

Home Surveillance system using Ultrasonic Sensors

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ABSTRACT

Each ultrasonic sensor module includes a transmitter and a receiver, and the modules are placed in a line direction. Because the ultrasonic transmission will spread at a beam angle, we use multiple ultrasonic receivers to receive the ultrasonic transmission. If any intruder passes through the ultrasonic sensing area, the ultrasonic transmission will be blocked by the human body. As the receivers will not receive any transmission from the ultrasonic transmitter, the system will sense when someone is passing through the surveillance area. We use a Majority Voting Mechanism (MVM) for a group of sensors. If over half the sensors in a sensor group sense a signal blocking, the majority voting program starts the Web camera. The mathematical equation and the sensing experiment show that we improve the system's reliabilities.

Index Terms — Embedded Surveillance System, Majority Voting Mechanism, Ultrasonic Sensor

application of the MVM, such as those relating to the enhancement of speech recognition probability by MVM [12].

I. INTRODUCTION

The MVM determines the voting result of multiple sensors of an ultrasonic receiver, and the embedded home surveillance system starts the Web camera to capture the images according to the MVM result. The Web server uploads the images after finishing the image capture. is becoming more important. An embedded surveillance system is frequently used in the home, office or factory for materials with different characteristics, combined with signal processing, which shows images. Moreover, ultrasonic transmission is sometimes used in examining pregnant women [10]-[11]. In addition, because a single receiver can be influenced by refraction and reflection, we use several sensors to receive the ultrasonic transmissions in order to enhance the reliability of the system. We extend some of the theory and image processing of the surveillance system and also for traffic monitoring but this configuration requires a high performance core, which works against some advantages of embedded systems, such as low power consumption and low cost. Some designs propose the use of different sensors to track the sequence of the human body movement. Other researchers construct an external signal to trigger the

II. MAJORITY VOTING MECHANISM

According to our MVM the resolution count must be greater than $0.5u_n$, with n being the total number of sensors.

To fit the extreme value of n we use $w_u n$ to deduce the relationship between $P_{multiple}(n) = P_m$ and $P_{single} = P_s$ in the extreme value of n [6].

$$P_m = (P_s)^{wn} \sim (1 - P_s)^{(1-w)n} \sim \left[\sum_{r=0}^n \binom{n}{r} (P_s)^r (1 - P_s)^{n-r} \right] \quad (1)$$

We define

$$f(k) = \sum_{k=0}^n \binom{n}{k} (P_s)^k (1 - P_s)^{n-k}$$

and $k \in \{0, 1, 2, 3, \dots, [(1-w)n - 1], [(1-w)n]\}$

As we expect that $f(k)$ will converge we need

to

embedded surveillance system by means of a PIR sensor, which is triggered when an intruder enters the monitoring area [6]. However, a PIR sensor has a high miss rate when the intruder walks at a slow speed. Hence, to solve this problem, we use ultrasonic sensors to implement an embedded home surveillance system. Ultrasonic sensors are already used in automatic cars and robots for measuring distance [7]-[9]. There is some use of ultrasonic transmission in medical detection, such as high-frequency ultrasonic transmission based on a specific result of ultrasound attenuation in different

determine whether $f(k)$ is a decreasing function. From the ratio test for the convergence function we learn that increasing the n value decreases the ratio gradually for each $f(k)$. The relationship is as follows.

$$1 \leq \frac{|f(1)|}{|f(0)|} \leq \frac{|f(2)|}{|f(1)|} \leq \frac{|f(3)|}{|f(2)|} \leq \dots \leq \frac{|f[(1-w)^n-1]|}{|f[(1-w)^n-2]|} \leq \frac{|f[(1-w)^n]|}{|f[(1-w)^n-1]|}$$

Let $n \rightarrow \infty$, so

$$\lim_{n \rightarrow \infty} \left| \frac{f(1)}{f(0)} \right| \left(\frac{1-w}{1-P_s} \right)^n = 1$$

We let $1/2 < w < 1$ and $P_s < w$

$$P_m = (P_s)^{wn} \sim (1-P_s)^{(1-w)n} \sim \sum_{r=0}^{(1-w)n} f(k) \quad \forall \lim_{n \rightarrow \infty} (P_m) < (P_s < w)$$

