Enhancement of the Sensing Distance of an Embedded Surveillance System with Video Streaming Recording Triggered by an Infrared Sensor Circuit

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Abstract: In this paper we propose a design for a home surveillance system with an enhancement circuit for the pyroelectric infrared sensor (PIR sensor) which has been included to improve the sensing distance. We implement the surveillance system with an embedded board which has the advantages of low power consumption, small size, low cost and high mobility. In this system we design an external circuit consisting of a PIR sensor to be the external interrupt. If the PIR sensor senses an intruder in the area, the embedded board is triggered by the PIR circuit and instantly captures the current image of the moment by web camera. In addition, by using an analog adder for the signal from the PIR we enhance the sensing distance. We also compare the distribution of the sensing distance between the uni-PIR sensor module and the enhanced sensor circuit module under different temperatures to obtain the average and standard deviation values of the sensing distance. By means of an analysis of our experimental data we can judge the stability of the PIR sensor circuit. Our design further allows the user to use either a PDA, a smart device or a PC to connect the video streaming server constructed on the embedded board to the internet in order to browse a webpage.

Keywords: web camera, PIR, embedded, video, analog adder.

1. INTRODUCTION

With more and more research being conducted, the technology is improving for the applications of surveillance systems. An important research area is how to combine home surveillance with an embedded system and monitor the area remotely. The embedded surveillance systems can be used in home multimedia applications, home safety and consumer electronics.

Much research aims at developing applications for the design of the smart camera for home or traffic surveillance in cooperation with an embedded system which uses the methodology of image processing to analyze and judge the surroundings. In addition, some researchers have designed a surveillance system based on IP which is implemented with an embedded system. The system compresses and transmits the image data packets to a WAP server. Then the users can link to the server by means of the IP address and monitor the real-time images in the surveillance area [1-4]. Other researchers have not only achieved real-time images with high-speed DSP core, but have now also achieved the peripheral control with ARM core [5] and subsequently formed implementations with a dual-core embedded board.

In surveillance, the pyroelectric infrared sensor (PIR) has already been widely used in various sensor circuit applications. Some researchers have also integrated PIR sensors with a home network management and surveillance system at a home gateway. The managing and controlling of ubiquitous sensors has been carried out by a PC server at home [6-7].

In addition, some related researchers have combined a sensor network with a surveillance system. Using the wireless sensors distributed in the surveillance area, when sensing the movement or intruders, the camera intensely monitors the area where the sensor is triggered until the security employee takes charge of this matter [8]. Otherwise, the system will manage the distributed sensor network with an embedded board and monitor the network via the distributed sensor nodes [9].

In this paper we describe in Section 2 the surveillance system architecture, in Section 3 we introduce our software and hardware design, in Section 4 we show the implementation and experiment results, and in Section 5, we draw the conclusions.

2. EMBEDDED SURVEILLANCE SYSTEM ARCHITECTURE

In this paper we design and implement an embedded surveillance system which is triggered by an external PIR sensor. Fig. 1 shows our embedded surveillance system architecture which includes a web camera, a PIR sensor circuit and an embedded board. By using a PIR sensor, we can detect when the intruder enters the surveillance area. The sensor sends the interrupt message to the kernel to capture the real-time image [10]. There are many General Purpose Input Output (GPIO) ports that connect with an external PIR sensor circuit and receive the interrupt signal which is launched by the PIRs. The embedded board offers two network interface ports for us on which to build the video streaming server for monitoring the surveillance area from a remote site. In addition to building the streaming server, we also build the web server on the embedded board that allows users to monitor the images captured by the web camera. Therefore the users can observe the surveillance area everywhere via the Internet by means of a smart device. In this paper we not only construct an embedded surveillance system, but also propose a method to enhance the PIR sensing distance, and we test by experiments.
3. THE SOFTWARE AND HARDWARE DESIGN OF THE EMBEDDED SURVEILLANCE SYSTEM

3.1 Software Architecture

Let us briefly introduce the software architecture of our design. First we introduce the software architecture development environment. Second is the architecture with information about the operation of both the Web server software and the streaming server software on the embedded board. Third is the architecture of accessing the digital signal via GPIO and launching the external interrupt to the processor.

