A novel anti-theft alarm system based on detection of magnetic field

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Abstract: This paper proposes a novel bidirectional anti-theft alarm scheme through detecting the magnetic field. The theoretical background and analysis of the approach of anti-theft alarm are presented. The circuit of burglar alarm is designed, fabricated and tested, and C language program is implemented and debugged. Feasibility of the developed scheme is proved by the experiments.

Key words: anti-theft alarm; magnetic field; C language

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Anti-theft alarm system has become a crucial section of the comprehensive protection of museums and exhibition halls. However, despite the fact that a number of anti-theft alarm equipments are available, they still can not satisfy the high safety protection requirements of such areas where priceless items are reserved. The existing burglar alarms have many drawbacks due to different technical leaks[1]. For instance, the multi-dimensional standing wave alarm, which is widely used in the museum, can be greatly affected by the flow of air, thus restricting it to be used in the environment with little air circulation. Another alarm, the passive infrared alarm, is prone to alarming incorrectly or failing to alarm as a result of being vulnerable to a variety of heat sources, light sources or radio frequency radiation interferences. Other alarms, like infrared and microwave alarm, active infrared rays intrusion alarm and glass break alarm, are all inevitably have problems of low detection accuracy, high false alarm rate and miss probability. Additionally, the present anti-theft facilities with high maintenance funds are mostly large and expensive. Therefore, it is of great necessity to develop a technique out of all these demerits.

As magnetic field is invisible, the detection of magnetic field is especially suitable for safety and alarm systems. At present, there are already some burglary-resisting installations referring to the detection of magnetic field. For example, the goods in the supermarket and bookshop are labelled magnetic strips, which will trigger the safety door to alarm unless they are degaussed because of the magnetic field interference between magnetic strips and the safety door. Anyway, this device is only applicable to a limited range of areas since the labels can be easily taken off. In addition, there is also burglar alarm system working by detecting the fluctuation of magnetic field. But it needs an exerted line to transmit the magnetic signal, which greatly restricts the field of application and is neither artistic nor practical[2].

This paper introduces a novel anti-theft alarm scheme, which mainly owns to the two-direction detection of the magnetic field strength between two devices. The whole system is under the control of microcontroller, which involves no extra data transmission line and has such characteristics as small size and low cost. Compared with the conventional approaches, this way of bidirectional detection greatly enhances the reliability of the system. This system is mainly dedicated to the security protection of muse-

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ums and exhibition halls where precious exhibits are preserved, but it also has some potential applications in other fields.

1 System structure and working principle

The bidirectional anti-theft alarm system based on the two-direction detection of magnetic field strength includes two similar parts: Device Ⅰ and Device Ⅱ, each of which consists of a magnetic source and a detection and alarm module. The detection and alarm module is made up of the following four portions: the magnetic field strength detecting unit, the master control unit, the alarm unit and the power supply unit. In practice, Device Ⅰ and Device Ⅱ are fixed on the exhibit and its base, respectively. Fig.1 is a schematic view of the structure of the system.

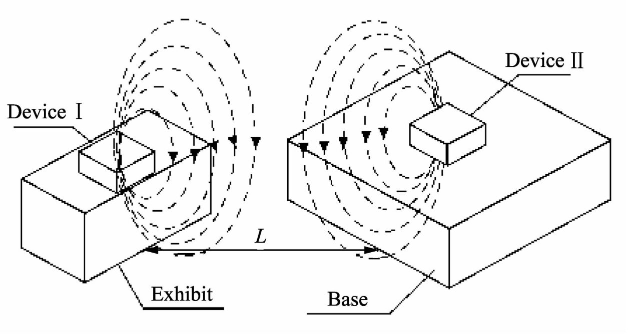


Fig.1 Structure diagram of anti-theft system

The system is controlled by the microcontroller, in which C language program is stored. Through detecting and processing the magnetic field strength signal between Device Ⅰ and Device Ⅱ, the function of alarm can be achieved. Fig.2 is the block diagram of the system and the working principle is as follows: Firstly, the magnetometer collects the signal of 3-axis magnetic field circularly and sends it to the microcontroller via I^2C communication protocol[3]. The data is processed in the microcontroller, which synthesizes the 3-axis magnetic field strength signal into one vector and calculates its absolute value B, which can be described by

