

# An Alerting Wireless Sensor System for Long Period of Immobilized Elderly in a Residential Room

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**Abstract**— This paper presents a low cost wireless sensor network system which is developed to be an alerting system for relatives or caregivers when the elder is immobile for a long period. The alerting signal is sent via the Internet link and a mobile phone. Remote transducers capture input signal from the mobility subject. If the target subject has immobilized behavior for long period, which is analyzed abnormal condition, the system will send the alerting messages to a selected mobile phone or Internet link. After detection of motionless elder from the set-point periods, the system immediately distributes messages via SMS on the mobile network and a server to warn a relative or a caregiver with the image option to send. The sensor modules have ease-of-installation with coverage area nearly 3 square meters, 80 % of detection level suitable for a small room and a bathroom.

**Index Terms**—Eldery Healthcare, Sensor network activated control, Automatic alerting system, Smart home awareness.

## I. INTRODUCTION

In busy schedule of working day, there is no one staying with elder at home resulting in their safety and health care. Being alone without caregiver, the high rate of accident might happen to senior citizens; nobody knows this or finds it when it is too late. Nowadays, advance technology has been adapted to help with daily life facilities including smart home, entertainment, security, and so forth. When elderly health care is combined with improvement of technology, concern about their safety seems to be relieved.

Any health care system can help with looking after or monitoring people, such as the distance measurement for ECG, blood pressure or heart beat monitor, and body temperature signals [1][2], etc. Wireless technique is another way to monitor overall behavior of people in a residential room or in the form of wearable sensor like wireless sensor on a hand wrist, or an ankle. However, these kinds of healthcare system or smart home are usually a complex system and are sold pricey. Some smart home system make the elder feel uncomfortable because of the monitoring cameras that disturb their privacy, especially in bathroom which is considered very dangerous with the slippery floor. This paper focuses on the outdoor and indoor environments [3] [4] as the empirical model for propagation prediction [5] and aims to the indoor wireless alerting system for a normal condition of elder in a small residential room such as

apartment or condominium.

The wireless sensor system can send report to a mobile phone or Internet link automatically. The big concern of this investigation is low cost of the device, ease of installation, and saving energy consumption. This paper is organized as follow. Section II briefly reviews about in-house behavior of the elderly and the mobilized body position. Section III explains about the architectures and some relevance information, and the experiments is mentioned in section IV. Lastly, Section V concludes this work and discussion.

## II. IN-HOUSE BEHAVIOR OF NORMAL ELDERLY

Taking care of senior family members or relatives is quite a serious issue nowadays and human behavior is sometime so complicate that mechanical invention cannot understand. However, these kinds of advance artificial healthcare system, packed with high price, can help with taking care of such people; the service system includes the sensor devices on a bed, the ECG monitoring system, movement detection inside rooms, and the in-house monitoring person at the service center. The surveillance camera for movement detection is another alternative for monitoring but this method disturbs privacy. This research provides in practical automatic detection system for an elderly who lives alone during a day time when other family members already leave home. To leave an elder alone in a house is a mortal danger. For that reasons, this system can purpose the good situation for the elder and family members with low cost system.

Wireless technology is very suitable for connecting and sending processed data at distance [8], the ISM band indoor propagation is used at 2.4GHz. The following list is the main selling points and alerting system requirements [9]:

- 1) Cost
- 2) Reliability
- 3) Safety
- 4) Ease-of-use
- 5) Convenience
- 6) Etc.

The cost is considered the most important selling point but reliability is big concern; Safety is a basic requirement; ease-of-use is one of attraction; and convenience makes an easier life style.

### A. Mobilized Body Position

During a day, almost humans do a lot of works and they have a regular body mobilization. At night, sleep positions change overnight from 3 to 45 times per night; on average 14.5 times per night. Around 13 different positions change

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Fig. 1. The example of sleep positions for human mobilization on bed

through the night for elderly, such as leg jerk, etc. immobilized period for elderly range up to 110 minutes [13]. The immobilization during day is shorter than at night.