Fig. 2 shows the software architecture of the system. At the bottom of the software architecture of the system we implement the bootloader which functions like the “BIOS” of a PC. We install our system with Linux OS (kernel edition 2.4.18) on the bootloader. We then download the root file system to complete the construction of our Linux. Our design differs from the purpose of Linux on a PC which builds the drivers like GPIO and Camera in a Linux kernel. We build these drivers in a root file-system to avoid wasting memory in the kernel. Therefore, when the system boots up, we use the instruction “insmod” to download the driver to the kernel and execute the driver.

We use a set of GPIO ports to receive the sensing signal and its software flowchart as shown in Fig. 4. At the beginning the GPIO port is at a high level (logic1) and the process starts scanning which port has been triggered. The detection mechanism is similar to keyboard scanning which scans repeatedly to ascertain the location of the interrupt. As the sensing signal is triggered, it changes the GPIO port to a low level (logic 0). When the GPIO receives the sensing signal, the GPIO launches the interrupt signal to simultaneously capture the real-time image. In the embedded surveillance system, to avoid wasting storage resources, we also implement the JPEG Codec on the embedded board to compress the real-time image into memory.

Fig. 3 The software flowchart of the embedded surveillance system.

In our design the embedded board communicates with the external sensor circuit by using a General Purpose Input Output (GPIO). When the PIR sensor detects someone intruding into the area, the sensor circuit launches the triggered signal to the GPIO. As a result of receiving an interrupt signal the system begins to capture real-time images and initiates video streaming. Fig. 3 shows the software flowchart of the surveillance system. At the beginning the system monitors the area and returns the sense signal of the PIR sensor as the interrupt signal to the embedded board to start recording the current image and to store the recorded images. On the right side of Fig. 3 the symbol A represents the start of the flowchart of the user machine interface. We can link up with the streaming server via the Internet, and we can also select whether we want to see the real-time video streaming or the stored image in the server [11].
3.2 Hardware Architecture

Fig. 5 shows the block diagram of the hardware implementation of the PIR sensor. When the sensor detects the temperature variation caused by someone passing by or being away from the sensor, it will produce a signal $v_1$. This signal is fed into two amplifier stages and a low-pass filter to get the signal $v_2$. Comparing the signal $v_2$ with $v_3$, the comparator’s output transmits the signal to either the output driver or the delay timer. Table 1 illustrates the specification of the PIR sensor circuit. In our design we do not adopt the design of the delay trigger as the system has to capture the real-time images immediately when detecting that someone has intruded into the area [12].

Table 1 The PIR sensor specifications.

<table>
<thead>
<tr>
<th>Spectral Response (μm)</th>
<th>Noise (μ-Vpp)</th>
<th>Output (mVpp, After 72dB amp. gain)</th>
<th>Supply Voltage (volts)</th>
<th>Operating Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5~14</td>
<td>20</td>
<td>3900</td>
<td>2.5~15</td>
<td>-30~70</td>
</tr>
</tbody>
</table>

In this paper the external PIR sensor circuit is the main hardware module of the system. Actually, from the point of view of the sensing distance and the sensing stability, the PIR sensor is not good. Therefore we design a unit-gain buffer circuit for preprocessing of the sense signal from the sensor circuit, and an analog adder circuit to enhance the sensing distance. Fig. 6 shows that the signal of the sensor is fed separately into two amplifying circuits. Because the sense signals from the PIR are too small, we input them into a pair of unit-gain amplifiers with a very high input impedance of more than 100 MΩ and a wide enough bandwidth of more than 1.2 MHz. Thus we reduce the loading effect of the sensor and obtain a very good additive effect for the sensor signal. First we input the output of the buffering circuit into the first level amplifiers in order to amplify the sensor signal. Then we input the two separate outputs from the first level amplifiers into the analog adder circuit. By adding two sense signals we enhance the signal level with a very low side-effect and enhance the sensing distance. We send the output signal from the analog adder circuit to the second level amplifier, and its output is fed into the ADC circuit and used as the trigger signal for capturing the current images.

