An Efficient Fire Sprinkler System Based on Ultrasonic Distance Measurement

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***Abstract*—The main objective of this paper is to develop a distance measurement system for a smoke detector circuit to measure the distance of fire. This ultrasonic distance measurement system will calculate the time of flights (TOF) of the reflected echoes from the smoke particle of fire. The reflected echoes are cross-correlated with the transmitted pulses to find the distance. The measured distance should be given to smoke detector by the sensor signal processing and then the fire sprinkler system can be activated through this triggering signal. The fire sprinkler system will spray required amount of water only in that particular fire originating place according to the measured distance. This proposed system is designed to reduce the extent of fire-spreading in an efficient way so that it can protect the properties and lives from further fire hazards.**

***Index Terms*—cross-correlation, fire sprinkler, Gaussian noise, linear estimation, minimum mean square error (MMSE), random noise, smoke detector, wiener filter**

I. Introduction

Different case studies in ScottsdaIe, Arizona and United States show that properties of millions of dollars are damaged due to the absence of proper fire protection systems [1], [2], [3]. The effect of fire is more dangerous when people are asleep at night and their houses do not have fire sprinkler systems. In terms of fire engineering, it is a basic need to measure the distance of fire to protect the people from fire and smoke. Basically, most of the people died from inhaling carbon monoxide which is a major component of smoke. Smoke is a by-product of fire which consists of carbon and other particles in the air when something is burning [4].

Smoke detectors are one of the amazing inventions to detect fire location [5]. Ordinary smoke detectors are cheap because they don't contain signal processing equipments. Previous smoke detection systems did not have perfect operational reliability [6]. Thus they results in false alarming in the event of fire. Therefore, they sometimes can't detect the accurate fire distance when the fire is dispersing. A study in Ontario, Canada shows that 21% fire protection systems did not operate because they could not detect the smoke originating area [7].

In this paper, a ultrasonic distance measurement system is proposed which can be integrated to the smoke detector to measure the distance of moving fire accurately. The system also contains a wiener filter to remove noise signals from the received echoes.

The ultrasonic distance measurement depends on pulse-echo method, which evaluates the TOF of the ultrasonic waves [8], [9], [10]. TOF is the time interval between the transmission of pulse and reception of the reflected echoes from smoke [11]. It is determined from the time of the peak in the cross-correlated signal between the transmitted and received signals [12]. Besides, the reflected signal from smoke is interrupted by different kinds of atmospheric noises of the hot environment. However, if we know the acoustic velocity of the travelling pulse, then we can measure the distance of fire from the product of TOF and the velocity [11]. Thus the proposed system improves the performance of the traditional fire detection system. Furthermore, the performance of the system is compared with the output from the system without a wiener filter and shows better resolution in distance measurement.

The rest of the paper is organized as: in section 2, Literature review of the wiener filter and cross correlation operation is discussed. In section 3, the proposed smoke detector system is analyzed. In section 4, simulation outputs are discussed. Finally, in section 5, the performance of the system is concluded.

II. Literature Review

A. Wiener Filter:

If x(n) is an input signal consisting of a desired signal, s(n) and noise signal, w(n), then we need to design a filter that removes the additive noise while preserving the desired signal s(n) [13]. Hence we need to use a signal estimated linear filter which approximates the desired signal d(n). The construction of the filter can be shown as Fig. 1:

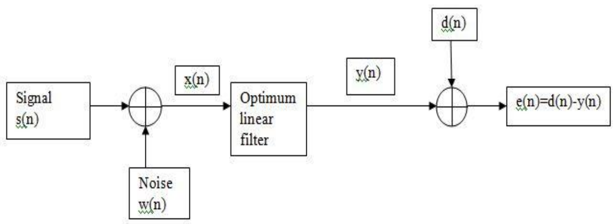

Figure 1. Wiener filter model

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The input signal to the filter can be written as x(n)=s(n)+w(n) and the output is y(n). The difference between the filter output and desired signal is the error signal, e(n)=d(n)-y(n). We have three cases here [13]:

1. If d(n)=s(n), the linear estimation is called filtering.
2. If d(n)=s(n+D), where D > 0, the linear estimation is called signal prediction.
3. If d(n)=s(n-D), where D > 0, the linear estimation is called signal smoothing

Wiener filter considers only filtering and prediction. This criterion used for optimizing the filter impulse response h(n) is the minimization of the mean-square error which provides smooth mathematical manipulation of the signals. All signals such as d(n), s(n) & w(n) etc are assumed to have zero mean and wide-sense stationary. This optimum linear filter having minimum mean square error (MMSE) is called a wiener filter. Wiener filter compares the frequency characteristics of the signals and noises. It is a two dimensional adaptive noise removal filter. It calculates the signal mean, standard deviation and variance. If noise variance is not given, wiener filter uses the average of all the local estimated variances. Then, it gives output by minimizing the error signal e(n).