$$B = \sqrt{x^2 + y^2 + z^2}, \tag{1}$$

where x, y and z represent the detected 3-axis magnetic field strength value, respectively. Then the judge whether B is in the set threshold range (B_{min}, B_{max}) is implemented. If B falls in the range, which indicates the exhibit is within the safe distance range(L_{min}, L_{max}), the system does not alarm. However, if B excesses the range, the microcontroller will send a signal to the alarm unit and trigger it to alarm[4]. Due to the fact that both Device Ⅰ and Device Ⅱ have a detection and alarm module, the two-direction alarm is realizable. And according to the fact that magnetic field decays with the increase of distance, the minimum and maximum threshold value B_{min} and B_{max} are measured when the distance L between Device Ⅰ and Device Ⅱ is the maximum L_{max} and the minimum L_{min} respectively. L_{max} can be set in accordance with practical situation, such as 2 m; L_{min} should be 0 theoretically, but actually it is reasonable when the two devices are next to each other. Additionally, the set threshold ranges in the two devices could be the same or not, which is determined by whether their magnetic sources are the same.

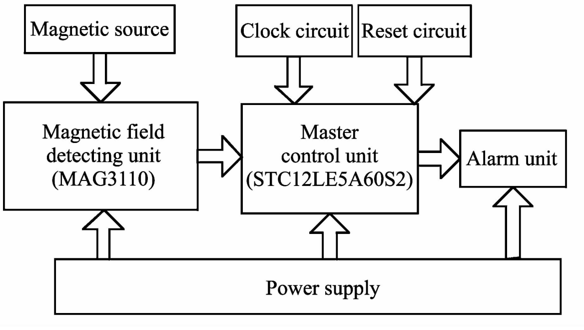


Fig.2 Block diagram of anti-theft system

2 Analysis and design of hardware

In order to simplify the peripheral hardware circuit of the anti-theft alarm system, the minimum system circuit of STC microcontroller is adopted, through whose I/O ports the data acquisition and system control are performed[5]. Each component of the hardware is detailed separately in the following paragraphs.

2.1 Magnetic source

Considering that magnetic source should be integrated within the detection and alarm module, it must be a small-size magnet with a reasonable magnetic field. In this design, the magnetic field strength of the magnet ranges from $-1\ 000$ to $+1\ 000\ \mu T$. For Device Ⅰ and Device Ⅱ, the selected size of magnetic source and magnetic field strength they generate can be different. But during the process of installation, special care should be taken to insure that magnetic field directions of the two are the same, so that the two magnetic fields will add to an enhanced effect.

2.2 Detection and alarm module

As the key component of this system, the detection and alarm module consists of the following four portions: the magnetic field strength detecting unit, the master control unit, the alarm unit and the power supply unit[6-7].

The detection unit of this module is mainly composed of magnetometer MAG3110 made by Freescale company and its peripheral circuits[8]. MAG3110 is a 3-axis magnetometer with superb performance. It has an internal A/D converter and an I^2C interface, thus reducing the external components needed for the integration of the electronic circuit. Moreover, the chip has a high sensitivity of 0.10 μT with the range of measurement ($-1\ 000$, $+1\ 000$) μT. Additionally, the package of the microchip is so small (2.0 mm × 2.0 mm × 0.85 mm) that it corresponds to the developing trend of micro-miniaturization and integration. The fundamental function of this unit is to detect the magnetic field full-scale and circularly and send the data to the master control unit.

In the master control unit consisting of the minimum system of microcontroller STC12LE5A60S2, the received magnetic field data is processed through C language programming, during which it is judged whether the detected value is within the set threshold range, and the result will decide whether to trigger the alarm or not. That is to give the alarm unit connected to the I/O port of the microcontroller a high or low voltage signal[9-10].

The alarm unit is primarily made up of a buzzer or a speaker, a PNP transistor and a current limiting resistor. This unit receives control signal from the microcontroller. If it is a high voltage signal, the transistor will turn off, and the system will not alarm; otherwise the transistor will turn on, and the system will alarm[9]. The circuit is not only simple in structure but also dependable in performance.

