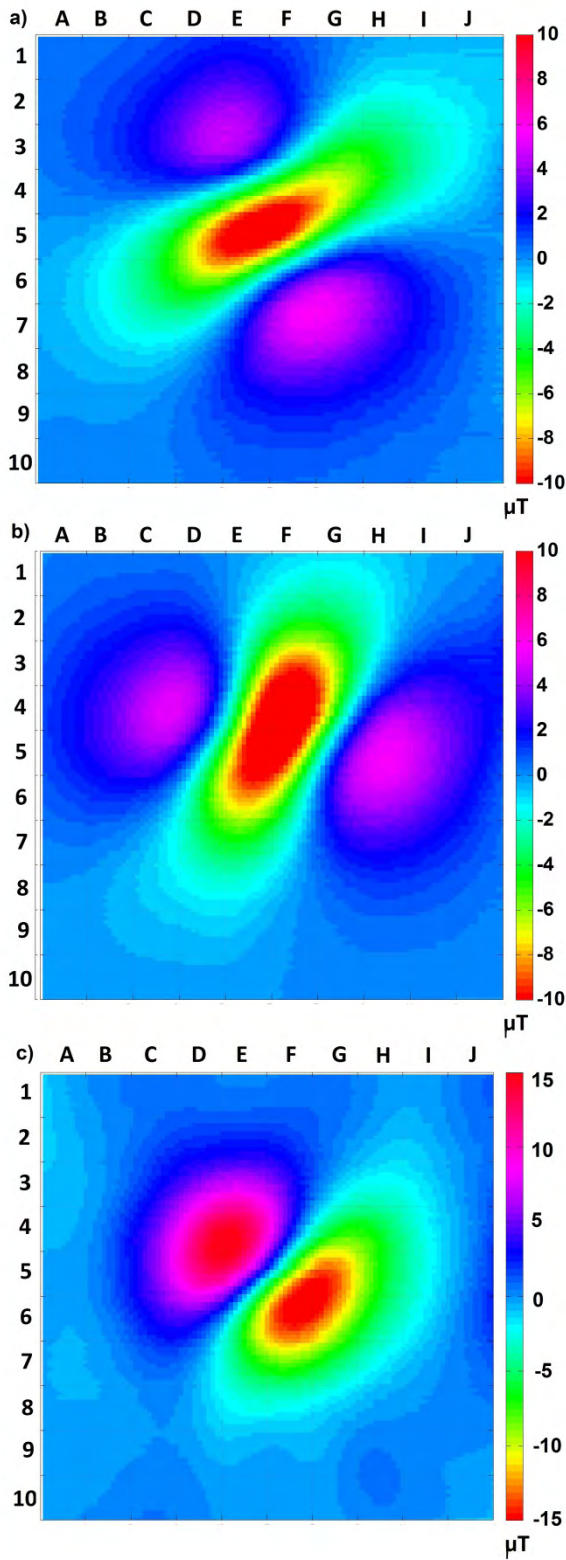


Fig. 6. Biplane differential measurement of magnetic induction vector, Sample 1 a) the value of the Bx component, b) By component, c) Bz component

Figure 6 shows the image of the bi-plane differential measurement of Sample 1 for the individual components of the magnetic induction vector, i.e.

Bx (Fig. 6a), By (Fig. 6b), Bz (Fig. 6c). The results clearly show, that on the magnetovision image, the easiest to recognize is the (x,y) position of the sample in the image of component (Fig. 6c), perpendicular to the plane of measurement.

