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Detection of Magnetic Anomaly Using Total Field Magnetometer

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ABSTRACT: Magnetic anomaly detection (MAD) is a passive method for detecting ferromagnetic objects to detect anomalies in the Earth's magnetic field, specific hidden targets. In this work, we aim at detecting a ferromagnetic moving target using a static referenced Total Field Magnetometer. We use the two magnetometers outputs to build a total magnetic field of the target. In most of the articles used Three-Axis Magnetometer but in this paper for the first time used One-Axis Magnetometer.This signal is subtract of two magnetometers outputs that we can use a signal integration to increase of SNR. Our analysis is supported by a computer simulation.The high detection probability and the simple implementation of the proposed method make it attractiv.

KEYWORDS: Magnetic anomaly detection (MAD),CFAR(Constant Rate of False Alarm).

I. INTRODUCTION

MAGNETIC ANOMALY DETECTION (MAD)has been used for decades to detect ferromagnetic targets.The static magnetic field is indifferent to weather conditions.Moreover, air, water, and most soils are practically transparent to the static magnetic field, which makes MAD especially attractive for detecting hidden targets [1]. As a passive method,MAD has an advantage over other techniques in staying unrevealed by the target. Several applications have been developed to detecta target by exploiting the magnetic anomaly it produces in the ambient earth magnetic field.

A ferromagnetic target generates a magnetic field,$\vec{B}$, whichin many cases can be modeled using a multipolemodel.Sinceinthiswork we will adopt the point magnetic dipole field model for the farfield[1].

$$\vec{B}(\vec{m},\vec{r}) = \frac{\mu_0}{4\pi}\left[\frac{3\,(\vec{m}.\vec{r})\,\vec{r}}{|\vec{r}|^5} - \frac{\vec{m}}{|\vec{r}|^3}\right] \tag{1}$$

Where the distance between the target and the sensor is $\vec{r}$, and μ_0 is the permeability of air.

A magneticsensor measures a net field composed of the target magnetic induction field, the earth magnetic field, and magnetic noise.in most of the articles usedThree-Axis Magnetometer but in this paper for the first time used One-Axis Magnetometer.In Three-Axis Magnetometers The target magnetic moment is denoted by

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$\vec{m} = m_x\hat{x} + m_y\hat{y} + m_z\hat{z}$ (2)

where$\hat{\boldsymbol{x}}, \hat{\boldsymbol{y}}, \hat{\boldsymbol{z}}$ are the unit vectors in the Cartesian coordinate frame,in this work whereof we use TotalFieldMagnetometers the$\vec{\boldsymbol{m}}$isscalaroroneaxis.scalar magnetometers only measure the amplitudeof magnetic field, not its components[2].
Compared to vector magnetometers, therefore, they can be assumed as:

$\vec{\mathrm{m}} = \mathrm{m}_0$ (3)

fig. 1 is an example of amplitude ofmagnetic field measured by the two total field magnetometers.In this work,we address the detection of a moving ferromagnetic target by a statictotal fieldmagnetometer.This case is suitable for applications such as intruder detection, car traffic monitoring. Nevertheless, the mathematical analysis and the results are also applicable to the case of a static target and a moving total field referenced magnetometer.Weusetwo magnetometeroutputs to build a total magnetic field of the target. This signal is subtract oftwo magnetometers outputs that we can use a signal integration to increase of SNR.we assumed that the dominate noise is additive white Gaussian noisewith a variance of$\sigma^2 = 0.002\, nT^2$[3].The threshold value was determined using the Neyman-Pearson criterion.This criterion is useful for achieving maximal detection probability under a constraint on the false alarm rate.