B.Cross Correlation Operation

Let us consider that, x(n) is the transmitted narrow band signal and r(n) is the received signal. We can write the received signal as:

$$r(n) = \alpha x(n - D) + w(n). \quad (1)$$

Where, α = attenuation co-efficient of the atmosphere, D = Time of Flight and w(n) = noise signal generated from the atmosphere. Attenuation increases with frequency which in turn distorts the received signal [11]. The cross-correlation function between x(n) and r(n) at time t is calculated as:

$$\mathrm{Cxr(t)} = \sum_{n=-\infty}^{\infty} \mathrm{r(n)x(n+t)}$$

$$= \sum_{n=-\infty}^{\infty} \{\alpha \mathrm{x(n-D)} + \mathrm{w(n)}\}\mathrm{x(n+t)}$$

$$= \sum_{n=-\infty}^{\infty} \{\alpha \mathrm{x(n-D)x(n+t)} + \mathrm{w(n)x(n+t)}\}$$

$$= \alpha \mathrm{Cxx(t - D)} + \mathrm{Cwx(t)}$$

But, Cwx(t) = 0 and Cxx(t) = $\sum_{n=-\infty}^{\infty} \mathrm{x(n)x(n-t)}$. Then we get from the above expression:

$$\mathrm{Cxr(t)} = \alpha \mathrm{Cxx(t - D)}. \quad (2)$$

At time t = D the cross-correlation function reached its peak value and from equation (2) we can write it's expression as the following equation:

$$\mathrm{Cxr(D)} = \alpha \mathrm{Cxx(0)}. \quad (3)$$

The time found from equation (3) is the TOF of the pulses. This data contains the time information for further calculation.

III. PROPOSED SMOKE DETECTOR SYSTEM

Depending on the methodology described above, we can make a block diagram of the total distance measurement system as shown in Fig. 2. The cross-correlation process is a recursive process of the single bit signals prior to which the multi-bit signals are turned into single bit signals. Smoothing of the received signal is done by wiener filter.

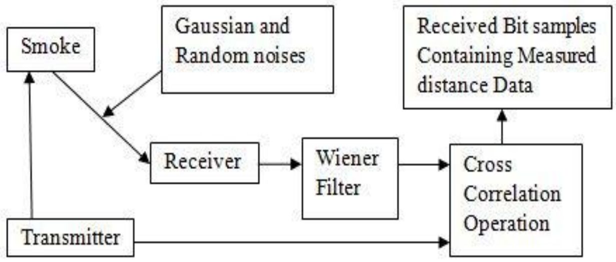

Figure 2.Proposed Block Diagram of the Efficient Smoke detector System.

An important feature of this proposed scheme is it can measure the accurate distance to activate the fire sprinkler which extinguishes the fire only in that particular fire originating place. So the scheme contains the feature of selectivity which means that it activates as small number of fire sprinkler systems as possible and properly measure the fire position with accuracy.

To design this smart smoke detector system, the whole system is divided into the following four steps:

Step 1: Smoke detection by ultrasonic transmitter:

At first an ultrasonic transmitter circuit transmits pulses towards the smoke. In normal cases, if there is no smoke in the room, the reflected pulse will bounce back in the same pattern. At that time, the sensor of the smoke detector will not remain active by keeping the fire alarm switch open. But when smoke generates from fire, the smoke particle will scatter the pulse and it will also be affected by thermal noises.

Step 2: Noise reduction by wiener filter:

The scattered pulses of the received signal are basically affected by the Gaussian noises and random noises which are generated from heat [14], [4]. The receiver receives this signal and sends it to wiener fitter to remove those high frequency noises. The wiener filter performs prediction and smoothing operation on the scattered pulses. The detailed procedure of the filtering action is discussed in section II.

Step 3: Fire position detection:

The cross-correlation function is executed between the transmitted signal and the received filtered signal to find the TOF [15]. The time of the peak of the cross-correlated signal is the TOF of the echoes. The distance is determined from the measured velocity and the measured bit samples TOF data.

Step 4: Activation of fire extinguisher:

At last, the measured distance is sensed by the fire sprinkler system which is connected to a reliable water source and fire alarm system [16]. Hence, it sprays water towards the appropriate distance of fire and closes the fire alarm circuit to sound the horn and make the operating people alert of the fire.