Finally, in the power supply unit, a button battery of 3.3 V is utilized to provide power for each unit of circuit. The advantages are that it takes up very small space and has a reliable and durable performance.

3 Analysis and design of software

Since there are a variety of inevitable electromagnetic interferences in the environment, the crucial problems to be solved are to reduce the false alarm rate as well as improve the detection sensitivity and response speed.

In traditional ways, the tradeoff between reliability and sensitivity has to be made. However, in the proposed system, an algorithm of vector synthesis and setting threshold range by the means of software programming are adopted to overcome this tackle.

3.1 Algorithm of vector synthesis

Since the adopted MAG3110 is a 3-axis magnetometer, its obvious merit is that it enables all-dimensional measurement of magnetic field possible and increases the sensitivity of the system. Nevertheless, when comparing one-axis of the measured magnetic field with the set threshold range, it is very likely that false alarms arise for some reasons[11].

Therefore, the algorithm of vector synthesis is taken in this paper. In the presented algorithm, all the 3-axis signals are taken full advantage of, i.e. the value of synthetic magnetic field B is calculated by Eq. (1). For B is inversely proportional to distance doubtlessly, the cases of false alarm caused by the false signal of one-axis can be avoided. In this way, the accuracy of the system is enhanced without lowering the sensitivity.

3.2 Setting threshold range

As stated above, when the distance L between Device Ⅰ and Device Ⅱ gradually increases to the maximum value L_{max}, and the magnetic field value between them decreases to the minimum B_{min}, it seems that the comparison between B and B_{min} is enough to decide whether to alarm or not, that is to alarm when B is smaller than B_{min}. But there are cases when burglar commits a crime with a strong magnetic source, and the system will not alarm under the condition that the magnetic source's magnetic field direction is the same as that of the system.

In order to avoid this situation, an upper limit B_{max}, which is measured when Device Ⅰ and Device Ⅱ are the nearest, is set. This way of judging whether B is in the range (B_{min}, B_{max}) strengthens the system to be more reliable.

3.3 Real-time performance

Real-time performance is an important factor for the anti-theft system. The response time of the proposed system is mainly related to the magnetic field detection and the data processing of microcontroller. On the one hand, the sampling time interval of MAG3110 ranges from 12 ms to a few seconds and the maximum output data rate can be 80 Hz. Furthermore, not only is the STC12 series microcontroller's instruction code fully compatible with that of traditional 8051 microcontroller, but also its rate is 8 to 12 times faster. Therefore, the overall response time of the system is about a few hundred milliseconds, which shows a superb real-time performance.

3.4 Software design

In the STC microcontroller, C language programming is utilized to perform vector synthesis of the 3-axis magnetic field strength signal and calculate its absolute value B. Then the judgment whether B is in the set threshold range (B_{min}, B_{max}) is conducted, the result of which will be in charge of the alarm unit.

The flow chart of the main program is shown in Fig. 3. The main program is primarily responsible for the initialization of start and reset as well as the control of the entire system by the means of calling each subroutine[12-13]. In the program of initialization, the measurement mode of the magnetometer MAG3110 is set, which mainly involves setting stack pointer and the assignment of corresponding registers.

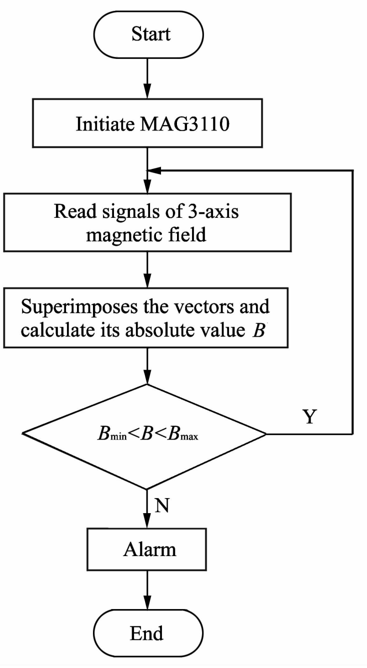


Fig. 3 Flow chart of the main program

4 Experiment design and results

4.1 Experiment design

In order to achieve the goal of anti-theft alarm in the way of monitoring the magnetic field, the changes of magnetometer's output data need to be studied as the magnetic field changes. In this experiment, Device Ⅰ and Device Ⅱ are chosen to be the same, the test circuit board and magnetic source are shown in Fig. 4. The measured data of magnetometer can be read out by connecting a LCD display to the circuit board with DuPont lines. During the process of experiment, the magnetic source should be attached to the circuit board. When the two devices become close to or far away from each other, the readings of the display should be recorded, especially when the distance between the two devices is the set maximum or minimum.