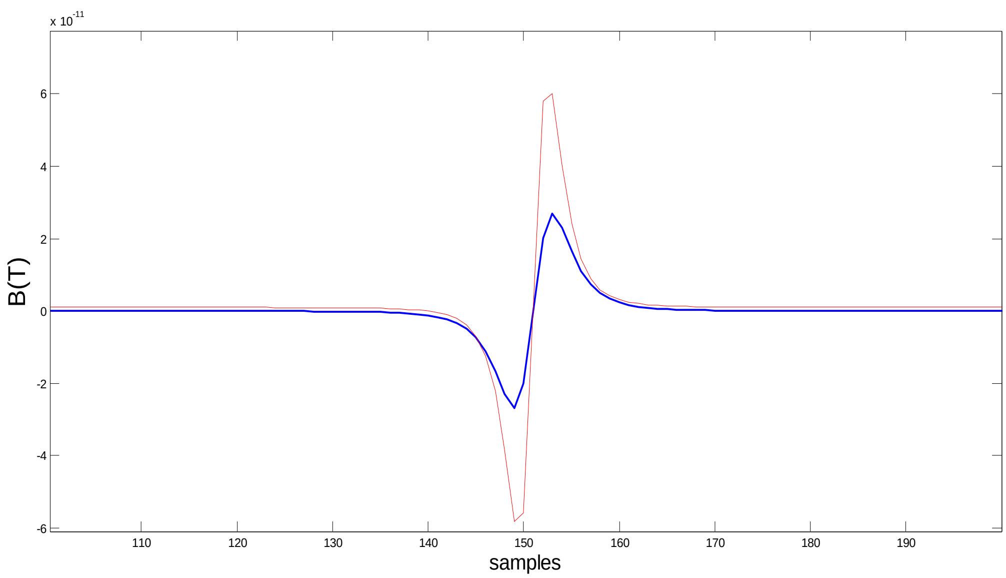

Fig.1 example of magnetic field measured bythe two total field magnetometer without noise

II. PROBLEM FORMULATION

Consider a magnetic measurement system which consists of a pair of total field magnetometers.One magnetometer is placed at the origin in order to detect the target, whereas the other is used as a reference.Here, we have used single-axis sensors; therefore, all the variables are considered in three-axis with two non-active axis;compared with the vectormagnetometer, it can be considered that the target and its surroundings are only in one dimension of the field to have both numeric field and flexible program which can be converted into three-axis.

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(4)

In this case, we have two magnetometers in one row in the x-axis. The target is assumed at a constant velocity, v, along a straight line in the y-axis, as shown in Fig. 2.
When a moving target passes exactly through the sensors, it is in the closest distance to the sensors at y = 0. The closest distance between the target and the magnetic sensor is called CPA showed by R0.

$\vec{r}$ is a vector starting from primary target location (r_0), extending perpendicular to the sensors and showing the direction of the target. Using (5), the target location is determined at any time.

$$\vec{r}(t) = r_0 + v.dt \tag{5}$$

Here, the Earth magnetic field, which usually ranges from 45µf to 65µf, is considered 50µf to match the three-axis mode in the same direction with target in y-axis[4].