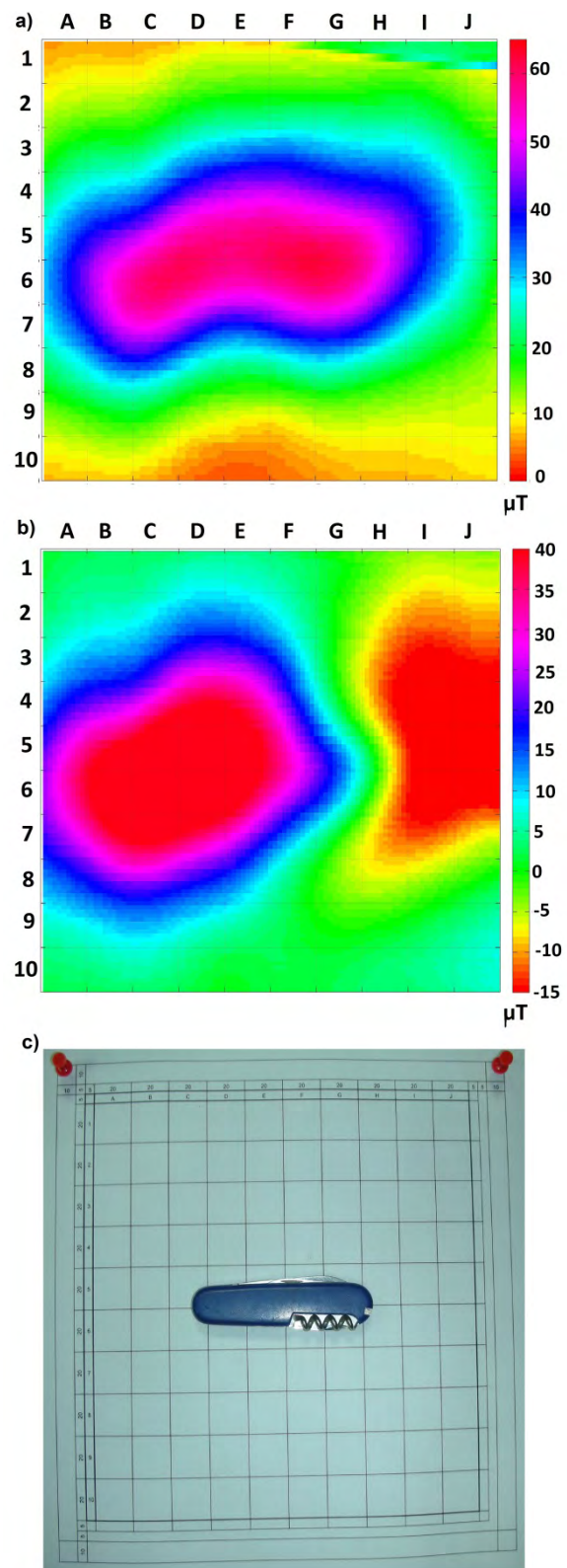


Fig. 7. Measurement of the position of dangerous object (Sample 3): a) biplane differential measurement, b) gradient measurement without background separation, c) a photograph of the actual position

Figure 7 shows the results of the application of the developed method of measurements to determine the location of a sample, relative to the measurement plane. In addition, the comparison of the results of the differential bi-planar (Fig. 7a) and gradient (Fig. 7b) methods was performed. The object subjected to the test was sample 3 – steel folding knife. The distance of the first

plane from the object was 50 mm. Bi-plane differential measurement results are shown in figure 7a, whereas gradient measurement without removing the influence of the background is shown in figure 7b. The position of sample on the reference grid is shown in Figure 7c.

Results of up to 60 μT were obtained for absolute value of the disorders (Fig. 7a) and -15 – 40 μT for the measurement of the background gradient (Fig. 7b). Based on the results, the location and size of the object can be determined, which is very useful from practical point of view.

4. Summary

Experimental setup for planar measurements of vector distribution of weak magnetic fields was developed. Moreover, new methodology of measurement, leading to decreasing the impact of magnetic background on the visualization of the results was presented. The developed methods allow a visualization of the distribution of the magnetic induction vector absolute values, its gradient as well as the value and direction of the magnetic flux density vector in different measurement points.

Obtained results indicate, that it is possible to detect and determine the location of dangerous objects. This opens the way to use magnetovision in public security systems, in particular for the detection of dangerous objects by police or mobile demining robots. Such system can also be used in non-destructive testing, for detection of structural defects of the tested objects.

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