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Improve Quality of Care with Remote Activity and Fall Detection Using Ultrasonic Sensors

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Abstract- In this paper a fall detection system is presented that automatically detects the fall of a person and their location using an array of ultrasonic wave transducers connected to a field-programmable gate array (FPGA) processor. Experimental results are provided on a prototype deployment installed at an assisted living community. The system can provide a cost-effective and intelligent method to help caregivers detect a fall quickly so that patients are treated in a timely manner. In addition to room monitoring and local alert functions, the system incorporates a personal computer and wireless connection to enable remote monitoring of patient's activity and health status.

I. Introduction

Falls are the leading cause of external injury the elderly. In the US there are annually 1,800 falls directly resulting in death [1] and approximately 9,500 deaths are associated with falls each year [2]. The frequency of falls increases once individuals have the first occurrence. This leads to a fear of falling in many individuals that increases self-restriction of activities [3]. In order to provide increased security and comfort in the elderly population, automated systems with timely reporting of fall events are critical to enable healthy aging in place as well as limit the damage caused by injuries during falls [4].

An intelligent yet cost-effective system that can detect a fall in areas where they would not necessarily be wearing clothing or desire to be monitored by a camera is the focus for the evaluation of this system. The setting for this test case is a bathroom in an assisted living community. The bathroom and the resident rooms are identified as locations where there is a high incidence of falls [5]. Identification of the specific individual can be tied to the residential apartment for clinical use and analysis. Currently, there are two popular methods are used to detect a fall: machine vision and accelerometer.

Vision tracking uses cameras at various locations and employ either manual or automated image processing [6][7]. The disadvantage of a vision based system is the cost of the specialized cameras as well as the need to add privacy filters in locations like the bathroom and bedroom. Deployment can also be complex and costly since several devices are needed to monitor the entire house.

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Another popular method for fall detection uses accelerometer measurements. A fall can be defined as a change in body orientation from upright to lying that occurs immediately after a large negative acceleration [8]. The main limitation of accelerometers is the inability to perform localization and tracking of a person. Accelerometers detect body orientation but do not have the ability to collect high-level, context aware activity recognition based intelligence. Another drawback for the detection of falls in a bathroom is the need to wear the fall monitoring device. Many elderly individuals at risk of falls do not remember to wear the devices so their falls go undetected. In an assisted living community, they might have to drag themselves to the pull cord or alerting device to request help.

In this paper, a novel system is proposed using ultrasonic waves to detect a fall. The initial pilot deployment is described and initial measurements from a single subject are reported. Installation is performed in the ceiling of the room so wearable components are not required and privacy is maintained without additional signal processing. Preliminary measurements of the sensing mode are described in detail by Shah, et.al, [9]. Sensing is based on the range finder property of the ultrasonic wave which enables determination of the latitude distribution of a certain area. A Field Programmable Gate Array (FPGA) based processor collects the sensor data and a mobile computer implements an inexpensive and non-invasive monitoring system. The Altera DE2 used in this prototype can be purchased for under $500 and the DE0 board can be substituted for under $200. The computer can be purchased for $250, sensors for $28.00 each unit, and the remainder of the system components are an A/D converter and Ethernet cables for the wiring. Total cost for deployment of 8 monitoring devices in a bathroom, excluding labor, is possible for approximately $750. The components of this system are shown in fig. 1.

II. System Architecture

The system is divided into two main components: the hardware, which is responsible for collection and processing sensor data, and the software, which is responsible for sending out alerts and notifications.

The hardware is an array of ultrasonic sensors used to measure distance between the sensor and an object within the shape of the ultrasonic wave up to maximum distance of 254 inches. The beam width changes with this distance as demonstrated previously [9]. Sensors are installed on a flat surface so the ping has a known trajectory without interference in the path. Only one transmitter is active at a time to prevent overlapping of signals so that reflections can be isolated. When an object is detected in the field of the active sensor it can locate the distance within one inch of resolution. This approach enables a plot of the latitude distribution for the plane facing the sensor surface.

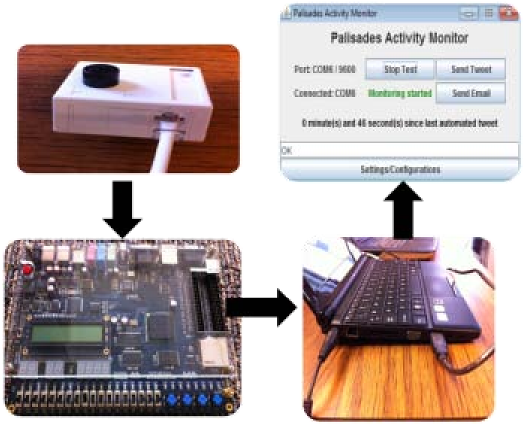

Figure 1: Fall Monitoring Components

Abnormal activity is detected by comparison with the default scenario in the room as well as the actions of the previous set of measurements. The dimensions of the room constrain the speed at which each position is checked, however, sensors can be triggered at a rate of 50ms so for a deployment in a 10 foot by 10 foot room with ceiling height of 10 feet, the density of sensors would be 4 and the maximum amount of time between polling of an individual sensor would be 50 ms. As shown in fig. 2, the default value for a room is on the left assuming furniture is not present. Furniture is mapped as part of the initialization process and is included as a background measurement. If the furniture is moved during system operation, the software can detect this background change but it is difficult in the current version of the deployment to differentiate between individuals and objects. Methods to improve this sensitivity are discussed in the results section of the paper.