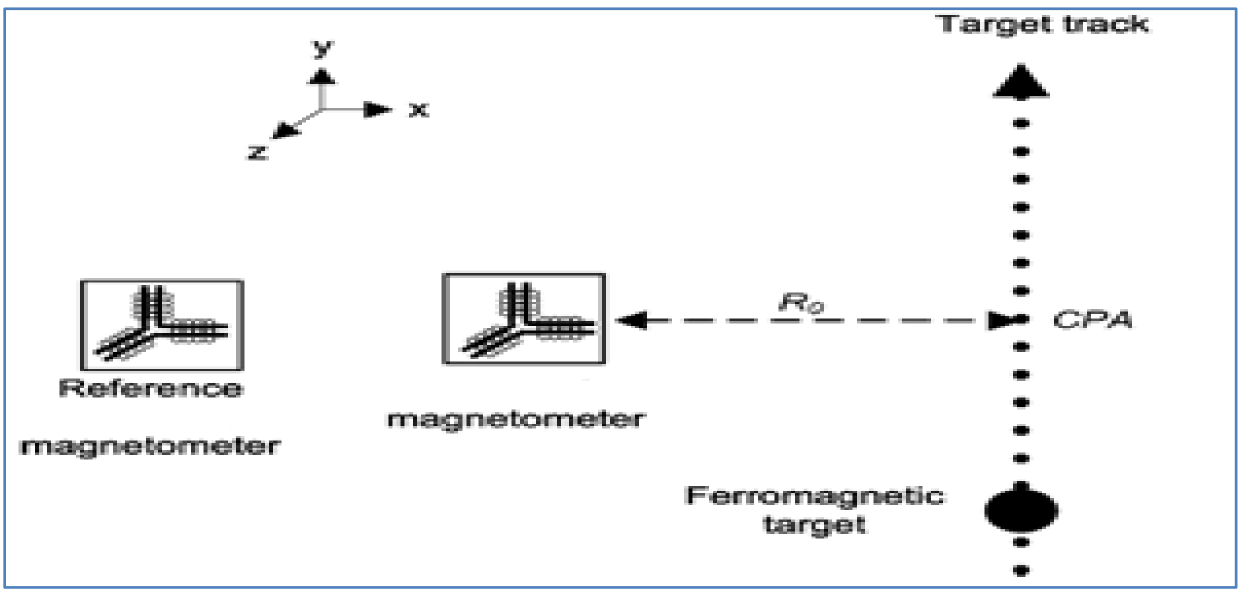

Fig.2 Two total field magnetometers detect a ferromagnetic target that moves along a straight line track with a constant velocity

Gaussian noise is the dominant noise.In addition, the noise inherent in the sensor is a factor of $\sqrt{2}$[3].

To calculate the total field, three factors including target magnetic field, Earth magnetic field and noise need to be taken into account. Thus, the total field $\vec{B}$ becomes as follows:

$$\overrightarrow{B_T} = B_{Target} + B_{earth} + \text{Noise} \tag{6}$$

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III. SIGNAL INTEGRATION METHOD

By measuring the magnetic signal,the received signal-to-noise ratio is smallas shown in Fig. 3.

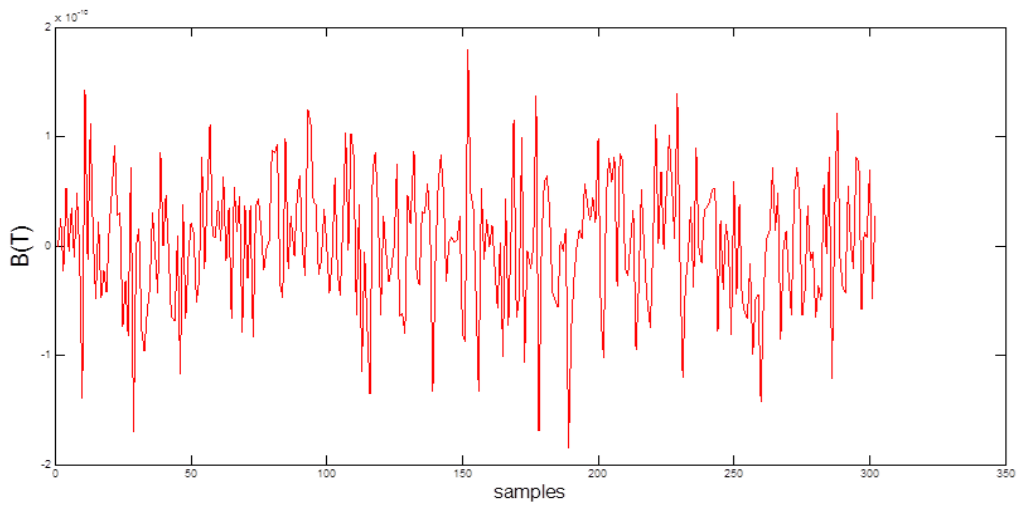

Fig.3 example of magnetic field measured by the total field magnetometerin the presence of noise

To compensate, the sample field of two sensors are initially subtracted; then, their square is used for detection, which did not acceptably increase SNR. The design of the model and the simulation results are shown in Fig. (3) and (4). Obviously, the target is not detectable.