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We rewrite (1), by letting $P_s = w$ and thus deducing

$$\overline{P}_m = 1 - P_m \text{ by the ratio test.}$$

$$\overline{P}_n = (P_s)^{(1-w)^n} \sim (1 - P_s)^w \cdot g(k)$$

$$\lim_{n \rightarrow \infty} (\overline{P}_m) = 1 \quad (3)$$

According to (2) and (3) the sensing probability of multiple sensors must be greater than the sensing probability of any single sensor. We know that when P_{single} is greater than 0.5, the

$P_{multiple}(n)$ will be greater than 0.5. Fig. 1 shows the improvement of the sensing probability of multiple sensors through majority voting. If the sensing probability of a single sensor is 0.7, the sensing probability of 7 sensors will be 0.874.

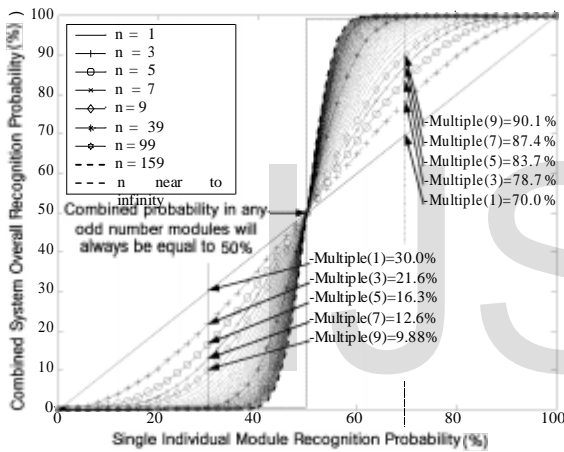


Fig. 1. Sensing probability of both single sensor and multiple sensors.

III. SYSTEM ARCHITECTURE

Fig. 2 shows our design which uses the embedded board as the system core. We separate the transmitter and the receiver by placing them on opposite sides. When an intruder enters the transmission direction, the human body blocks any ultrasonic transmission. If the receivers do not receive a transmission, the embedded home surveillance system counts the sensing states of all ultrasonic sensors. If, because of the result, the MVM is used, the Web camera immediately begins to capture the images of the intruder. After capturing the images, the embedded surveillance system uploads these images to the Web page through the Internet. The user can then watch them on either a PC or a PDA by connecting to the Internet.

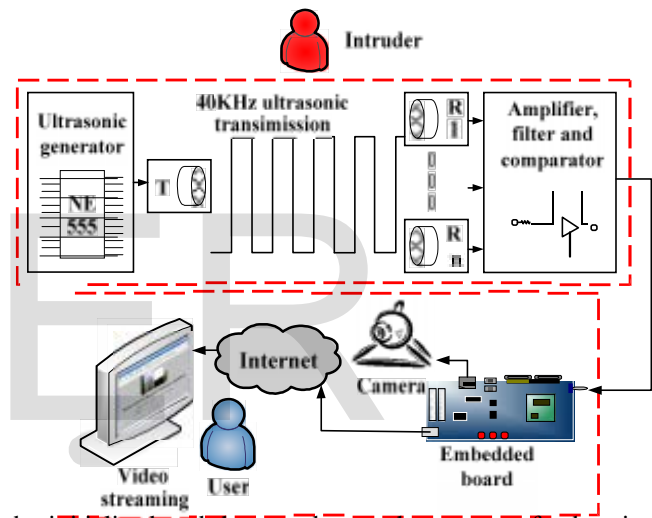
A. Software modules

Fig. 3 shows the software modules of the embedded system. The bottom layer is the bootloader; it lies between the development kit and the firmware of the operating system. It manages the hardware in the development kit which needs to

through the services of the OS kernel, and can handle the requirements of the user by scheduling and multitasking of the kernel. Now we burn the root file system above the kernel. The root file system is also called the application layer. After

cross-compiling the application program that we need to execute, we compress it and put it into the root file system. In our experiment we bundle the USB Web camera driver and the general purpose input and output (GPIO) driver into the root file. We use the command 'insmod' to load the drivers into the kernel and the command 'rmmod' to unload them

again. The external sensing circuit communicates with the embedded board by means of a GPIO and captures the images by a USB Web camera through the parameter setting and hardware communication protocol of the driver.



be initialized and then marks out the memory for burning the OS kernel. The second layer from the bottom is the OS kernel, and we use the Linux OS kernel 2.6.9 in our experiments. The system can execute each application program procedure

Fig. 2. Embedded home surveillance system architecture using multiple ultrasonic sensors.