As the example sleeping positions on Fig. 1. adapted from [13], it is the fundamental sleep positions such as starfish, free faller, etc.

### III. ARCHITECTURES

#### A. Location and Radiation

The sensors on the wireless modules are installed in fixed locations in the house. Normally, the locations to install the wireless devices are usually on middle of the rooms in line-of-sight for sensors on coverage beam and for that reason some of the wireless module location at non-line-of-sight to the concentrator. This work stresses how the detection can alert immediately to the relative in a distance from a house. Eventually, in a view point of 2-dimension the positions of a TRx can communicate in clarify data and can identify each other. In Fig. 2, on the left-hand,  $S$  is concentrator of system;  $I$  and  $E$  are the sensor nodes located in coverage area;  $R$  on radius range between  $0 < r < radius_{max}$  thus  $E$  is inbound on the edge of  $S$  when  $S$  is a member of  $R$  area, and  $O$  is outbound of  $S$ . The right-hand fig shows the e-zone that can gain more coverage area and shrink it by a transmission power [10]. On center shows the triangular line sides between  $SI$ ,  $SE$  and  $IE$  on the radius  $R$  for energy conservation distance in simple calculation of  $d_{IE}$  can communicate directly because  $d_{IE}^2 = d_{IS}^2 + d_{SE}^2 + 2 d_{IS} d_{SE} \cos \alpha$  if  $d_{IS}^2 + d_{SE}^2$  is less than or equal  $d_{IE}^2$ . Then " $I$ " node should send information directly to " $E$ " node for energy saving of all nodes inside coverage area but some situation as the triangular inequality if distance between " $I$ " to " $E$ " is larger or has a weak transmission power, a  $S$ -node has to handle as a pathway from " $I$ " to " $E$ ". The pathway  $\Delta l$  from a source node to a sink node has time-variance on distance as  $t = \Delta l/v$  between source and sink positions. A  $v$  is a velocity of propagation in multidimensionality. This consideration is on time-to-send for reduced collision frame. In real life, the installation location is not flat. The distances have to calculate on 3 dimensions;  $j$ ,  $k$  and  $i$  so that in practical installation and configuration of the system. The  $\alpha$  angle is not easy to be found because of the location and the direction of each node.

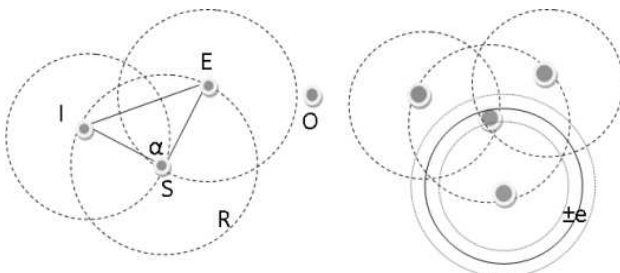


Fig. 2. Locations and coverage areas.

Locations depend on the transmitter powers, sensitivity of receivers, and obstructions. The obstructive components build a path loss to signal strength [6]. Typically, to separate the states of the operation mode are an idle state, transmit-state, receive-state, and sleep-state, adhesion exempt processing state of the controllers. The important dimension is time to interact between nodes. The timing for each node activates at  $t'$  and collision of data possibly happening, but normally an elder with others in the separated rooms can generate the message from two sources. Although next concern is energy power, longest path consumes more power to send information than shortest path. Distance and gradient between a Tx and a Rx on power law of distance