$$C(n) = B_1(n) - B_2(n), y = |C(n)|^2 \tag{7}$$

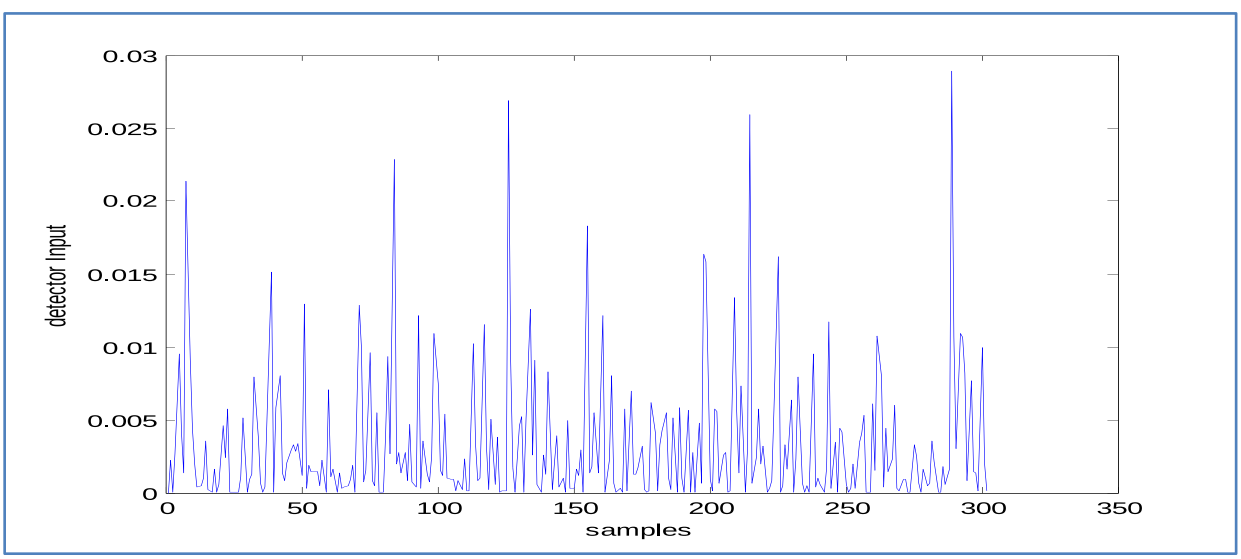

Fig.4Detector input before of signal Integration

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According to [6], if n signals are integrated in a coherent process, SNR of the integrated signal will be n-times larger than a signal only in the presence of white noise. Here, the integration is repeated for N = 50; finally, the samples are averaged by (8) and simulation is done, as shown in Fig.5 Obviously, some peaks appeared.

$$B_m = \sum_{n=1}^{N} B(n), n=1,\dots,N \quad (8)$$

Therefore, the coherent signal integration is used to increase SNR. Thus, n samples, rather than one sample, of the signal are taken in time; using the sum of these n samples and their squared difference, thus, a signal with adequate SNR is obtained.

$$C_m(n) = B_{m1}(n) - B_{m2}(n)y2 = (1/N)|C_m(n)|^2 \quad (9)$$

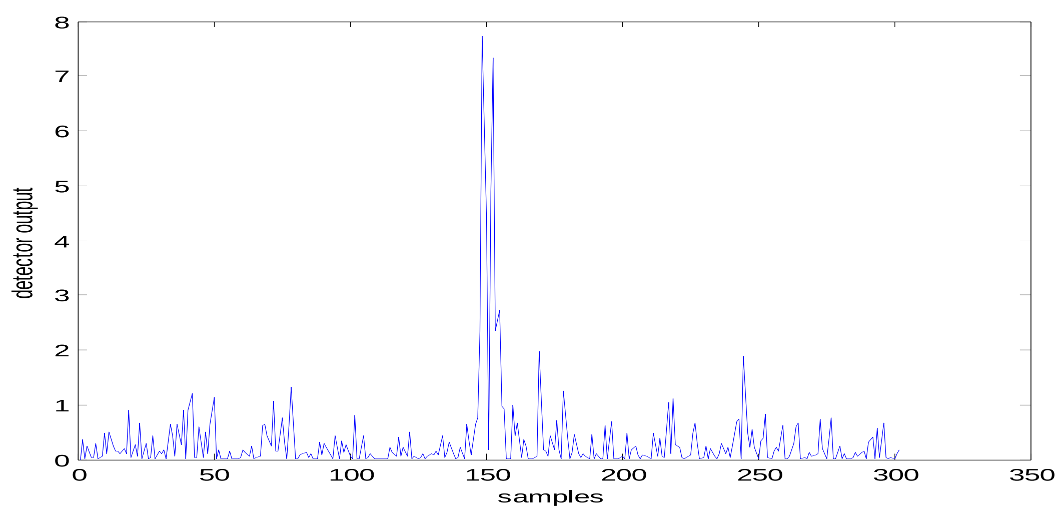

Fig.5Detector input after of signal Integration

IV. DETECTOR

There are several criteria for detection, of which the most famous is Neyman-Pearson detection. For signal detection, the decision will be based on a simple hypothesis testing for samples. In this paper, CFAR is used to keep the constant false alarm rate[6].

$$\begin{cases} H_0 & : x[n] = w[n] \\ H_1 & : x[n] = s[n] + w[n] \end{cases} \quad (10)$$

Different types of CFARs show different behaviors considering clutter statistical characteristics and noise. In This paper, assuming a Gaussian noise, uses CA-CFAR, which is more common than other methods.

