USE OF A TIME-VARIATION ULTRASONIC SIGNAL AND PIR SENSORS TO ENHANCE THE SENSING RELIABILITY OF AN EMBEDDED SURVEILLANCE SYSTEM

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ABSTRACT

In this paper we design and implement an embedded surveillance system by use of a time-variation ultrasonic coding signal with multiple pyroelectric infrared sensors (PIR) to detect an intruder in a home or a storehouse. The ultrasonic sensor module consists of a transmitter and a receiver which are placed in a line direction; however, ultrasonic sensors with the same frequency are subject to interference by crosstalk with each other and have a high miss rate. To overcome these disadvantages of the ultrasonic sensor, we propose a coding mechanism to reduce both crosstalk and environmental interference and to enhance the distinguishing features of the signal. In addition we use a time-variation coding signal to make the system more reliable against the breaking of the system when the coding signals vary. Both ultrasonic sensors and PIR sensors are managed by the majority voting mechanism (MVM).

Index Terms—Surveillance System, Coding Signal, Majority Voting Mechanism, PIR Sensor, Ultrasonic Sensor, Time-variation

1. INTRODUCTION

Recently surveillance systems have become more important for home safety. The embedded surveillance system, frequently used in a home, an office or a factory [1-3], uses a sensor which is triggered to turn on a camera [4-5]. Some designs use different types of sensors to achieve reliability by means of the different features of each sensor [6-7]. In this paper we extend our previous design not only by using both multiple PIR sensors and ultrasonic sensors as a sensor group, but also by using the MVM. Ultrasonic receivers and transmitters are located at opposite ends [8-9]. However, to reduce the interference from other frequencies in ultrasonic signals, we use a coding signal to enhance the ability to distinguish all random interference [10]. To enhance system reliability, some of our previous research focuses on improving the shortcomings of the ultrasonic sensor. Some parts of the previous research explore both the influence of attenuation in air and the crosstalk of ultrasonic signals by using a coding signal [11-12], while other parts of this previous research provide improvement of the ultrasonic signal by using different coding signal types [13-14]. Still other parts of previous research use time-variation to transmit different messages with respect to time for a receiver. For a faster and useful time-variation coding mechanism some previous research projects explore the influence of both the environments and any noise on the time-variation coding signal [15]. Some previous research projects use hardware and software modules to implement a real-time operation system for a quicker and easy extending function [16]. For the delay time between the transmitter and the receiver some use the RLNC in delay and throughput [17]. Some use the coding signal in the ultrasound image to improve the SNR [18-19]. Others analyze the difference of the encryption mechanism from the merit and deficiency of the database [20]. We propose adding to the number of bits of time-variation by means of both coding and encryption to reduce the probability of code breaking.

2. SYSTEM ARCHITECTURE

Fig. 1 shows our design which contains several ultrasonic and PIR sensor groups. In the modules of the ultrasonic sensor groups both the transmitter and the receiver are separated. The transmitter circuit generates a multi-frequency square waveform, and the receiver circuit amplifies the received signals and filters out any noise. When a transmitter transmits a time-variation ultrasonic coding signal, the ultrasonic receiver determines whether there is an intruder passing through the sensing area. If there is no intruder, the MCU (Micro Controller Unit) will use the predefined ultrasonic signal pattern to decode the received signal.

![Figure 1. An embedded surveillance system with the time-variation ultrasonic signal.](image-url)
The use of both the relay stations and the frequency conversion extends the sensing range. Our design reduces the environmental interference with the ultrasonic signal. All sensing signals are input to the embedded surveillance system by the GPIO (General purpose input and output), and the MVM program counts the number of sensing states to determine whether to adopt the MVM or not. The PIR sensor groups obtain the sensing signals from human temperature. If the voting results of both the ultrasonic and PIR sensor groups pass the criteria, the embedded surveillance system starts the Web camera to capture images.