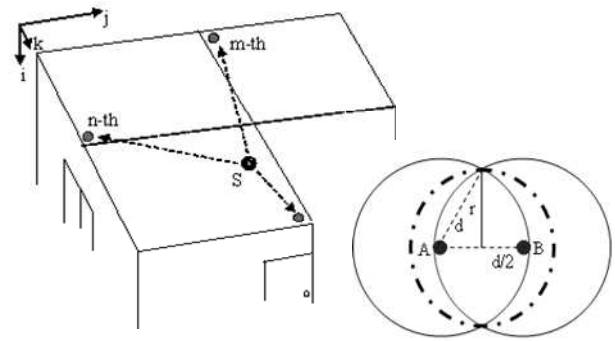


Fig. 3. Locations and coverage areas of the wireless nodes

depends on power of rational distance  $d$  and gradient  $n$  and path loss at 1 m on (1).

$$Power(dB) = n \log d^{10} (dB) + Path\_loss(dB) \quad (1)$$

Activation time is very fast when occupied at time  $t$  varies to  $t_n$  depends on arrival time from the detection point,  $v$  is speed of light on homogeneous medium. For example, the  $j$ ,  $k$ , and  $i$  are reference directions of the coordinates at any node.

This work has used frequency in range of the ISM band. The 2-dimension is easily calculated to explain and to adapt for finding a 3-dimension scheme. The radiation pattern depends on the antenna shape and a transmission power. The directional antenna can reduce energy to carry the data to a receiver. Most of wireless devices choose the microstrip antennas for smaller packaging in variety of shapes, and, normally, to build on the printed circuit board products in the several loop shapes. For a loop antenna has two directions of main lobes in opposite sides and the beams can enforce to other direction by a reflector, Fresnel zone and near field will higher than normal and that can reduce energy consumption from directional gain. From the fundamental concept of geometry, it can calculate radius " $r$ " of coverage area in Fig. 3. Thus assume all nodes have " $r$ " radius. From  $A$  to  $B$ , a center between  $A$  and  $B$  equal to  $d/2$  that is a center of a middle dash circle to guarantee the operated region of  $A$  to  $B$ , thus always not less than  $r = d_{AB}/2$  on weak energy and at strong energy point which  $r > d_{AB}/2$  and if the network has joined a new  $C$  node. The way of calculation repeats again same as  $A$  node and  $B$  node, additional a  $D$  node can connect to a  $C$  node but for a  $B$

node cannot reach then in active state if the length of " $r_{DB}$ " more than " $r_{DC}$ " that means  $r_{DB}=r + \Delta r$  or  $r + \Delta r > r_{DC} \geq r$  then a  $D$  node can communicate to a  $C$  node on concurrent of an  $A$  node to a  $B$  node in different transmission channels.

### B. Transducer Devices

The touching sensors are not comfortable to most of healthy persons in particular and also unaccepted for the patients, but they cannot discard. Distinctively several elderly dislike any touching devices or do not want carry it all the times because they might think that to it seems like they are in worst conditions as a patient. This is an appropriate reason to develop an alerting system for good-condition elderly, which can detect over a sleeping room, a living room, a bathroom, and so forth. Thus condition of immobilized behaviors of an elderly will be detected with installed indoor device. The system uses ultrasonic transducers to detect the moving pattern in approximate range of 3.5 meters from acoustic wave and a PIR to detect body infrared wave from an elder's movement with the Fresnel lens to extend the service range for more than 2 meters. Another one is a sound sensing module which is very suitable for snoring or teeth-grinding persons that can identify their living and install adjacent to a bed and a sofa.

The important thing is an emergency switch (Em) that is designed to activate when an elderly is pushing or pressing it. The Em should be installed nearby the walk path or kinds of a chair, a bed, and a toilet ware.

### C. Wireless Sensor Network Structure

A structure of the wireless sensor network consists of a mobile phone and a wired network to Internet. Both of them are connected to a wireless concentrator with the wireless nodes in a structure as Fig. 4. As the shown structure operating demonstration assumes that WP1 sending a message to WC1 as a concentrator which forward the message to MD1 and M1 through the Internet in both ways via a lease line of Internet and the mobile network. This structure for a WC1 has the two options, on one hand uses a microcontroller board with the 2 interfacing ports to M1 and MD1. The other hand uses a cheap personal computer with the same interfacing of the first structure that can add more the optional devices if an elderly want to capture on the redundant working state. Both structures can send the messages to a server via the Internet and a mobile phone. When a relative receives alerting message from a server or from the M1, he/she can browse information from anywhere immediately and response back to the elder's residential room.