In this method, an adaptive threshold varies to keep the constant false alarm rate by averaging the samples. Fig.6 shows a block diagram of CA-CFAR.

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Following envelope detector and coherent integration of N samples, this method selects one sample as the sample (cell) under test (Cut).

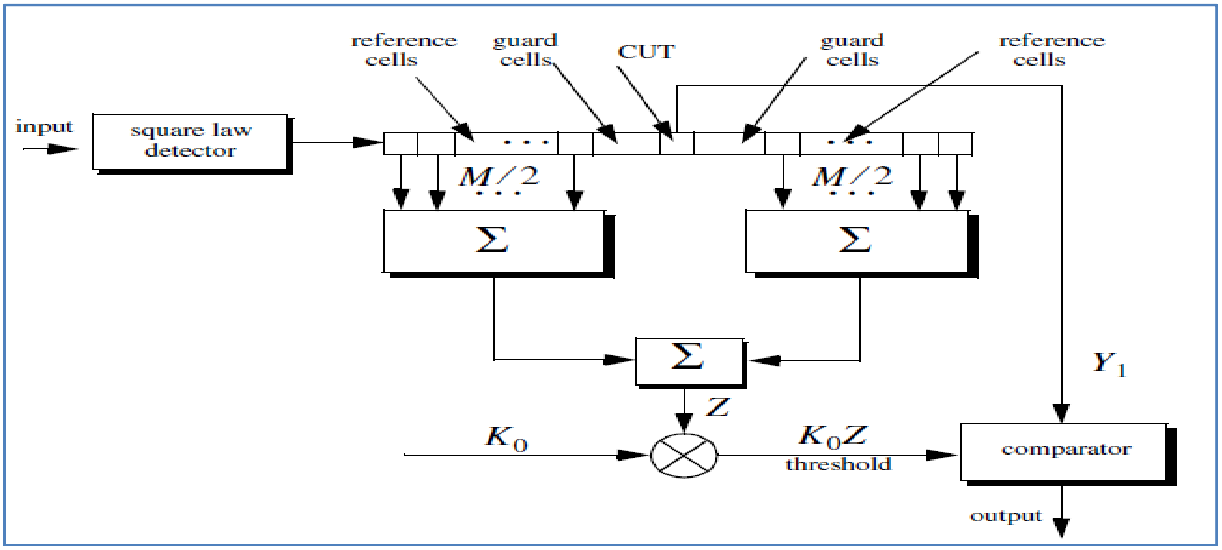

Fig. 6 block diagram of CA-CFAR.

The two units around the Cut are considered as the guard cells. The both sides of guard cells known as reference cells are averaged and compared with the threshold value. The comparator output determines presence (H_1) or absence (H_0) of the target.

This algorithm and simulation, as shown in Table 1 and Fig.7, determines that the noise level has been accurately estimated and the target is correctly detected.

Table.1 SIMULATION PARAMETERS

Symbol	Quantity	value	Units
m	Target Magnetic Moment	0.06	$A.m^2$
v	Target velocity	10	$^{m}/_{sec}$
CPA	Closest proximity approach	6	m
dt	Sampeling period	0.1	sec
n	Number of Integration	50	
σ^2	noise variance	0.002	nT^2

V. CONCLUSION

Obviously, MAD is as a good way to detect ferromagnetic targets; the most important advantage of MAD is its ability to detect a wide range of targets, passive and hidden. This study used a pair of total field magnetometer which numerically measures the magnetic field for both economic efficiency and reduced amount of computation and, more importantly, the easier implementation.

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In this detector, no proper SNR was initially encountered after measuring the magnetic field; using composition and signal integration, eventually, a proper SNR was achieved. Finally, the required threshold was determined using CFAR.