Fig. 6 The block diagram of sensor circuit enhancement.

In this paper, in order to extend the sensing distance of the PIR sensor circuit, we distribute the sensor circuits we constructed in the surveillance area. Fig.7 shows the diagram of sensing a distance extension via sensor distributing. If the detection distance of a set of sensor circuits is about 7 meters in average, we can extend the sensing distance by distributing many sensors in a large area. For example, we can set the sensor circuit surrounding the surveillance to broaden the sensing area. In the end we feed the triggered signals after digitizing them into “OR” logic gates. When a set
of all sensor circuits is triggered, the embedded board launches an interrupt via a GPIO to capture images.

Fig. 7 The diagram of the sensing distance extension via sensor distributing.

4. IMPLEMENTATION RESULTS

In this paper, the CMOS web camera captures the external image signals and allows the user to monitor by means of synchronous video streaming. We implement the software modules in the Linux C language for the video display and for the triggered signal while sensing the variation of the environment temperature. We also build a streaming server and a Web server on the embedded board to allow the user to browse the recording video on the surveillance system.

In the streaming server we use VLC (streaming server), a program for constructing a video streaming server. It implements RTSP (Real Time Streaming Protocol) and RTP/RTCP (Real Time Protocol/Real Time Control Protocol) and is also an open source code program. The main program functions with C language, and it is convenient to understand and to revise. Fig. 8 shows the RTSP flowchart of the system operation [13].

Fig. 8 The RTSP flowchart of the system operation.

Fig. 9 shows the implementation and the displaying of the real-time video streaming on the embedded system platform. The software of the embedded development board shows the video streaming on the LCD and captures the current images via a CMOS camera. In addition we construct a streaming server on the system for the user to monitor via the browser. Fig. 10 shows the remote access by which we open the Web browser and input the IP address on the embedded board. We can link to the embedded video streaming server and build the operation interface by using a boa Web server. When we click the link “View saving images” we will observe four images which have been saved. Each image’s resolution is 320 × 240. By using JPEG compression, each image’s size is about 2K to 3K bytes. The embedded board’s storage volume allows 2000 to 3000 images to be saved on it. If necessary, we can plug in SD cards or an external hard disk to extend an insufficient memory. Then the video streaming server transforms the media format captured by the camera into the streaming format for remote site accessing.

Fig. 9 The implementation and the displaying of the real-time video streaming on the embedded system platform.

Fig. 10 The implementation and the displaying of the real-time video streaming on the embedded system platform.

Fig. 11 shows the experiment results of measuring the sensing distance of the PIR sensor by means of an
analog adder with two circuit modules-one is the uni-PIR module and the other is the enhanced circuit module. We analyze the sensitivity and stability of the sensor by measuring the sensing distance and calculating the average and standard deviations of the sensing distance. In Fig. 11, Group A represents 200 detection experiments with the uni-PIR circuit module under 24, 26, 28 and 30 degrees Celsius separately. We record and accumulate the number of trigger times for the sensing distance with a resolution of 10 cm. Group B represents 200 detection experiments with the enhanced circuit module under the same environmental conditions and temperatures. For Group A we find that when the environment temperature is lower, the average sensing distance is much greater. We conclude that the PIR sensor works better at a lower temperature and that the sensing distance is shorter at higher temperatures. On the other hand, when we analyze the standard deviation calculated from the measurement statistics we find that when the environment temperature is higher, the difference between the maximum and minimum sensing distance is greater. The value of the standard deviation represents the sensor’s stability because the sense signal as the interrupt signal can have a range of amplitudes. From the measurement results of Group B we find that the average value of the sensing distance is about twice that of Group A. Although the peak of the broken-line graph is not extreme and the standard deviation is larger than for Group A, we do actually extend the sensing distance. In this paper we have doubled the sensing distance by using a single sensor with the analog adder, and have carefully avoided the loading effect of the sensor.