The program of the MVM contains a detection of the GPIO function, a counting and majority vote function, an image capture function and a Web server, as shown in Fig. 4. The embedded system always scans the GPIO sockets, all of which are connected to ultrasonic receivers. To verify the state of each ultrasonic receiver, the embedded system determines the voltage levels of the GPIO sockets. When the system reads 5V from a GPIO socket, we know the ultrasonic receivers, which have been blocked, will execute the majority voting program by counting the number of states of each ultrasonic receiver. The majority vote is achieved by the sensor groups of the different GPIO sockets, and the result determines whether to adopt the MVM or not. If the result is not to adopt the MVM, we know that the ultrasonic receivers have probably been blocked because of refraction and reflection. The embedded system then returns to the initial state, scanning the GPIO sockets. If, as a result, the MVM is adopted, we know that the ultrasonic receivers have been blocked by an intruder. The embedded system interrupts the detection procedure and starts the Web camera which then begins to capture images. When this is finished, the embedded system starts the detection procedure over again. When the intruder has left the monitoring area, the counts of the GPIO

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sockets do not adopt the MVM. The embedded system uploads the captured images by means of the Web server and the streaming server through the Internet.

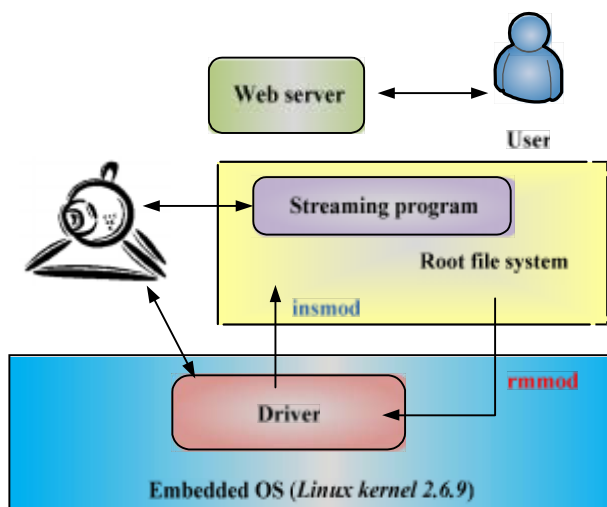


Fig. 3. Software modules of the embedded system.

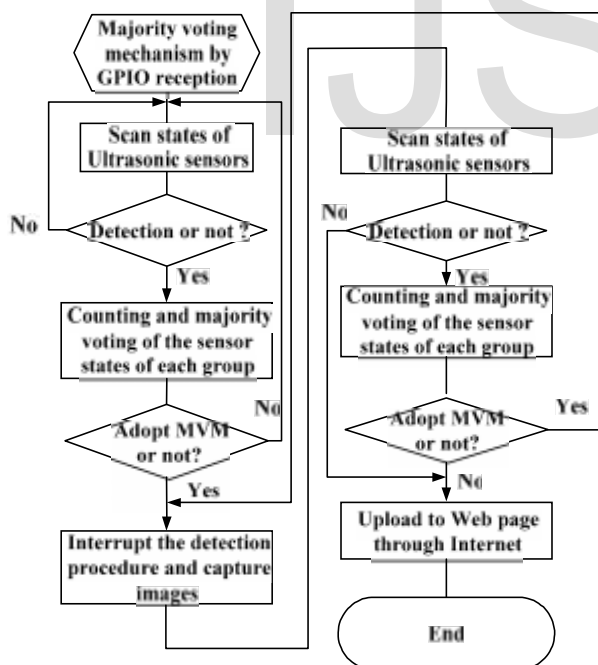
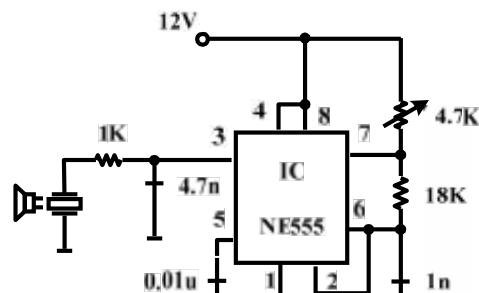


Fig. 4. Majority vote and GPIO receiving flowchart.