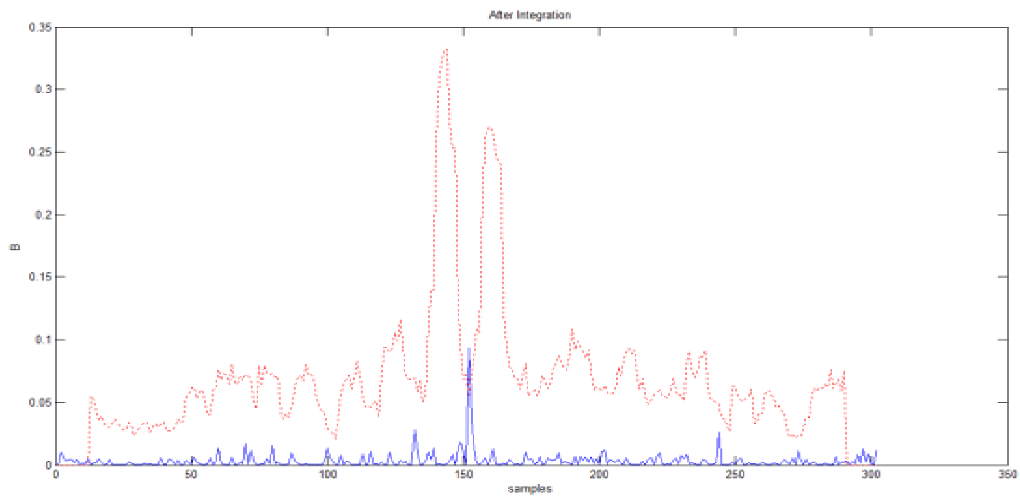

Fig.7 Detector output

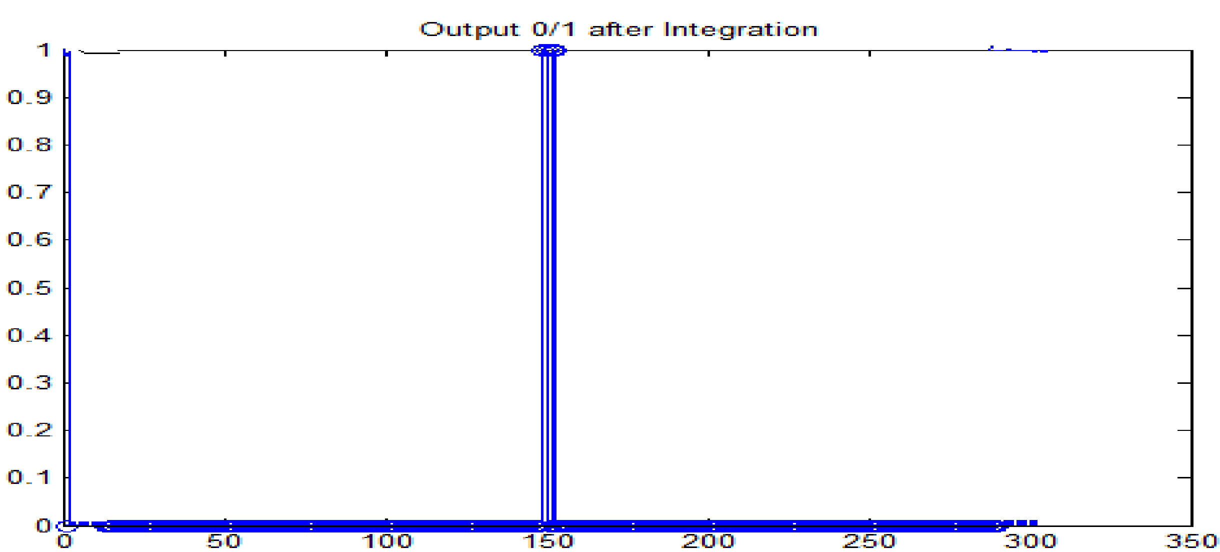

Fig.8Detector outputAs 0/1

detection.Applications of this class are used for perimeter protection,issuing an alarm whenever a person passes by the sensor with a ferromagnetic item.This study was completely dynamic with many features, including fixed ferromagnetic target and moving reference magnetometer, as noted earlier. For three-axis magnetometers, the same method can also be used for longer distances and in different directions. Further research can find technology of other applications in this area, because this technology can be used for detection of tanks and other equipment,

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broken or immersed ships, marine mines and submarines[8].The detector simple implementation makes it attractive for real-time applications such as intruder

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