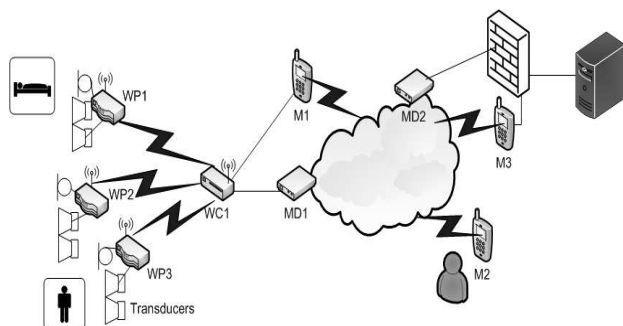


Fig. 4. An immobilized detecting structure of a monitoring system

Indoor wireless system is concern with energy consumption and backup power system. On Fig. 5., the system is separated into 2 diagrams. The first one is concentrator part consisted of a TRx, a mobile phone (M1), a modem (MD), an emergency switch (Em), and a backup battery. The second diagram consists of a TRx, a signal

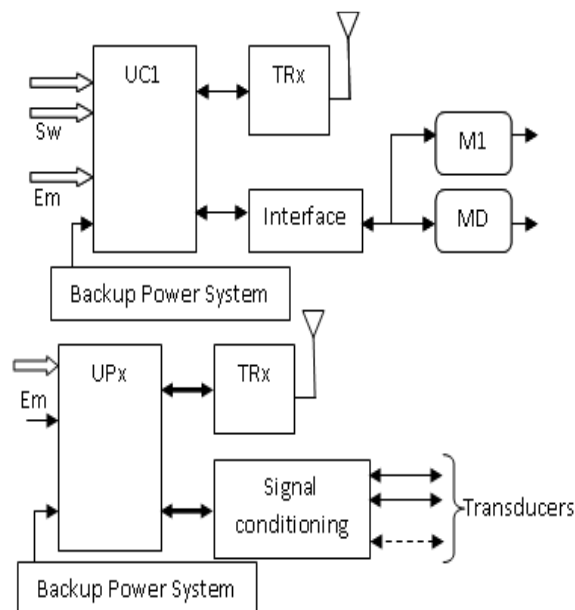


Fig. 5. Diagram of a concentrator and a wireless sensor node

conditioning circuits to get the input signals from the transducers. The UPx is a combination of a microcontroller with the timers, an EEPROM memory for storing telephone numbers, the transmitter levels, and the initial-connection codes.

## IV. IMPLEMENTATION AND EVALUATION U

### A. Locations and Transducers

There are two devices' installed positions in a room that proposed in this work, one on the top of corner and point out at the transducers to a bed in a small bedroom, the other is on the top of a table nearby the half of an elder's body. The author concerned about the reflected wave from the wall and the ground floor.

There are two types of the reflected wave: 1) built from concrete or tile, and 2) built from wood. The transducers use the thermopile array devices, the condenser microphones, and the ultrasonic transducers. A thermopile array TPA81 can detect infrared from the human temperature of the radiant heat of wavelength and measure among adjacent points simultaneously. The microphones are built up by the high gain OP-AMP detecting approximately 0.5-meter range and the small ultrasonic transducers are transmitted and received the pulses in nearly 3-meter range; this system is suitable for a small room.