B. Hardware modules

Fig. 5 shows the ultrasonic transmitter circuit. We use a typical oscillator chip, NE555, to design a square waveform generator, and adjust the resistances and capacitance to generate a 40 KHz frequency. The ultrasonic transducer will transform the voltage waveform into an ultrasonic

shows the ultrasonic receiver circuit. We use the amplifier to enlarge the voltage waveform, and the filter suppresses any frequency besides 40 KHz. The comparator determines the level of the voltage waveform which is the method used for the ultrasonic transmission, whether blocked or not. Because the ultrasonic sensor will be influenced by refraction and reflection, we design several ultrasonic receivers to receive the ultrasonic transmission. The receiving states of all receivers are input to the embedded home surveillance system which uses the MVM depending on the results of the ultrasonic receivers.



transmission. The transducer of the receiver transforms the ultrasonic transmission into the voltage waveform. Fig. 6

Fig. 5. Ultrasonic transmitter circuit [13].

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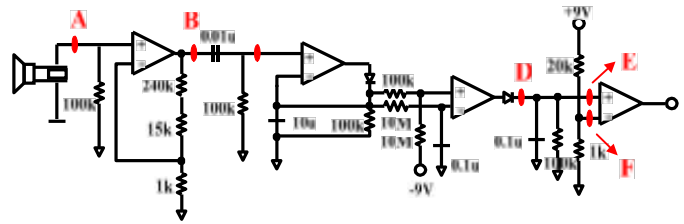


Fig. 6. Ultrasonic receiver circuit.

Fig. 6 shows the receiver circuit with the measurement points A-F. The receiver circuit receives the sine-wave shown in Fig. 7 for point A as a result of a very small voltage waveform. We use the amplifier to amplify the signal, as shown at point B. Then we use the rectifier and filter to convert the sine-wave to a DC voltage as shown in Fig. 8 at point D. Finally, to input the signal to the embedded board of the GPIO socket, the comparator is used to limit the output to 5 V. First of all, at point D the signal goes through a simple RC filter into the comparator as shown at point E. By using the law of the voltage divider the comparator reference voltage is set at 430 mV. When the input is lower than 430 mV the comparator doesn't receive the signal, and output will be 0 V. When it is higher than 430 mV, the signal is received, and output will be 5 V or logic 1. Then the logic 1 is input to the embedded board and executes the majority votin

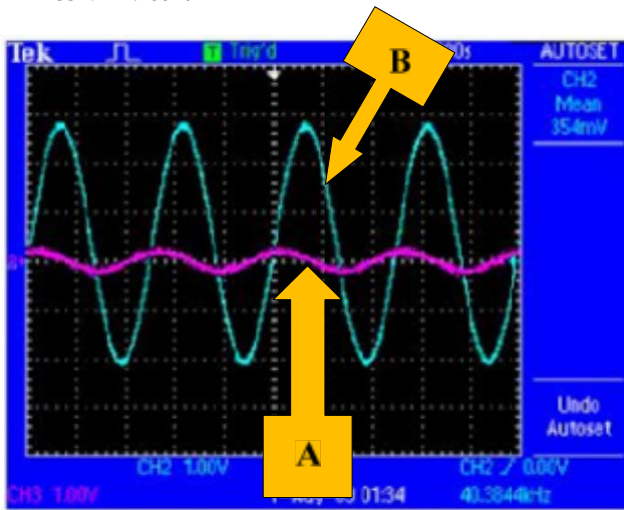


Fig. 7. Input and amplified signal.

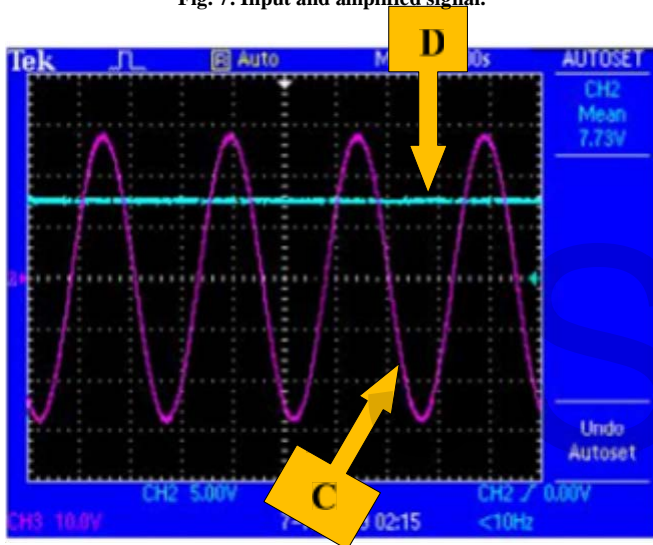


Fig. 8. Original signal and rectified and filtered signals.

