# Ultrasonic Array Sensors for Monitoring of Human Fall Detection


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***Abstract*— A way to reduce the falling risk in the area where closed-circuit television (CCTV) is not available has been studied systematically using ultrasonic sensors for detection. The ultrasonic sensors, behaving a receiver and a transmitter, connect to Arduino microcontroller in order to send the signal via WiFi to computer. The sensors are positioned to array on top and wall of room. Then, the threshold signal is analyzed to find the action such as stand, sit and fall by comparison between top and side signal. The various side signals can indicate the failure. In addition, the signal processing can achieve the temperature around the simple leading to classify an object or a human. The accuracy to indicate the fall is 92 percentages.**



**Keywords— fall detection, ultrasonic sensor, wireless**


## I. INTRODUCTION

Most of the accidents in the elderly are related to falling. The World Health Organization (WHO) [1] estimates that the frequency of falling in the age of 65 years is 28-35% which is increasing to be 32-42% in the age of over 70 years. The more the fall frequency of the elderly occurs, the greater cost of medical treatment in each country is required. Moreover the fall in the elderly is the leading cause of death and serious injury if they are not rescued in time. According to this reason, a fall detection system is introduced to detect and alarm when the falling occurs in order to prevent risks caused by a fall [2]. For example if the fall detection system can detect and send an alarm to the rescuer in time, the risk of serious injury and complication diseases will be reduced especially for the elderly who live alone.

The fall detection system is an assistive device. The objective of using the fall detection system is to detect a fall and send an alarm to the monitoring people in order to reduce risks of injury caused by a fall. The fall detection systems are divided into three groups [3] which are the wearable device group [4], the ambience sensor group [5] and the camera (vision) group [6]. Mustapha et al. [4] proposes the obstacle detection system (ODS) by using the suitability of multiple sensors which are infrared (IR) and ultrasonic (US). However the limitation of this method is that it requires the button pressing by people. According to this reason this method cannot be used in the case that the victim loses consciousness before pressing the button. Yun et al. [5] proposes the automatic fall detection system using voice recognition (Fade). However the performance of this method relates to the device position such as the acoustic and vibrations sensor. According to this reason, this method dose not detect victims when they stay outside the monitoring area. Rougier, C. and Meunier, J. [6] proposes a method to extract features by using the movement of the head in 3D and compared using a single camera. However using the camera for tracking the human movement is not suitable for using in a private room such a bathroom, a bed room and so on. To solve this problem, the ultrasonic sensor [7] is introduced to replace the monitoring by using the camera. This method uses the information sent by the ultrasonic sensor. However this method cannot classify the fall gesture and the position of the fall.

This paper proposed the ultrasonic array sensor for monitoring the human fall detection. The array of ultrasonic sensor is used for detecting the human fall. Moreover, this method can classify fall gesture and position of the fall by using the changed distances which are measured by each ultrasonic sensor. This paper uses two arrays of ultrasonic sensor located at the top and side of the room to detect the human fall and the position of the fall. Two temperature sensors are used for error checking in the anti-crash system.

## II. PROPOSED SYSTEM OVERVIEW

### *A. Analysis of body postures*

The gesture of the human body is generally divided into five categories which are standing, sitting, lying, running and jumping, as shown in Fig. 1. This paper uses the data given by the sensors to analyze these gestures

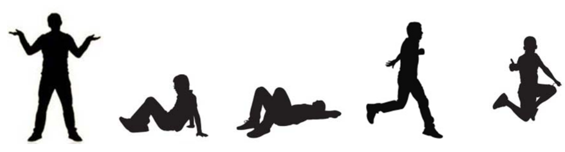


Fig 1. Human body postures.


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The causes of falls are the internal and external environmental impact such as slope ground, slippery ground, ground depression, ground level, being struck by an object and so on. The patients get acute disease or subacute disease impact such as faintness, stroke, and epilepsy, sudden de-force, loss of consciousness that affect the loss of body control, falls and so on [8]. The fall is generally varied within about 500 ms [8]. Healthy people are able to stand up by themselves. However it is difficult for the elderly patients to stand up by themselves. This is because their response and muscle strength decrease due to their age and illness. According to this reason, the elderly falling leads to injuries. The human fall postures normally consist of the forward fall, the backward fall, and the sideways fall and the backward fall as shown in Fig.2. The different fall postures damage different body parts. The elderly and patients often tend to fall forward or backward in a sitting position which damages the legs, the knees and the spine. The falling in side way position, which is the easiest to be found and causes the most damage, causes of the bone fracture and the complication of other diseases such as the systemic inflammatory response syndrome.