According to the experiment above, the threshold range can be determined. So the following procedure should be verifying whether the system could alarm effectively when the distance between Device Ⅰ and Device Ⅱ excesses the safe distance.

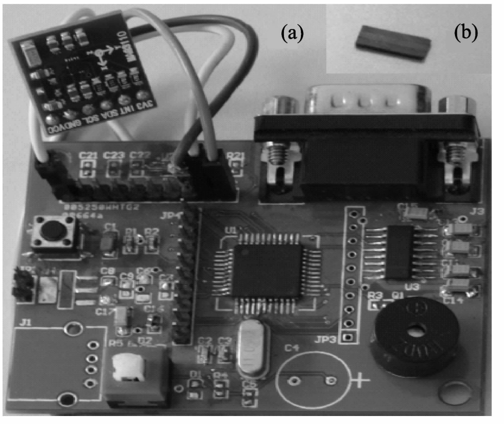


Fig. 4 Test circuit board (a) the magnetic source (b)

4.2 Experimental results

It can be clearly observed that the readings of the two displays decrease rapidly when the distance between the two devices becomes farther; on the contrary, the readings increase sharply when they come closer. It can also be concluded that magnetic field decays at a great speed with increasing distance.

By repetitious testing, the optimal range of distance between the two devices is set as (0.05 m, 1.3 m), Fig. 5 illustrates the readings of one display when the two devices are next to and 1.3 m away from each other. And the corresponding upper threshold is

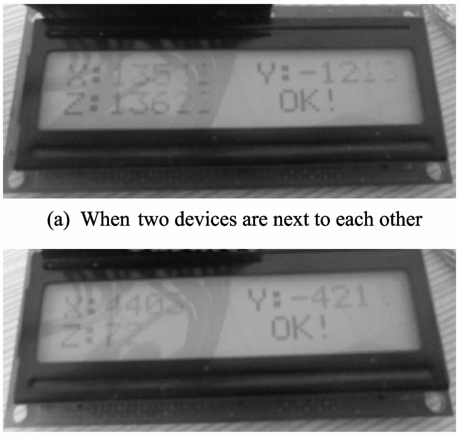
$$B_{max} = \sqrt{13\ 511^2 + (-1\ 213)^2 + 13\ 622^2} = 54\ 921\ 171 \times 10^{-2}\ \mu\text{T}.$$

The lower threshold is

$$B_{min} = \sqrt{4\ 403^2 + (-421)^2 + 72^2} = 766\ 585 \times 10^{-2}\ \mu\text{T}.$$

So the range of threshold is (766 585, 54 921 171) $\times 10^{-2} \mu$T.

The threshold range above is set in the microcontroller by means of C language programming. The results of a number of experiments, in which Device Ⅰ is taken away from Device Ⅱ, demonstrate that neither Device Ⅰ nor Device Ⅱ alarms if the distance between the two devices is within the threshold range; Otherwise, both of them alarm.



(a) When two devices are next to each other

(b) When the distance between two devices is 1.3 m

Fig. 5 The readings of one display (**unit**: $\times 10^{-2} \mu T$)

5 Conclusion

This paper introduces a bidirectional anti-theft alarm system with excellent performance, which depends on the detection of magnetic field. The hardware of the system is simple but experimentally demonstrated to be reliable and practical. And the real-time monitoring, two-direction alarm and variable safe range are accessible by C language programming in the microcontroller, which is the control core of the system. Furthermore, due to the system's superior characteristics of small size, low cost, high accuracy and sensitivity, it can be applied to a wide range of areas more than museums and exhibition halls.

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