### B. Radiation Power of Transceivers and Link

In the concept of radiation is concern with the air service area in Fresnel zone and guarantee the successful communication of carrier message to the receiver. The author proposed the selective power transmitter for 5 different gain up or down power gain steps in a set of  $p=\{X,H,M,L,S\}$ . Firstly assume, the transmitter sends a

medium power to a receiver, startup a counter and waits for acknowledge signal back for a signal strength level evaluation by ID and “M” (Medium power) message if a concentrator cannot response back to a sensor module in a period, the status is out-of-range, or far away more than “ $r + \Delta r$ ” that is unreachable. Then repeated the pervious process again by increasing the power gain more in a step by ID and “H” (High power) if a sender can get “H” from a receiver in acknowledge state, a sender stays at state of “H” gain. Another way, assume first time at the medium power the sender sends the ID and “M” to a receiver then a receiver can get the message and sends it back. The source has to decrease power for one step then a source sends ID and “L” (Low power) to a receiver in the second time. The system will repeat the process until a sender cannot receive a level message, then a sender has to increase more power for one step and stored status. Thus a status LED on, the message ID + “L” carries on a package at PAYLOAD in Fig. 6. that guarantee safety margin of connection as in (2). The process is automatically setup, that why this is an ease-of-install system. The TRW2.4G RF module has 4 levels of transmission power that used in this experiment; 0dBm, -5dBm, -10dBm, and -20dBm [15]. The important connection is a connected code that is adapted from the concept of AIS [12] as on Fig. 6. via the regions of complementarities of the paratope and epitope of idio type represented such as “10011  $\oplus$  01100” the result is “11111” or “10001  $\oplus$  01110” equals to “1111” that means both connection codes are accepted then information transferred to a sink node. If a paratope exclusive-or to an epitope as “11011  $\oplus$  01100” equals to “10111” the result can identified that means not a member node and discard received data that opposite of the antigen process.

$$Pmin_{w_i}(dBm)=Recv_{Threshold} + Path_{loss}+Safety\_Margin \quad (2)$$

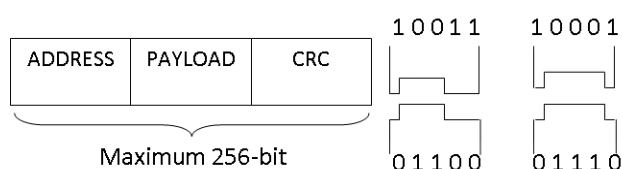


Fig. 6. TRW-24G package without preamble and the connection codes

TABLE I  
EXAMPLES OF COMPLEMENTARY VALUES FOR CONNECTION CODES

Source ID		Complementary Code ID	
Dec	Bin	Dec	Bin
19	1 0 0 1 1	12	0 1 1 0 0
20	1 0 1 0 0	11	0 1 0 1 1
21	1 0 1 0 1	10	0 1 0 1 0
22	1 0 1 1 0	9	0 1 0 0 1
23	1 0 1 1 1	8	0 1 0 0 0
24	1 1 0 0 0	7	0 0 1 1 1
25	1 1 0 0 1	6	0 0 1 1 0
26	1 1 0 1 0	5	0 0 1 0 1
27	1 1 0 1 1	4	0 1 0 1 0
28	1 1 1 0 0	3	0 0 0 1 1
29	1 1 1 0 1	2	0 0 0 1 0

$$2a + b = c \begin{cases} 1 \leq a \leq 2^i - 2 \\ b = 1 \text{ if } c \text{ is odd} \\ b = 0 \text{ if } c \text{ is even} \end{cases} \quad (3)$$

As on (3), the provided values make the connection codes. On this work the setting the range of  $a$  from 1 to  $2^i - 2$ , and  $i$  is the number of bits at here and  $i$  equals to 5 then  $2^i - 2$  is 30 because this setting has been designed for expandable to 3-group configuration of the sensor networks. Thus, the system has to be applied different codes on several channels to reduce the interference. The author selected the connection code values from a Table I.

The operation is *Source ID*  $\oplus$  *Complementary Code ID*. The result equals to true. *Source ID*  $\oplus$  *Complementary Code ID* equals to zero for all bits or some bit, thus, the output is false. This means that the evaluation is inadequate to use this message. However, this process has to be completed in all bits because all bits are exactly adequate to formulate the output state.

