

Security applications of magnetic sensors

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Abstract. Magnetic sensors are often used for security and military applications such as detection, discrimination and localization of ferromagnetic and conducting objects, navigation, position tracking and antitheft systems. We give only general overview, few remarks and some interesting references on these applications.

1. Introduction

Magnetic sensors are key elements in many security and military systems. Traditional sensors such as fluxgates, induction coils and resonance magnetometers are complemented by new sensor types such as AMR (Anisotropic MagnetoResistors), GMR (Giant Magneto-Resistance), SDT (Spin-Dependent Tunelling) and GMI (Giant Magneto-Impedance) sensors [1]. The aim of this paper is to shortly review the mentioned applications, show few examples and give references to interesting papers.

The main requirements for the sensors in critical applications are:

- reliability
- high sensitivity
- selectivity (low false alarm rate)
- resistance against overload and vandalism
- self-adaptability (e.g. for changing background signal)
- self-testing features
- environmental resistance including radiation [2]
- some applications require small size, weight and power consumption
- price is of concern mainly in multi-sensor systems

2. Detection of ferromagnetic objects

DC magnetic detectors usually use the distortion of the Earth's field caused by the permeability of the ferromagnetic object ("soft component" of magnetization). The ferromagnetic object may also have some permanent magnetization ("hard component"), but it is not predictable, unless the object is intentionally marked by permanent magnets.

This technique can be effectively used for objects in larger distances from the sensor. Either the sensor is moving over the buried object such as UXO (Unexploded ordnance) [3], or the stable sensor detects moving target such as vehicle [4].

If the detected object is small and close to the sensor, it is often more effective to use active field generator instead of the passive method which rely on the Earth's field.



2.1. Detectors using the Earth's field.

The Earth's field has a magnitude of 30 to 60 μT and direction from horizontal (in the equatorial region) to vertical (at the poles). The practical detection limit is 1 nT, which corresponds to signature of 1 kg iron object in 3 m distance or 1000 kg object in 40 m distance. The challenge is to detect such small field anomaly under the field variations (man-made or natural), which may reach hundreds of nT. This is usually solved by using gradient sensors or more complex sensor fields. Localization of the target and estimation of its magnetic moment under uncertainty is a complex task [5].

Another sources of errors arise when the measurement is made by 3-axial vector sensors from the moving platform: recalculation into geographical reference system is possible only when the sensors are very linear and orthogonalized. Resonance magnetometers are resistant to this type of error, but they provide neither directional field components nor their gradients which are important for target localization [6].

2.2. Detectors using artificial magnetic field.

This technique is used to detect small objects close to the sensor. In such case the artificially generated field can be much stronger than the Earth's field. The generated field is usually low-frequency bipolar squarewave, which allows suppressing the background Earth's field. Using low frequency decreases the influence of conducting objects in the vicinity.

Magnetic imaging systems are used to scan magnetic ink on banknotes and important documents. Some secure paper has embedded magnetic particles or pieces of magnetic wires [7].

3. Detection of conducting objects using eddy currents

Eddy current metal detectors utilize excitation (primary) field in the frequency range of 1 kHz to 100 kHz. The two main types are continuous-wave (CW) and pulse detectors. The magnetic field sensor measuring the secondary field caused by the eddy currents is traditionally an induction coil [8], recently also AMR sensors are employed [9]. The major task is to suppress the large excitation field in order to measure the small secondary field. Pulse detectors utilize time discrimination: the measurement period starts after the decay of the excitation field. CW detectors use gradient coil system or the detection coil just perpendicular to the excitation coil. Similar techniques are used both for the portable metal detectors and detection frames for access control.

3.1. Time-domain detectors

In the early years the pulse detectors with time-domain signal processing were popular due to their natural ability to discriminate spurious response of "difficult" soil caused by magnetic particles. The magnetic field from these particles decays much faster than the response from the circulating eddy currents. The disadvantage is that the time domain signal is susceptible to deformation by spurious capacitances which change with changing humidity and temperature. More sophisticated methods of signal processing are therefore very difficult to implement. Typical pulse duration is 400 μs with 200 Hz repetition rate. The eddy-current response is monitored between 10 μs and 1 ms after the decay of the excitation pulse.

3.2. CW metal detectors

These devices allow processing the secondary field in the frequency domain using synchronous detectors. Modern CW detectors have multi-tone excitation in order to acquire more information about the measured object. The amplitude and phase at each frequency depends on the conductivity, permeability and geometry of the target and complex information allows discriminating false targets such as metal clutter and magnetic rocks. The signal from soils containing superparamagnetic particles with magnetic viscosity can be suppressed by measurement of the frequency characteristics [10].