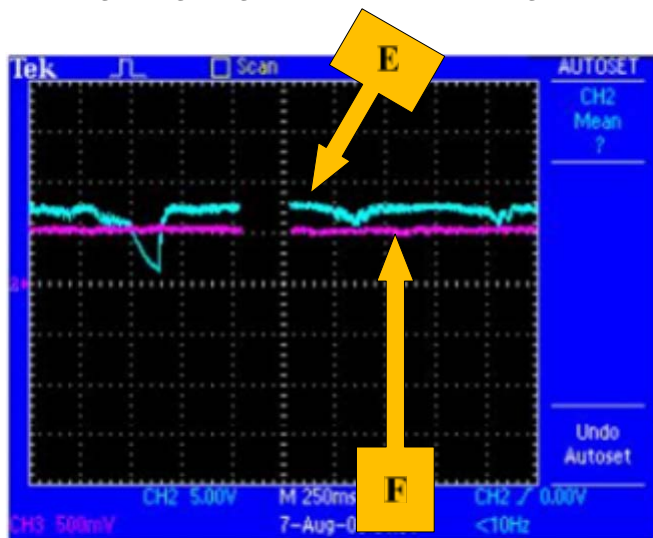


Fig. 9. Input of the comparator and reference voltage.

IV. IMPLEMENTATION RESULTS

In the experimental results, according to the specification of the components, we found that if the ultrasonic sensing distance is more than 6 meters, and if we give the transmitter the same direction as the sensing direction of the receiver, the ultrasonic transmission will be blocked when an intruder enters the transmission path of the sensing area. As decided by the MVM, our design detects the intruder and turns the Web camera on. The scattering angle of the ultrasonic sensors is very large with a fast scattering attenuation rate. Therefore, because of our observations at different distances and with perpendicular directions, the receiver is adjusted to within 100 cm of the scattering distribution. The transmitter is aligned with the direction of the receiver. We then measure the amplitude of the voltage waveform with a spacing of 10 cm. Table I shows our measurement of the amplitude of the voltage waveform of each node. Fig. 10 shows the scattering distribution of the plane curves. Our ultrasonic transmitter is placed at 50 cm, the center. If we move from the left to the right, the amplitude of the voltage waveform becomes smaller. An increase in the distance also causes a reduction of the amplitude of the voltage waveform. When the distance is 7 m, even while the ultrasonic signal of the receiver has the same direction as the transmitter, we find the amplitude of the voltage waveform has been reduced to near the comparator's reference voltage. Hence the scattering causes the amplitude of the voltage waveform to become gradually lower than the reference voltage. To increase the amplitude of the voltage waveform we place a PET bottle at the front end for focusing.

TABLE I
ULTRASONIC SCATTERING AROUND RECEIVER

Distance from the edge	3m	4m	5m	6m	7m
0cm	1.07V	0.80V	0.53V	0.35V	0.24V
10cm	1.18V	0.91V	0.63V	0.48V	0.32V
20cm	1.20V	0.95V	0.70V	0.55V	0.48V
30cm	1.23V	1.01V	0.73V	0.58V	0.50V
40cm	1.36V	1.10V	0.81V	0.62V	0.50V
50cm	1.41V	1.15V	0.96V	0.7V	0.52V
60cm	1.35V	1.13V	0.79V	0.64V	0.50V
70cm	1.25V	1.08V	0.73V	0.59V	0.49V
80cm	1.21V	1.02V	0.71V	0.53V	0.46V
90cm	1.20V	0.95V	0.63V	0.46V	0.35V
100cm	1.10V	0.84V	0.55V	0.33V	0.29V

Fig. 11 shows the receiver after adding the PET bottle. Table II shows the physical measurement of the amplitude of the voltage waveform, Fig. 12 shows the scattering distribution of the different deviations of the distance with perpendicular direction. We found that the ultrasonic signal increases at the central point and achieves the effect of focusing. We use multiple ultrasonic sensors to receive the ultrasonic transmission to enhance the reliability of this system.