2.1. Software modules

We choose Embedded Linux as our operating system. The program of the majority voting mechanism contains a detection of the GPIO function, a counting and majority voting function, an image captured function and a Web server. The embedded system scans the GPIO sockets, which are connected to external PIR sensors and ultrasonic sensors. To verify the state of each PIR and ultrasonic sensor, the embedded system reads the voltage levels of the GPIO sockets. When the system reads 5V from a GPIO socket, we learn that the ultrasonic sensors or the PIR sensors have been triggered and will execute the majority voting program by counting the state of each ultrasonic and PIR sensor. The majority voting is achieved by the sensor groups of the different GPIO sockets. The embedded system, when interrupted by the detection procedure, starts the Web camera to capture images. When this is finished, the embedded system starts the detection procedure over again. If the intruder is still in the monitoring area, the count of the GPIO sockets’ voltage levels continues the operation of the majority voting mechanism, and the embedded system again starts the Web camera to capture images. The embedded system uploads the captured images through the Internet by means of both the Web server and the streaming server.

2.2. Hardware modules

We use two groups of the external hardware circuits, the PIR and the ultrasonic sensor group. As the PIR sensor produces a weak voltage, we input the sensed signal to a two-stage OP amplifier to amplify the weak voltage by about 1000 times. Since the amplified signal changes between both positive and negative voltage, we input this signal to the absolute value circuit, and then we input it to the adjustable comparator to compare both the sensing voltage and the reference voltage which are set according to the environment temperature.

Fig. 2 shows the ultrasonic transmitter circuit which uses a pulse width modulation (PWM) function in the MCU to send out the desired frequency of the ultrasonic signal. The ultrasonic transducer transforms the voltage waveform into an ultrasonic transmission, and the transducer of the receiver transforms the ultrasonic transmission into the voltage waveform.

Table I shows our comparison of the sensing characteristics of both the ultrasonic sensor and the PIR sensor [6]. We have found that the ultrasonic sensor and the PIR sensor can both compensate each other and enhance the overall sensing probability in our design.

3. ULTRASONIC INTERFERENCE

Ultrasonic transmission is a sound transmission which is easily interfered with by other frequencies from random ultrasonic signals. The signal interference causes difficulties in setting up the reference voltage. Therefore we propose a coding signal to reduce the crosstalk and increase the reliability of the system. According to the features of the coding signal our design enhances the ultrasonic signal pattern to distinguish the random ultrasonic interferences.
Fig. 4 is a typical ultrasonic signal. Fig. 5 shows an ultrasonic signal being interfered with by another ultrasonic frequency. As signal interference causes difficulties in setting up the amplitude of the reference voltage, we use the coding signal to enhance the characteristics of the ultrasonic signal.

Figure 4. Typical ultrasonic signal.

Figure 5. Ultrasonic signal with interference by another frequency.

4. FEATURES OF CODING SIGNAL

In this design we use a coding signal to increase the reliability of the ultrasonic sensor group. Eq. (1) is the function of the probability of code breaking. Eq. (2) is the function of reliability. According to Eqs. (1) and (2) we know that with one bit, if the probability of code breaking is 0.5, the reliability will be 0.5. From Eq. (2), to increase the reliability, we need to increase the number of bits in the ultrasonic signal code.

\[
P = p^n \quad (1)
\]

\[
R = 1 - P \quad (2)
\]

In our design we use a 16-bit number coding signal that has 8-bits in two steps. Using Eq. (1) and Eq. (2), we know that if the number of bits is \( n = 8 \), the probability of code breaking is \( P = \frac{1}{2^8} \). The reliability is equal to \( R = 1 - P = 0.996 \). The reliability is close to 1 by using 16 bits.

Typical time-variation codes of the ultrasonic signal are shown in Fig. 6. If our system uses two group signals, each group has an 8-bit coding signal. When one group transmits, there will be idle time between the groups. Each idle time will decrease crosstalk and the probability of a miss rate. The reliability of our design is shown in Eq. (3).

\[
R_{\text{code1}} = 1 - \frac{1}{2^n}, R_{\text{code2}} = 1 - \frac{1}{2^n}
\]

\[
R_{\text{code1}&\text{code2}} = 1 - (1 - R_{\text{code1}})(1 - R_{\text{code2}}) = 1 - \frac{1}{2^{2n}}
\]

(3)

The reliability of our design is \( \frac{65535}{65536} \) in Eq. (3). If we use multiple groups with a different number of bits, then we have the reliability as shown in Eq. (4).

\[
R_{m \times n \text{ bit codes}} = 1 - \frac{1}{2^{m \times n}}
\]

(4)

Figure 7 shows that when adding bits, the length of the coding signal increases, and the probability of code breaking decreases. For instance, when using a 20-bit code, the reliability would be closer to 1 than with a 10-bits code.

