Multi sensor system for automatic fall detection

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***Abstract*—To reduce elderly falling risk in the area where video surveillance system is unavailable due to privacy reason and so on, we need a monitor system which does no recognize what they are doing. This paper presents an elderly-falling detection system using ultrasonic sensors. The ultrasonic technology-based multi sensors are couple of receiver and transmitter together, which are connected to Arduino microcontroller in order to send the elderly person's fall related signal using WiFi to the processing unit. The sensors are positioned as an array on the roof and wall in the room. The signal is analyzed to recognize human by sensing distance, and detect the action such as standing, sitting, and falling by pattern matching with the standard templates of top and side signal. In experiments, the proposed system can recognize accuracy of falling detection is 93% approximately.**

I. Introduction

In 2015, world population of 7.2 billion is projected to increase over 1 billion within 12 years and reach 9.6 billion in 2050 [1]. The World Health Organization (WHO) [2] predicted that next 30 years the population of the elderly will increase to 11.1% -18.6%. Therefore, many research topic is are currently to develop surveillance system and care for the elderly. Most of the accidents in the elderly are related to falling. WHO [3] 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 [4]. 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 a signal to alarm the monitoring people in order to reduce risks of injury caused by a fall. The fall detection systems are divided into three groups [4] which are the wearable device group [5], the ambience sensor group [8] and the camera (vision) group [6]. Mustapha et al. [7] 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 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. [8] 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 [9] 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. In [9], the problem of detecting falling occur because using the ultrasonic sensor for a single point which can detect that fall. However the problem cannot be isolated gesture, standing, sitting and falling or changing the position, such as standing for a sitting from the sitting of a falling. The authors propose a method for fall detection. This method use two arrays of ultrasonic sensor to detect human fall [10]. First array is located at top of the room model while another one is the located at side of the room model as shown in Figure 1. This method can detect the position of human fall by different pulse level measured by each ultrasonic sensor. The different distances calculated these pluses are used for human fall detection and gesture classification.

II. PROPOSED SYSTEM OVERVIEW

A. Human gesture analysis

The gesture of human body is generally divided into five categories which are standing, sitting, lying, running and jumping, as shown in Figure 2. This paper uses the data received from the sensors to indicate these gestures.

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

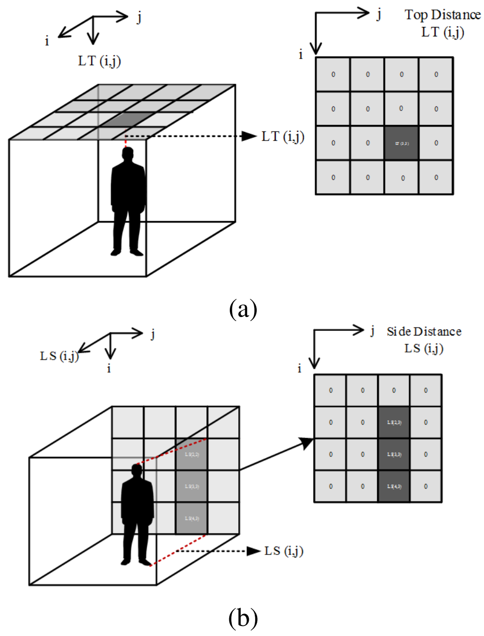

Fig. 1. The example model in propose method.

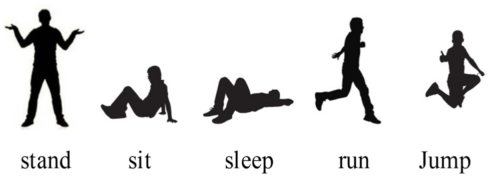

Fig. 2. Human body gestures.

of consciousness that affect the loss of body control, falls and so on [11]. The fall is generally varied within about 500 ms [11].

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 Figure 3. 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.

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

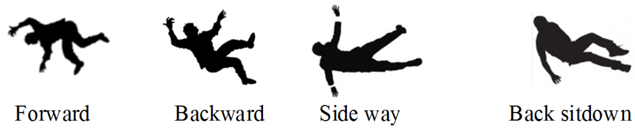

Fig. 3. Human fall postures.

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 [12]. Figure 4 shows the measurement technique for the ultrasonic sensors.

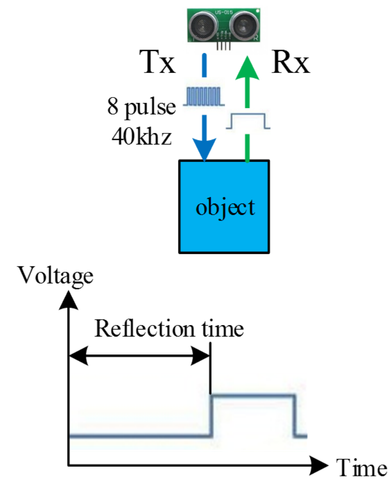

Fig. 4. Distance measurement is using ultrasonic sensor.

C. WiFi Module

The system is required to be set up 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.

D. Microcontroller

Microcontroller is an important tool in the system because it can control Sensor and WiFi 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.