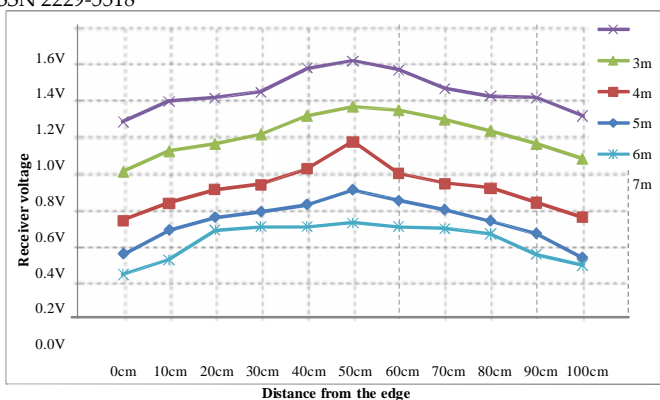


Fig. 10. Curve showing distribution of scattering.

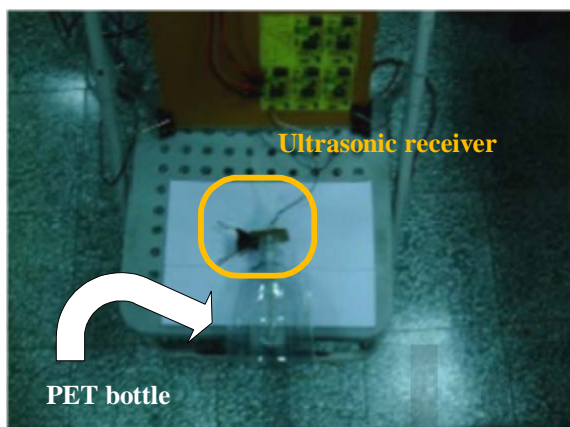


Fig. 11. Receiver after adding PET bottle.

Fig. 13 shows the environment for the experiment. We place the ultrasonic sensors on the walls around the room. The ultrasonic transmission will be blocked when an intruder enter into the transmission path of the sensing area. Fig. 14 shows the diagram of the experiment. The distance between the transmitter and the receiver is 6 m. Fig. 15 shows the receiver circuit and the transmitter circuit, including an LED, which is turned on/off according to whether the receiver receives an ultrasonic signal or not.

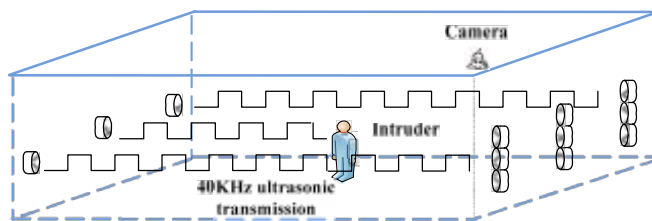


Fig. 13. Experimental environment.

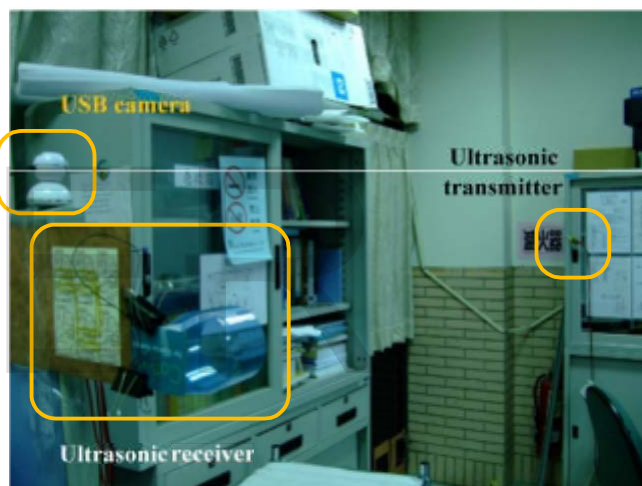


Fig. 14. Ultrasonic sensor diagram of experimental transceiver.