IV. SIMULATION OUTPUTS

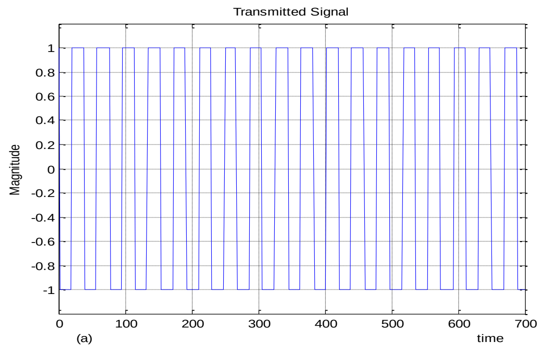

Figure 3. Transmitted pulse from transmitter.

Fig. 3 shows the transmitted pulses from the transmitter and figure 4 shows the scattered pulses which are received in the receiver. Fig. 4 shows that the reflected echoes from the smoke is affected by thermal noises.

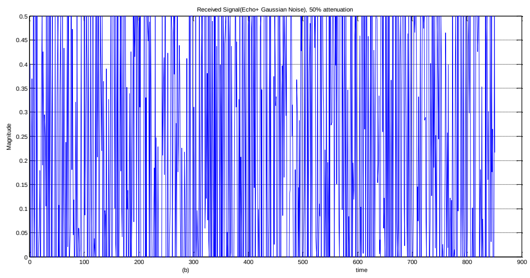

Figure 4. Received Signal in Receiver.

Fig. 5 shows the cross correlated signal between the transmitted pulses and the received echoes. It shows several peaks in the cross-correlated signal, which encounters errors in measuring the accurate distance. Therefore, the system will not be effective in measuring the fire distance.

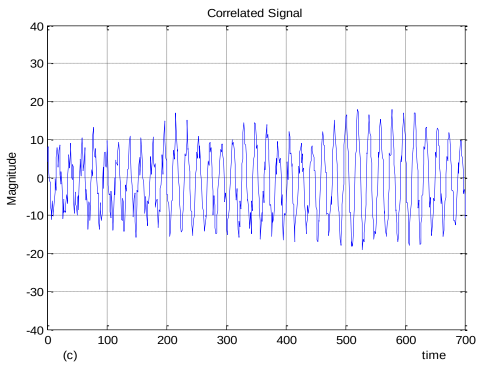

Figure 5. Cross-correlated signal containing measured distance bit samples without wiener filter.

Fig. 6 shows the wiener filtered output signal. The filter removes considerable amount of thermal noises from the received signal. Fig. 7 shows the cross-correlated signal between the transmitted pulses and the filtered signal. The peak of the cross-correlated signal is found at around t=500samples. From which we can determine the TOF easily.

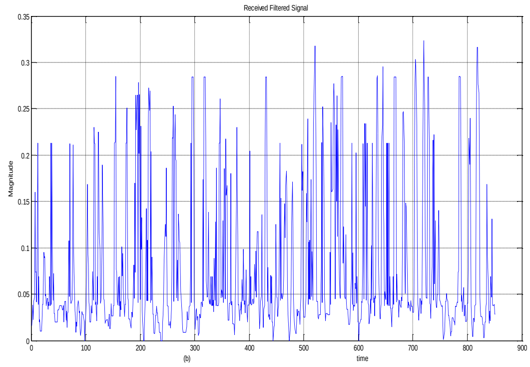

Figure 6. Wiener filtered output signal.

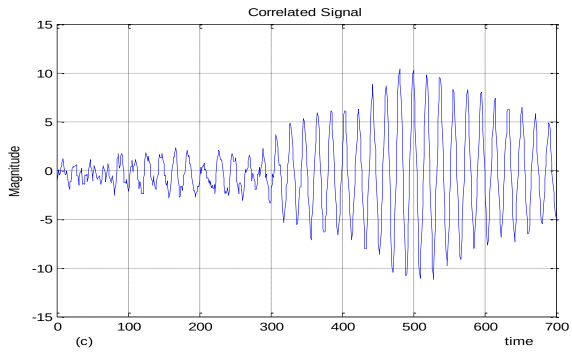

Figure 7. Cross-correlated signal containing measured distance bit samples with wiener filter.

V. CONCLUSION

In this paper, an efficient system is proposed to measure the distance of the fire source for a smoke detector system. The transmitted signal and the received signal are cross-correlated with and without a wiener filter. Proper smoothing operation is carried out by the filter to measure the distance for actuating the fire sprinkler system. We can extinguish the fire immediately by properly actuating the fire sprinkler system which prevents fire-spreading and thus protect the properties. The proposed smoke detector system can serve this purpose with a low cost signal processing unit in an efficient and selective way. Thus, the operational reliability of this system is improved with a great extent. In future, it can enable us to realize a real time distance measurement system for a smoke detector integrated with a servomotor operated transmitter.

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