E. Fall detection system

The proposed system is divided into two main sections. The first section is the hardware which is used for storing and processing the information given by the sensors. The other section is the software section which is used to decide the state of falling and monitoring.

The proposed hardware consists of the ultrasonic sensor array. The information given by these sensors are used for measuring the distance between the object and the ground. Figure 5 shows the flowchart of the fall monitoring system. The proposed method is tested in the room model, size 30×30 cm, which consists of 16 Tx, and Rx ultra-sonic sensors on the top and each side of the room as shown in Figure 6. The size of human model is 20.33 cm. tall and 2.54 cm wide. The angle of the ultrasonic transmission is changed by changing the distance [13].

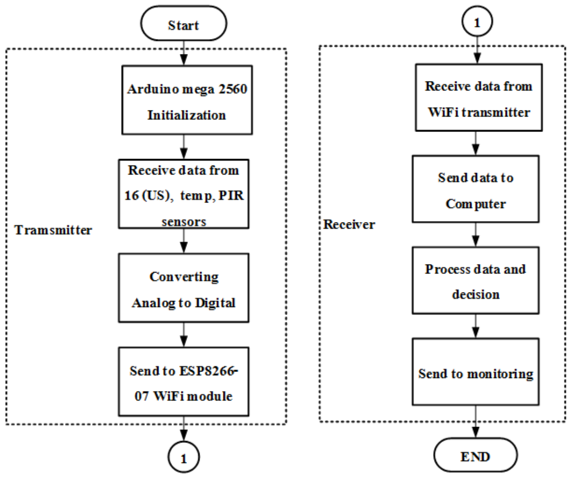

Fig. 5. Flowchart of the fall monitoring system.

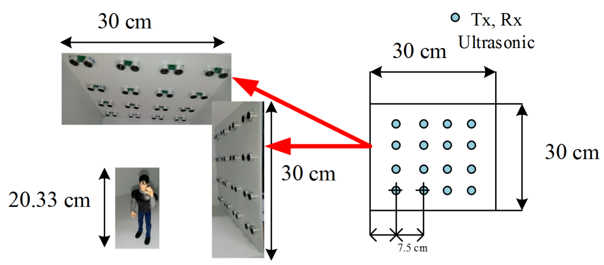

Fig. 6. Ultrasonic models entering on the top and sides.

The proposed system has been tested successfully for model environment to determine its functionality and limitations towards the sensitivity of detection for certain distance. The correlation between the detection object and angle would give enough information to calculate the distance using the triangulation method as show in Figure 7.

The value of L (width) can be determined by tangent equation below:

$$L = 30\ tan\ \theta^{\circ}$$

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

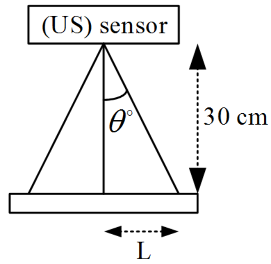

Fig. 7. Measurement distances using triangulation method.

sensors. The fall state is decided by measuring the changed distance from the ultrasonic sensors.

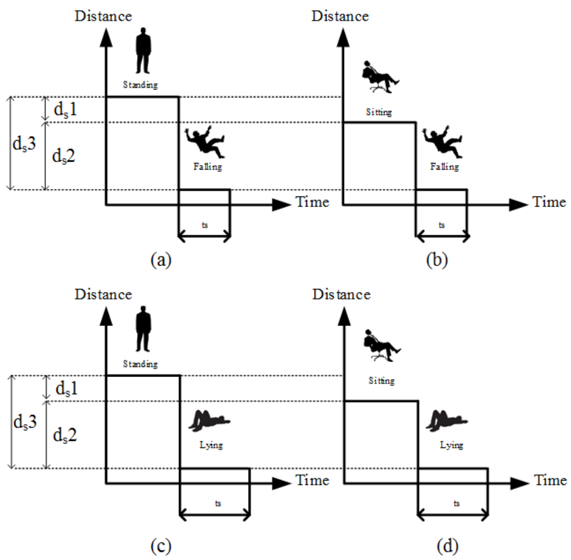

Fig. 8. Fall Recognition.

Figure 8 show a classification to 4 situations in order to separate an appearance for stand, sitting, lying and fall by observing from both parameter (distance and duration) [14]. The appearance of stand and sitting into fall is shown as Figure 8 (a) and (b) with duration (ts) less than 0.75 ms. On the other hand, the action of the stand and sitting into lying with the duration above 0.75 ms is displayed in Figure 8 (c) and (d).

III. RESULTS AND DISCUSSIONS

This paper uses the ultra-sonic information given by the ultrasonic sensors from the top and side of the room to detect human falls. The gesture of the human is classified as setting, standing and falling state by using the information from all ultrasonic sensors on the top and the side of the room. All information given by the ultra-sonic sensors are collected in an array form. The changed distances which are measured from both arrays of the ultra-sonic sensors on the top and the side of the 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 Figure 10. Hence this paper uses the distance calculated at 25°C as the reference temperature in the anti-crash system in order to reduce the errors. Moreover, the information given by the ultrasonic sensors consist of noise that causes distance errors. According to this reason, this paper reduces noise by using the digital filter method. The accuracy of the proposed method is 93% as shown in Table I.