TABLE II

ULTRASONIC SCATTERING AROUND RECEIVER WITH FOCUSING

Distance from the edge	3m	4m	5m	6m	7m
0cm	0.60V	0.53V	0.48V	0.43V	0.39V
10cm	1.26V	0.74V	0.62V	0.56V	0.48V
20cm	1.41V	0.82V	0.76V	0.71V	0.54V
30cm	1.40V	0.96V	0.86V	0.82V	0.56V
40cm	1.81V	1.30V	1.12V	1.01V	0.66V
50cm	2.52V	1.72V	1.41V	1.32V	0.78V
60cm	1.83V	1.31V	1.18V	1.04V	0.64V
70cm	1.44V	1.01V	0.90V	0.83V	0.58V
80cm	1.40V	0.85V	0.81V	0.75V	0.55V
90cm	1.31V	0.78V	0.65V	0.61V	0.51V
100cm	0.81V	0.61V	0.52V	0.46V	0.42V

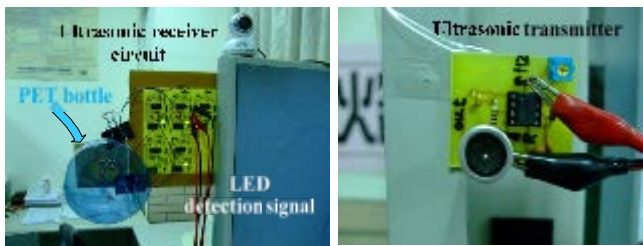
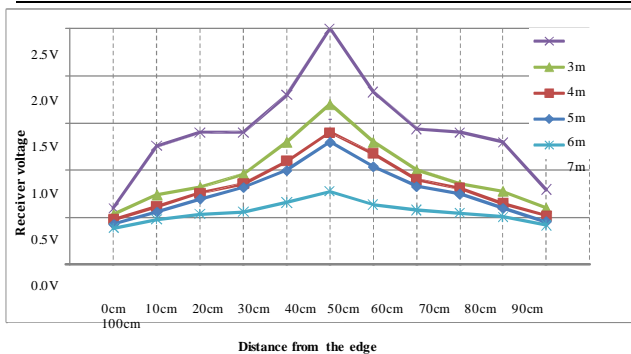


Fig. 15. Ultrasonic receiver circuits and transmitter circuit.



For this design we observe and measure the operation of the single sensor and multiple sensors at 1 m, 2 m, 3 m, 4 m, 5 m and 6 m separately. Table III shows the primary results of our experiments.

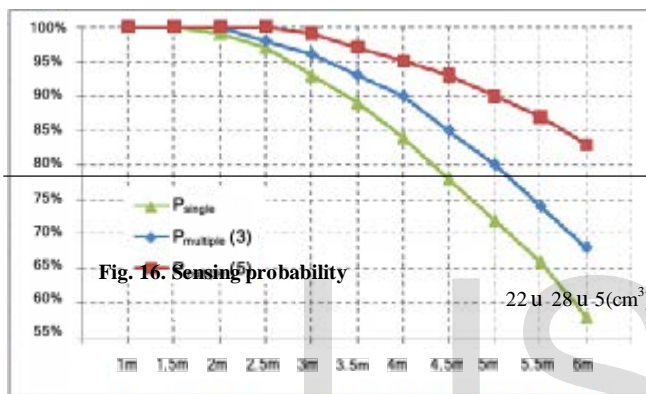
Fig. 16 shows the sensing probability enhancement from 58% to 83% at 6m by using 5 sensors based on our experiment.

Fig. 12. Curves showing the scattering distribution after adding PET bottle focus.

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TABLE III
IMPLEMENTATION RESULTS OF DIFFERENT SENSING
DISTANCES AND
NUMBER OF SENSORS

Distance	Overall sensing probability		
	1 sensor	3 sensors	5 sensors
1 m	100%	100%	100%
1.5 m	100%	100%	100%
2 m	99%	100%	100%
2.5 m	97%	98%	100%
3 m	93%	96%	99%
3.5 m	89%	93%	97%
4 m	84%	90%	95%
4.5 m	78%	85%	93%
5 m	72%	80%	90%
5.5 m	66%	74%	87%



enhancement by using MVM.

V. CONCLUSION

Our experiment shows that the overall sensing probability improves with the use of multiple sensors having an MVM. The result is a higher cost because of the use of multiple sensors, amplifier circuits and the voting circuit. However, the improvement of the reliability significantly reduces the occurrences of false alarm from the home surveillance system

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