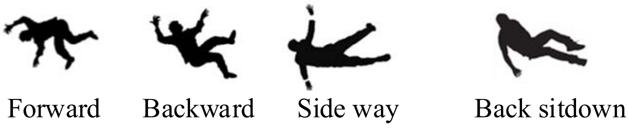


Fig 2. Human fall postures

### B. *Ultrasonic Sensor*

In general, the ultrasonic sensors often use the approximately frequencies as 40 kHz with an 8 pulses signal waveform. The sensor radiates a pulse signal, Tx, to the object and then receives the reflected signal, Rx, back to the sensor. The distance is measured by calculating the time used between the reflector targets and the sensor [3]. Figure 3 shows the measurement technique for the ultrasonic sensors.

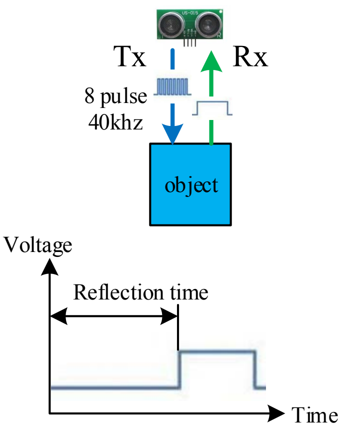


Fig 3. Distance measurement using ultrasonic sensor

The reflective sound is provided under the condition that that the dimension of the reflective surface is greater than the sound wavelength [10]. Figure 4 shows the sensitivity of the sound which depends on the pressure and temperature of the gas that the wave travels through. In ultrasonic application, the sensitivity of the sound is affected by the environment such as the pressure and the temperature. For example the sensitivity of the sound will be increased by 1% when temperature is increased to be 10° F (6°C).

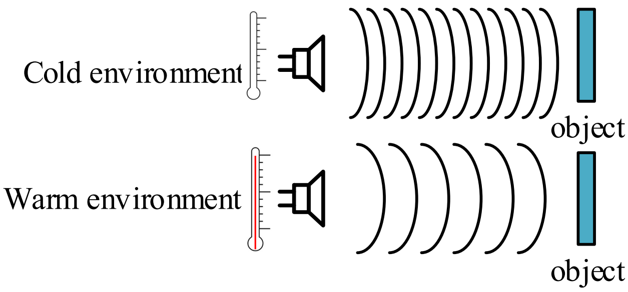


Fig 4. Temperature Effect.

A typical ultrasonic distance measurement system. The time between the transmitted sound and the received sound, t, is used to measure the distance, d:

The distance (d) [11] is calculated by Eq. (1) and Eq. (2)

$$d = \frac{C_{AIR} \times t}{2} \quad (1)$$

$$C_{AIR} = 20.0457\sqrt{273.15 + t} \;\; m/s \quad (2)$$

where CAIR is the velocity of sound.

t = Tx to Rx Time

This paper set the reference temperature at 25°C which provides the velocity of sound, CAIR = 346.13 m/s in order to check the system error. This is because the distance between sensor and object error is caused by temperature error. The distance error is approximately 0.18% when the temperate is chanced at 1°

### C. *Wifi Module*

The system is required to be setup on the ceiling and side walls using the WiFi ESP8266-07 which is a small module. This module uses less power and supports a wide variety of clients, Access Point and Client+AP ESP8266. It is connected by the Serial (UART 3.3V) and it works with a microcontroller.


Fig 5. ESP8266-07 wifi serial transceiver module.

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### D. Microcontroller

Microcontroller is an important tool in the system because it can control Sensor and Wi-Fi module. Thus the Arduino microcontroller is selected as key components in the transmitter and receiver system.

This paper uses Arduino Mega 2560 (AT mega2560) as the microcontroller because it has sufficient input pins to receive information given from all ultrasonic sensors.

### F. Fall detection system

The proposed system is divided into two main sections. The section is the hardware which is used for store and process the information given by the sensors. Another section is software section which is used to decide a state of falling and monitoring.

The proposed hardware consists of the ultrasonic sensor array. The information given by these sensors are used for measure distance between object and ground Figure 6 shows a block diagram of a monitoring system fall. The proposed method is tested in the room model size 30 x 30 cm which consists of 16 Tx, Rx ultrasonic sensors in each top and side of the room as shown in Fig.7. The sizes of human model are 20.32 cm. tall and 2.54 cm wide. The angle of ultrasonic transmission is changed by changing distance [10]. Figure 6 shows the block diagram of a monitoring system fall.

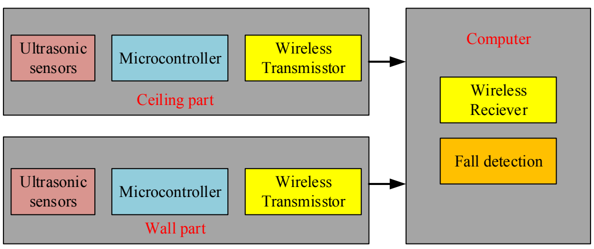



Fig 6. Fall detection system.