When a person walks under the beam, the return reading is compared to the default and assumptions are made as to the pose of the individual. The range of expected height values for walking are calibrated to the resident during installation. Additional determination of the seated height is performed during installation. Falls are detected by a rapid transition from the standing or seated position to the ground.

The software shown in the upper right of fig. 1, transmits the sensor responses returned by the FPGA to a netbook using an R232 cable. A Java program continuously reads the sensor responses from the serial port and sends out notifications every 3 minutes based on the sensor response status ("OK" or "EMR"). If an emergency (EMR) is detected, the EMR signal is sent out immediately to the email of individuals registered in the setup. Testing of these alerts can also be triggered manually to ensure the system is communicating.

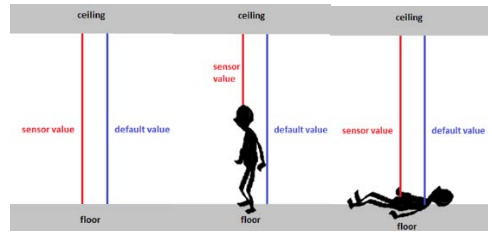

Figure 2: Pose recognition

III. Fall Detection Algorithm

The algorithm includes two parts: initialization and decision-making. The initialization procedure aims to establish an idle condition of the measured plane. The flow chart of the operation of this algorithm is provided in fig. 3. An idle condition is assumed if a sensor has a constant reading for 60 seconds. There are four functions used for the initialization procedure. The input function reads the ultrasonic sensors measured result. The save function places the value from the sensor into the base value variable. A five second delay between sensor readings is implemented with the delay function. This is a rather crude averaging filter similar to mechanical switch debouncing to reduce the noise in the input. The compare function is used after a second input reading is taken to see if the initial value and the final value match so that false readings are avoided.

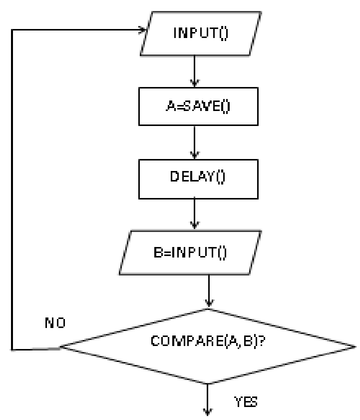

Figure 3: Initialization Procedure

After the initialization routine is performed to gain a baseline measurement of the room, a second algorithm is used for regular monitoring of the sensor values as shown in fig. 4. The decision-making procedure is able to detect the sign of a fall. This algorithm compares the sensor's present result with the base value from the initialization routine with two time parameters. The first time parameter counts the time elapsed after an abnormal activity. A second time parameter is used to eliminate the pseudo-sign of fall. There is a looping function used for the decision-making procedure. The system sequentially reads each sensor and uses a compare function to detect the sign of fall. The compare function checks whether the present reading from a sensor is consistent with the saved base reading. The system will recheck the same sensor to eliminate the pseudo-sign of fall after a five second delay in case of an inconsistent result returned by the compare function. Further, the system will issue an emergency signal if a different reading at a sensor lasts for more than one minute.

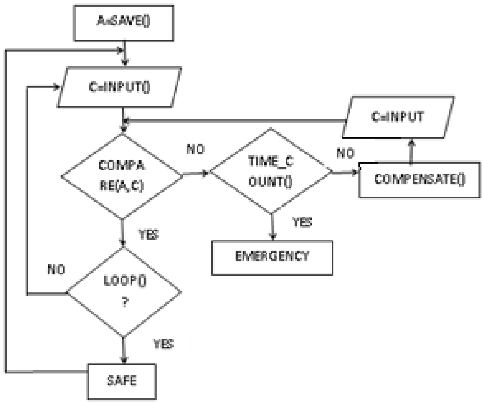

Figure 4: Decision-Making Procedure

IV. Eldercare Monitoring Deployment

After characterization of the system in the controlled environment of a lab, an IRB-approved informed consent study was initiated at the Palisades assisted living community in Colorado Springs. A subject in the assisted care wing was recruited and the system was installed in the bathroom. For the initial trial, only 8 ultrasonic sensors are used and the complete installation limited to the bathroom – an area in which elderly people commonly fall. Three sensors are placed in the shower and the five remaining sensors are placed around the rest of the bathroom to provide sufficient fall coverage. The installation is shown in the images of fig 5.