5. IMPLEMENTATION AND EXPERIMENT RESULTS

In the experiment results we found that an ultrasonic signal would be affected by both environment sounds and the amplitude of the reference voltage. Those factors affect both the transmission distance and the error rate in detecting. We therefore put the transmitter and the receiver on both ends of the sensing area and make sure the intruder passes through if the outside group has detected an individual.

Our design uses multi-frequencies ultrasonic sensors to improve the crosstalk of interference in hardware and uses MVM to reduce the miss rate from the environment interference of sensors [9]. To reduce the miss rate we add the ultrasonic coding signal in order to enhance the distance between signal patterns and to eliminate any interference by the environment.
Fig. 8 shows the time-variation coding signal. Signal_1 of our code is between idle times A and B and signal_2 is between idle times B and C. We judge the intruder with the results of both signal_1 and signal_2. The idle time is used to reduce the receiver miss rate between groups.

Fig. 9 shows the decoded signal. When we transmit a time-variation ultrasonic signal, as the transmitter and receiver will have a time delay between the red dot lines and the blue dot lines, we add an idle time to reduce the crosstalk of the ultrasonic signals.

The idle time is used to reduce the receiver miss rate between groups.

Fig. 10 shows the flowchart of the submodule used to processing the time-variation coding signal after the intruder has been detected outdoors, the MCU software submodule of the time-variation ultrasonic signal is executed as shown in Fig. 10. This submodule transmits the time-variation ultrasonic signal with signal_1 and signal_2 and the receiver checks whether the signal is correct or not. If the signal is correct, the ultrasonic sensor group continues for some seconds to make sure that there is no intruder. If the coding signal is blocked by the intruder and is not correct, this blockage starts the majority voting mechanism (MVM) to make sure of whether there is any detection.

The system encrypts the code signal with characteristics in time-variation. Fig. 11 shows two signals forming an encryption coding signal. The red dot line stands for the start, and the blue dot line the end of the signal. The pointing arrows represent the idle time. In the signal, the first 12 bits mean information and the last 4 bits mean the error detection code. When the intruder is passing through the detection area of the ultrasonic sensor, the signal will be blocked, the number “1” in the signal will be reduced, and the system will detect the intruder.

Although the time-variation codes make the signal different with time, they may be cracked and thus result...
in the same signal within a short time. To improve this, we propose our time-variation encryption mechanism to encrypt the time-variation coding signal with time. Fig. 12 shows the flowchart of the time-variation encryption mechanism. When the system enters the detection mode, the MCU chooses a time-variation coding signal and encrypts it with the variation of the real clock time. The receiver can decrypt the signal due to the real clock time and judge the correctness.

Fig. 13 shows that our design consists of both the internal software module and the home embedded system software module. When an intruder has been detected, the MCU wakes up the majority decision to test the threshold and then turns on the power supply for the indoor sensors. If the indoor sensors detect no intruder when the outdoor sensors are misjudging, the MCU turns off the power of the indoor sensors and goes back to the alert state. If the indoor sensors detect an intruder, the MCU turns on the Web camera to capture images in keeping with the decision of the MVM.

Our experiment shows two different types of sensors which enhance the overall sensing probability by using the MVM to reduce the shortcomings of both the ultrasonic sensors and the PIR sensors. Our design furthermore improves the reliability of the overall system by adding a

6. CONCLUSION

Our experiment shows two different types of sensors which enhance the overall sensing probability by using the MVM to reduce the shortcomings of both the ultrasonic sensors and the PIR sensors. Our design furthermore improves the reliability of the overall system by adding a
time-variation ultrasonic signal to reduce the effect of ultrasonic signal interference.

7. REFERENCES