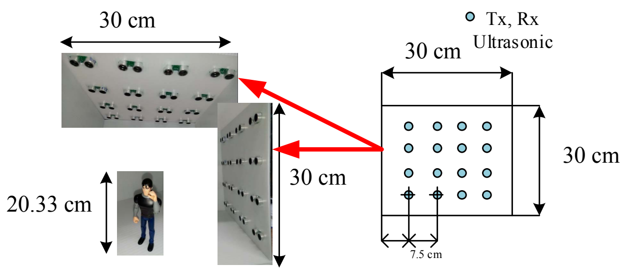



Fig 7. Ultrasonic models entering on the top and sides.

The proposed software section is divided into 2 parts. The first part is the Arduino programming for calculating the distance between the human and the ground, and the noise attenuation from the sensors. The other part is the falling decision part given by both the top and side array of ultrasonic sensors. The fall state is decided by measuring the changed distance from the ultrasonic sensors.

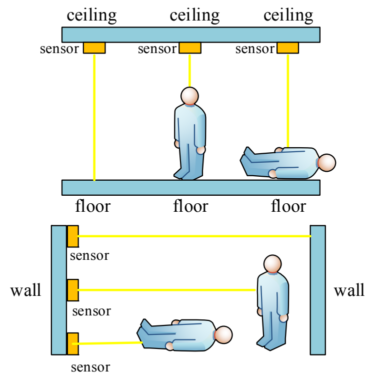



Fig 8. Fall Recognition.

## III. RESULTS AND DISSCUSIONS

This paper uses the ultrasonic information given by the ultrasonic sensors from the top and side of the room model to detect human fall. The gesture of the human is classified to the setting, the standing and the falling state by using the information from all ultrasonic sensors from both top and side in the room model. All information given by the ultrasonic sensors are collected in an array form. The changed distances which are measured from both arrays of the ultrasonic sensors in top and side room model are used for detecting the human gesture and the human position. Figure 9 shows the example of appearances which are the sitting, the standing and the falling state from both top and side view. The experimental results of both top and side view are shown in Fig. 10. The distance calculated by the time traveling of sound wave measured by ultrasonic sensors to detect the object as shown in Eq. (1). However the velocity of sound (CAIR) depends on the room temperature as shown in Eq. (2) which affects the distance calculated by Eq. (1). Hence, this paper use the distance calculated at 25°C as the reference in anti-crash system in order to reduce the errors. Moreover, the information given by the ultrasonic sensors consist of noise caused distance error. According to this reason, this paper reduces noise by digital filter method. The accuracy of the proposed method is 92%.


Fig 9. Examples appearance

Ultrasonic Sensor Array

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 |
| 2 | 0 | 16.5 | 16.5 | 0 |
| 3 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 |

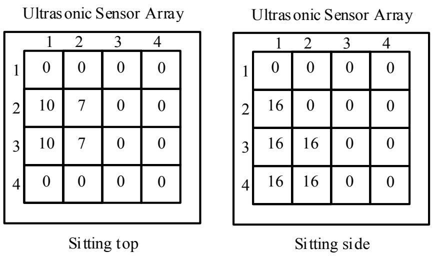
Standing top

Ultrasonic Sensor Array

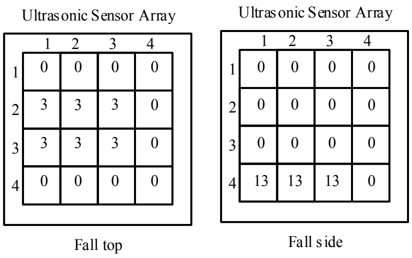
| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 |
| 2 | 0 | 18 | 18 | 0 |
| 3 | 0 | 18 | 18 | 0 |
| 4 | 0 | 18 | 18 | 0 |

Standing side

(a)




(b)




(c)

Fig 10. An example of the experimental results from the sensors on both sides of (a) stand (b) the sitting (c) falling.

## IV. CONCOUTION

The ultrasonic array sensor for monitoring the human fall detection is proposed. The proposed method is tested on the room model, size 30 x 30 cm. The ultrasonic sensors are used for detecting the gesture of the human model. Each array of the ultrasonic sensors consists of 16Tx, Rx ultrasonic sensors. Two arrays of the ultrasonic sensors are at the top and the side of the room model. The different gestures and positions are detected by the changed distances which are measured by the information received from the ultrasonic sensors. The experimental result is that the accuracy of the proposed system is 92%.

## V. FUTURE WORK

The research in the future will focus on the efficiency improvement on fall detection. However using only the ultrasonic sensor provides not enough information. The other kinds of sensors, for example vibrations and sound detection, should be considered to use in order to create the smarter and more effective fall detection.

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