3.3. Eddy current imaging systems

Imaging systems allow even more effective target discrimination. Line plots or 2-D or even 3-D magnetic maps contain images which can be recognized by comparing them to the catalogue of standard images of known targets such as landmines [11]. Creating the map needs precise position information which is non-trivial task. Many imaging systems use sensor fields in order to reduce the necessary scanning.

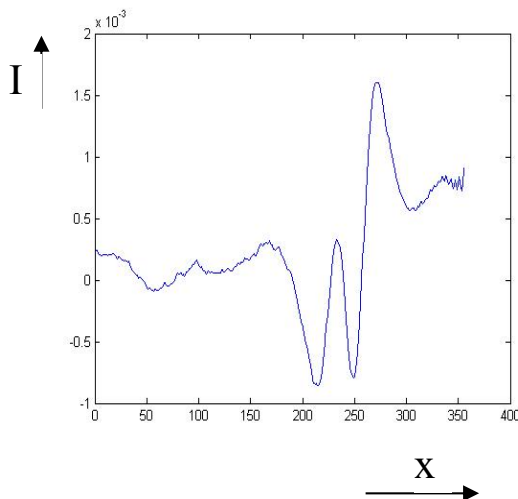


Fig. 1: Example of intensity line plot of landmine [12]

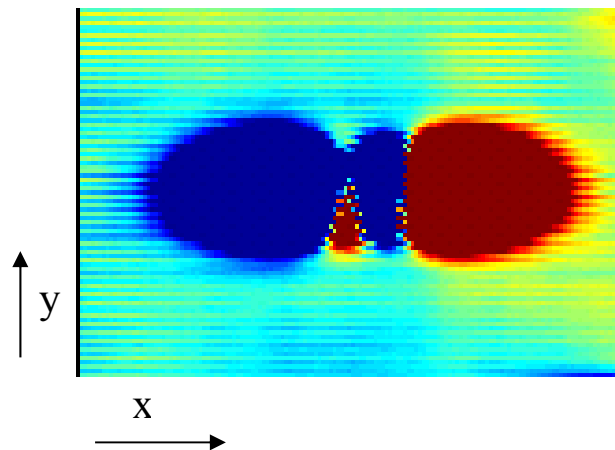


Fig. 2: Example of 2-D intensity map of landmine [12]

4. Navigation using the Earth's field

Modern magnetic compass is electronically gimbaled: it uses 3-axial magnetic sensor and two inclinometers to calculate azimuth in any position. The precision achievable with fluxgate sensors is well below 0.1° and it depends mainly on the precision of the inclinometer. Compasses using AMR or GMI sensors usually have 1° precision [13].

Some advanced military navigation systems utilize also local anomalies of the Earth's field.

5. Position tracking and local navigation using artificial field

These devices are used to precisely monitor the local position and orientation of important objects such as helmet of the pilot, or for underwater or indoor navigation [14]. The system usually consists of stationary field source in the form of coils or long current conductors. The moving object carries either set of magnetic sensors or passive markers.

In the first case calculation of the position and rotation angles requires 3-axial magnetic sensor and multiple independent field sources which can be distinguished either by time or frequency multiplex. This can be reduced to a single field source if the information from other sensor types such as inclinometers or gyrocompass is used.

Passive resonant targets are monitored by stationary magnetic sensors. Using sensor field allows increasing the detection range while keeping high spatial resolution. This technology is also used by antitheft systems using magnetic markers. The main types of magnetic markers are

- LC tanks utilizing electrical resonance [15]
- Magnetoelastic tapes and wires utilizing mechanical resonance [16]
- Wiegand wires utilizing large domain jump

All these effects are easily detectable by remote coil.

Some older antitheft and tracking systems utilize permanent magnet and DC magnetic sensors such as AMRs or fluxgate [17], [18]. $1\text{cm}^3/5\text{g}$ NdFeB magnet has magnetic moment of about 5Am^2 , which gives 500 nT field in 1 m distance [19]. The range and accuracy of such system is therefore strongly limited.

6. Conclusions

Magnetic sensors are essential elements for many security applications as magnetic field is invisible and penetrates through most of materials. The Earth's field is omnipresent and cannot be switched off, so it gives backup to all navigation systems.

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