TABLE I
EXPERIMENTAL RESULTS

	Array sensor		Accuracy
	Top	Side	
Standing	96%	94%	95%
Sitting	89%	92%	90.5%
Fall	94%	93%	93.5%
Average accuracy			93%

Fig. 9. Examples appearance.

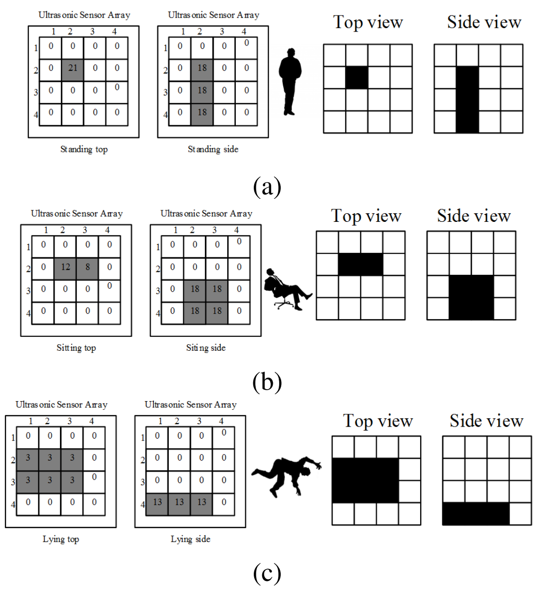

Fig. 10. An example of the experimental results from the sensors on both sides of (a) standing (b) sitting (c) falling.

IV. CONCLUSIONS

The ultrasonic array sensor for monitoring the human fall detection is proposed. The proposed method is tested on the room model, size 30 × 30 cm. The ultrasonic sensors are used for detecting the gesture of the human model. Each array of the ultrasonic sensors consists of 16 Tx, 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 93%.

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 to create the smarter and more effective fall detection.

REFERENCES

[1] United Nations, Department of Economic and Social Affairs, Population Division (2013). World Population Prospects: The 2012 Revision, Highlights and Advance Tables. Working Paper No. ESA/P/WP.228.

[2] United Nations, Department of Economic and Social Affairs, Population Division (2013). World Population Ageing 2013. ST/ESA/SER.A/348.

[3] World Health Organization, "Global report on falls prevention in older age," (http://www.who.int/ageing/publications/Falls_prevention7March.pdf]).

[4] Raul Igual , Carlos Medrano, Inmaculada Plaza, "Challenges, issues and trends in fall detection systems," *BioMedical Engineering OnLine*, 2013, 12:66.

[5] M. Mubashir, L. Shao, L. Seed, "A survey on fall detection: Principles and approaches," Neurocomputing 2012, 100:144-152. OpenURL

[6] C. Rougier and J. Meunier., 2010, "3D Head Trajectory using a Single Camera," *International Journal of Future Generation Communication and Networking*, Vol. 3, No. 4, pp. 43-54.

[7] B. Mustapha, A. Zayegh, and R.K. Begg, "Multiple Sensors Based Obstacle Detection System," *24th International Conference on Intelligent and Advanced Systems (ICIAS2012)*, Seoul, Korea, pp. 562-566, 20 - 23 May, 2012.

[8] Yun L., K. Mun H. and Mihail P., 2012, "A Microphone Array System for Automatic Fall Detection," *IEEE Transactions on Biomedical Engineering*, Vol. 59, No. 5, pp. 1291-1301.

[9] Y. Huang and K. Newman, "Improve Quality of Care with Remote Activity and Fall Detection Using Ultrasonic Sensors," *34th Annual International Conference of the IEEE EMBS*, San Diego, California USA, pp. 5854-5857,28 Aug - 1 Sep, 2012.

[10] C.Nadee and K. Chamnongthai, "Ultrasonic Array Sensors for Monitoring of Human Fall Detection," 12th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 2015.

[11] Y.-P. Kuo, H.-H. Hsieh , N.-S. Pai and C.-L. Kuo, "The application of CMAC-based fall detection in Omni-directional mobile robot," Advanced Robotics and Intelligent Systems (ARIS) international Conference on, pp. 64 - 69, Tainan, Taiwan, 2013.

[12] M. Ishihara, M. Shiina and S. Suzuki, "Evaluation of Method of Measuring Distance Between Object and Walls Using Ultrasonic Sensors," Journal of Asian Electric Vehicles, vol. 7, No. 1, pp. 1207-1211,June 2009.

[13] Freescale Semiconductor, "Ultrasonic Distance Measurer Implemented with the MC9RS08KA2," AN3481datasheet, 2008, [Revised Feb. 2015].

[14] B.S. Lin, J.S. Su, H. Chen and Ching Yuh Jan, "A Fall Detection System Based on Human Body Silhouette," *9th International Conference on Intelligent Information Hiding and Multimedia Signal Processing*, pp.49 - 52, Oct 2013.