when the detection distance is more than 7 meters, even though the amplifier gain of the sensor system is large enough, not only the triggered signal, but also the noise is amplified. This is because when the detection distance is too great, the detection signal is too weak and the environment noise may interfere with detection. Therefore we have to compromise on the number of inputs of an analog adder, amplifier gain and detection distance.

Fig. 11 Sensing distance versus trigger times under various temperatures with different sensor circuit modules.

Fig. 12 shows the detection feature of the PIR sensor circuit with an enhancement by three inputs of an analog adder which are not sharper than the solution by two inputs of an analog adder, as shown in Fig. 6. From the detection experiment statistics of Fig. 12 the detection feature of the PIR sensor becomes unstable, which means that the standard deviation of the statistics is spread out. Since the signal of the PIR is too weak

Fig. 12 Sensing distance versus trigger times under various temperatures by the sensor circuit module with three inputs of an analog adder.

Fig. 13 illustrates the sensing signal amplitude curves of different individual distances. The sensing amplitude is obviously large when the heat source is 1 meter in front of the sensor. The amplitude reaches 300 to 400 milli-volts. But if the amplitude is getting weak, either the distance is too great or the environment temperature is too high. Fig. 14 illustrates the individual curves at various environment temperatures. We use a single set of the PIR sensor circuit with an analog adder to measure the maximum amplitude of the detection voltage versus the detection distance. These measurements show not only that the amplitude generated from a single set of the PIR sensor circuit with an analog adder can be too small for a detection distance of 7 meters but also that the environment noise can interfere with the detection signal.

Fig. 13 The sensing signal curves at different distances.
5. CONCLUSIONS

Table 2 illustrates the performance and the power consumption of our design. We have measured that the power consumption is about 0.63W which is very low under the 70mA current. The kernel, which possesses a 400MHz clock rate, provides for about 100 users to log on and browse the embedded server whose average response time is about 284ms. “Sensor circuit A” represents the uni-PIR module and “Sensor circuit B” represents the enhanced sensor circuit module with an analog adder. Therefore we have designed and implemented a surveillance system with both low power consumption and low cost. We have also enhanced the sensing distance of the uni-PIR sensor circuit by using the analog adder.

Table 2 Performance measurement and power consumption of our design.

<table>
<thead>
<tr>
<th>Platform</th>
<th>Clock</th>
<th>Idle state power</th>
<th>Running video streaming power</th>
<th>Response time</th>
<th>Frames/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embedded monitor system</td>
<td>400 MHz</td>
<td>3.75 W</td>
<td>4.25 W</td>
<td>284 ms</td>
<td>6~8</td>
</tr>
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Comparison of sensing distances

<table>
<thead>
<tr>
<th>A single sensor circuit</th>
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<table>
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<tr>
<th>Temperature</th>
<th>24$^\circ$</th>
<th>26$^\circ$</th>
<th>28$^\circ$</th>
<th>30$^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average distance</td>
<td>3.4985 m</td>
<td>3.1905 m</td>
<td>2.9575 m</td>
<td>2.8220 m</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.3028 m</td>
<td>0.3740 m</td>
<td>0.3804 m</td>
<td>0.4006 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sensor circuit with 2 inputs of an analog adder/3 inputs of an analog adder</th>
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| Average distance | 6.69/6.96 m | 6.29/6.69 m | 5.78/6.46 m | 5.59/6.65 m |
| Standard deviation | 0.38/0.57 m | 0.44/0.61 m | 0.47/0.63 m | 0.48/0.67 m |

REFERENCES