The mobile phone has to be connected via interfacing port and to be initialized by the AT commands from a microcontroller to handle a mobile phone. The UPx has to identify status of alerting system and send the alerting message to a concentrator UC1 while sending the SMS message to a mobile phone and a server via mobile base-stations and lease line Internet respectively. Finally, the server calls a relative's mobile phone and a caregiver in autonomous action.

### C. Sensor Node Controllers

The processor units use several CPUs 8-bit, and 16-bit, among of MSP430 board, MCS-52 board, 16f628, and 16f877 board. In the viewpoint of time to send and receive the messages between a WC1 and a WPx depended on the signals from those transducers. In this state the timing is quite important because in Section II during day the timer has to count shorter and fine-tune by adjust to the longest temporal period after immobilized of body and during the night tuned to another temporal value after watched the movements for a while.

In practical experiment, it is separated into 2 modes. Firstly, the WPx detects and processes by a node that works together with a timer for counting the temporal period and to decide to send the alert signal. Secondly, the WPx detects the mobilized signal and sends a message to the WC1 then it has to evaluate together with a timer at a WC1 then makes a decision to send the message to a relative mobile phone and a server. On Jackson's model feedback loop from the first mode, the process handles in queues less than the second mode. The second mode operation has a lot of process in queues among the WPx at each room to monitor if there are more than a person in the different room at the same time



Fig. 7. The transducers with the indicators and the transceiver modules

#### D. Evaluation Result

On Fig. 8., the prefix-W stands for the wood structure, and the prefix-T stands for the tile or concrete because the experimental rooms were decorated by the woods or the tiles. The distance between a participant and the transducer node was more than 3 meters that is hard to detect. The percent of correction is nearly 80% for distance less than 3 meters from 50-trial on each length. This indicated values were averaged between the ultrasonic transducers for more-than-3-meter-long service zone and a thermopile array with the nearly-3-meter-covered-distant by the Fresnel lens. The two operations had been setup for the test: the first mode on each of the WPx sensor node sent a message frame in low traffic rate while the second mode on each of the WPx sensor node sent more messages to a WC1. The decision had been made by the WC1 then it sent the alert message to a relative.

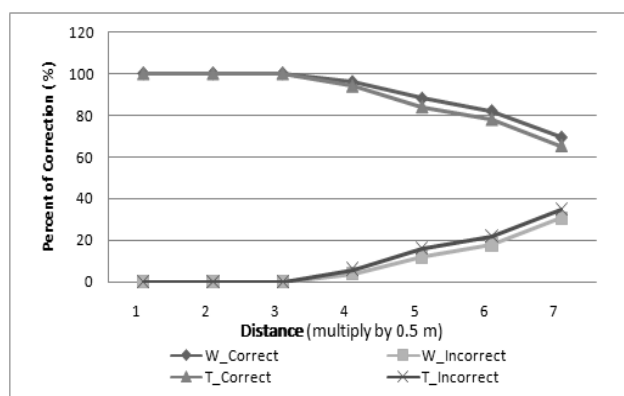


Fig. 8. The evaluation results in the tile and the wood decorated

#### V. CONCLUSION AND FUTURE WORKS

The participants have been accepted for various particular results because of the low cost, uncomplicated installation, user-friendly system, and easy maintenance but the system takes time to adjust the parameters to suitable for each of participant. The system is suitable for a small bedroom, living room, and bathroom. It is strongly recommended to adapt to an apartment. Moreover, the non-further add-ons cost can be utilized in the long term, however, it can be adapted by adding more sensor points or wireless sensor nodes. The future step is to develop more interfacing of other signals from different transducers and to collect the data to manipulate in an agent manner. It is an alternative way for elderly usage

#### ACKNOWLEDGMENT

The author would like to thank all those colleagues, friends, and students; without them this work will not succeed.

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