Installation of the system required a significant amount of time and testing but this was expected for the pilot version. Sensors are mounted on the ceiling as shown in 5(a) and the cables are run to the FPGA and netbook which is placed on the shelf as shown in 5(b). Proper placement and leveling of the sensors as well as calibration for the user was the majority of the time commitment.

Several site visits were also required during the first three months for the fine tuning of the system to allow remote access and tweak the fall detection algorithms to avoid false positives. Additionally, a user manual was created to provide training to the staff on the use of the system. A screen shot of the user interface is shown in fig. 6. This interaction is still in progress but the system operated for several weeks at a time for the remainder of the six month trial. Late night IT maintenance caused some problems with stability and required resetting of the Twitter interface remotely. There was also the need for reinstallation of one of the sensors on the ceiling of the bathroom since it became unattached due to the humidity in the environment.

(a) Sensor Installation

(b) Netbook Placement

Figure 5: Bathroom Installation at Palisades

Figure 6: Health Monitor User Interface

Currently, the system sends out automated notifications using both Twitter and email, allowing alerts through different channels of communication, quickly, and to multiple recipients. Data logging is not currently performed so the height and specific location of the falls are not reported. There are plans are to incorporate this into the data transfer but the first step is to stabilize the system in the field and ensure the Java and Twitter interfaces are capable of reporting activity.

The system updates the status of the subject to a specified Twitter account which is available to all caregivers. This data is composed of OK pings every five minutes. When the EMR occurs, an email is generated immediately as shown in fig. 7.

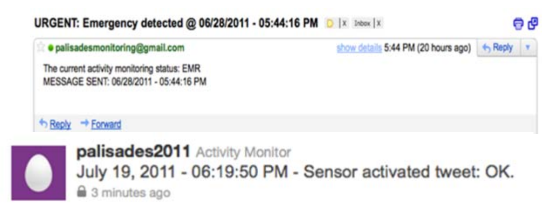

Figure 7: Twitter and Email Sample of the System

Verification of the detection of the fall is collected by direct phone contact with the Palisades to determine if the system is operating properly or if it is sending a false alarm. Over the course of the trial, there was a weekend where the system sent out several alarms. Three alarms were sent out over the course of an evening and then the system was reset using the logmein tool. Emergency messages continued that weekend around noon the next day and also late in the evening in the month of August. It was discovered there was a glitch in the software interface between the Java code and the twitter account that was causing these false alarms when the internet connection is lost. Modifications were made to account for the evening IT maintenance so that signals could be buffered and the system would reset after the maintenance was performed. In December there was another long interruption to the system over a weekend and, an actual fall was missed. After the event in December, the system was reset and the monitoring was in operation through January. No falls were detected during this time frame and the system remained operational.

V. CONCLUSION

After a six month trial in the Palisades Assisted Living community, the system demonstrated the capability to detect falls. This length of time was required for the first deployment to fine tune the software and remove the occurrence of false positives. In the future, deployments in additional rooms are possible and should require less time for operational stability based on the knowledge gained in this pilot trial.

The system is capable of monitoring and recording the activity of a person using ultrasonic range finding. The system is able to collect the data of a person's daily activity and develop his (or her) activity pattern using a sophisticated algorithm and the signal processing capability provided by an FPGA processor. Daily activity patterns can be stored in future versions of this system to help physicians and caregivers determine activities that lead to a fall and detect the fall in a timely manner to reduce risk of further injury.

There are additional refinements required before the system is ready to expand into additional rooms. The ability to store data is beneficial so that activity patterns can be detected and locations of falls can be identified. The implementation of the sensors on the ceiling could be improved by incorporating a wireless interface to eliminate the use of the Ethernet cables currently connecting the sensors to the FPGA. Additionally, the portability of the remote monitoring software could be enhanced by creating an interactive web based interface. The new interface would free the users from their ordinary workspaces and give more flexibility on choice of terminal devices. Users can download the stored data from the system directly from the web.

Another issue that was not expected or factored into the pilot deployment was the use of a walker by the resident. Readings of the height of the walker made it difficult to distinguish where the person was in relation to this device since it was moving in the space. For example, if the person fell near the walker, would the height change be detected with this in the field. In addition to the sensors placed on the ceiling, sensors could be placed on the walls so that measurements can be made in the horizontal and vertical plane to isolate a person from a walker. Other single-point sensing modes could be employed that do not violate privacy of the resident. A combination temperature and humidity sensor could distinguish the heat signature of a person and from a device.

Ultrasonic technology offers promising potential in the field of activity monitoring. This project hopes to provide additional insight into the use of ultrasonic activity monitors and establish a solid foundation on which future developments can be made. With further improvements and additional research, ultrasonic activity monitoring systems have the potential to work both effectively and practically in reducing the number of hospitalizations and deaths caused by elderly falls. In time, such systems should be capable of being not only reliable and accurate in detecting falls, but also affordable and user friendly.

VI. ACKNOWLEDGEMENT

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