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Elderly Personal Safety Monitoring in Smart Home Based on Host Space and Travelling Pattern Identification

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Abstract: The ratio of elderly has been increased in many countries, like America, China, Europe, Korea and Japan. Elderly personal safety has become a social problem in these countries. Smart home technology has been expected to settle down such problem and received much more attention globally. This study intends to provide an economic solution to monitor the movement of the accessory of elderly in the smart home, identify the hot space the elderly is likely to stay, capture the travelling pattern of the elderly who living in the smart home and then expose the possible danger when the elderly stays at a space beyond the period defined in the captured patterns. The family members, neighbor or doctor of the elderly will be informed consequently when the elderly is recognized to be unsafe. A prototype has been developed and the approaches were approved to be sufficient to check the scenarios. The pattern rules with very short duration were ignored and all the rules were customable and could be trained all the time. Simulation is introduced which validates the suggested approach as well.

Key words: Location-aware, error tolerant location, RSSI-based distance measurement, indoor location detection, living pattern capture

INTRODUCTION

Several countries have already entered the era of aging population, including America, China, Korea and Japan (Chang *et al*., 2009). The aging population of China has increased to 1.6714 billion by the end of 2009 which is 12.5% in total Chinese population. That is, there is 1 elderly every 8 people. Compared with the year 2009, elderly population increased 725 million, with the proportion increased by 0.5%. Most elderly suffered from chronic illnesses such as hypertension and diabetes in 2010. Therefore, health care for the elderly should be recognized as a social problem, reported by the Xinhua News Agency, China (2010). Smart home technology turns out to be an efficient approach to enable the elderly live happy with less support (Chang *et al*., 2009; Yang and Helal, 2008; Alamo *et al*., 2009; Ming *et al*., 2010; Zhou *et al*., 2010; Helal *et al*., 2008) while a safety enhancing mechanisms is proposed (Yang and Helal, 2008), web service is used to manage the medication (Alamo *et al*., 2009), human intention change is detected and analyzed (Chang *et al*., 2009; Ming *et al*., 2010), ubiquitous service and home automation are suggested (Liao and Tu, 2007; Yilmaz, 2010; Xiaohu and Guangxi, 2006; Alam *et al*., 2011; Hussain *et al*., 2008) and integrated mobile solution for personal health care is provided (Zhou *et al*., 2010; Helal *et al*., 2008).

Considering that the sudden disease, such as cardiovascular disease, cerebral thrombosis and stroke, has an upward trend in the elderly in recent years, some experts argued that fast rescue and timely treatment should be provided to the sudden illness to enable the elderly survive from the emergency easily (Yang and Helal, 2008; Alamo *et al*., 2009; Zhou *et al*., 2010). Though there are some systems enable the elderly to call for help when they are in trouble or emergency, these systems are not sufficient when the elderly lose consciousness (Zhou *et al*., 2010; Helal *et al*., 2008). To detect the emergency as early as possible is essential in such situation, is the main purpose of our research.

In this research, a smart home is divided into several rooms and each room can be further divided into several spaces. It is assumed to be unsafe if the elderly remains at a space beyond threshold period. The family members, neighbor or doctor will be informed consequently if the elderly is recognized to be unsafe by the system. Initial rules can be established for the safety checking, while the living pattern of the elderly can be used to refine the rules so as to better detect the unsafe situation. Typically the living pattern of the elderly can be reflected as a set of

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movement queue (Chang *et al*., 2009) but here in this paper, the spaces where the elderly stay with very short duration are filtered out in the queue. Only those spaces where the elderly stay with more than predefined threshold duration will be contained in the queue, such that the pattern and related rules can be significantly reduced and simplified and the rules can be easily defined and trained all the time.

MOTIVATIONS

Estimation the location of devices is import to reduce the routing and computing in ubiquitous computing (Hightower and Borriello, 2001). Global Positioning System (GPS) (Yin *et al*., 2011), wireless enhanced 911(E-911) are good for outdoor environment with coarse granularity but not good for indoor or building-dense environment (Pahlavan *et al*., 2002). AT&T's Active Badge (Want *et al*., 1992) which uses diffuse infrared technology and could get room-size accuracy. Active Bats (Harter *et al*., 1999), another project from AT&T, uses an ultrasound time-of-flight Lateration technique and get more accurate (9 cm), while requiring large scale deployment and high cost. Microsoft RADAR records the received signal strength (RSS) from several 802.11 access points and estimate user location in office or home environment by comparing to empirical measured data (Bahl and Padmanabhan, 2000). MIT Cricket (Priyantha *et al*., 2001), Carnegie Mellon University (Small *et al*., 2001), IBM (Xiang *et al*., 2004), Maryland University (Youssef *et al*., 2003) and Pittsburgh University (Kaemarungsi, 2005) also have related research and system evaluation.

ZigBee is a low cost, low power consumption, low complexity, low data rate, high reliability and high security two-way radio communications technologies (Chen *et al*., 2011). It is remarked as a promising open standard comparing to the other wireless networking techniques such as IrDA, WLAN (Jabri *et al*., 2008), Bluetooth (Subhan *et al*., 2011) and UWB (Wheeler, 2007; Dong-Mei and Qin-Yu, 2010). Though its data rate is not high, ZigBee is still a good choice to be used in some small range of intelligent environment such as smart home (Chang *et al*., 2009).

Received Signal Strength Indication (RSSI) (Aamodt, 2006; Wang *et al*., 2008) is popular used to estimate location of devices in indoor environment. It has attractive features due to its low device complexity and low cost of nodes and related infrastructure, comparing to the other similar location estimation techniques such as TOA, TDOA and AOA (Niculescu and Nath, 2003; Bahl and Padmanabhan, 2000; Savvides *et al*., 2001).

ZigBee technique (Wheeler, 2007) and RSSI-based estimation algorithms (Aamodt, 2006; Alvarez *et al*., 2010) has been used in our research (Xu *et al*., 2011a, b), other location techniques (Hightower and Borriello, 2001; Pahlavan *et al*., 2002; Small *et al*., 2001; Xiang *et al*., 2004; Kaemarungsi, 2005; Bahl and Padmanabhan, 2000) could also be used to enhance the accuracy of the location detection when there is no critical budget limitation.

RSSI BASED LOCATION APPROACH FOR INDOOR DETECTION

RSSI based location detection: The RSSI is a function of the transmitted power and the distance between the sender node and the receiver node. It decreases with increased distance as the Eq. 1:

$$RSSI = -(10N \log_{10} D + A) \quad (1)$$

where, N is the signal propagation constant, also named propagation exponent, D is the distance from sender node and A is received signal strength at a distance of one meter.

After the parameters (N and A) have been calibrated in a real environment, the distance D can be estimated as Eq. 2:

$$D = 10^{(RSSI-A)/10N} \quad (2)$$

Positioning system is composed of the reference nodes and blind nodes. The reference nodes are static nodes located with known position which know its location and can tell the other nodes its location through communication among nodes. The blind nodes receive data from the reference nodes, gain the coordinates of reference nodes and distance between reference nodes and itself, finally send these data to positioning system and calculate the coordinates of blind nodes.

RSSI based location approach is used in this research to detect the location of the elderly. Several anchor nodes have been deployed around the smart home and a blind node is suggested to be attached with the elderly. Assuming the four anchor nodes have been known as $P_i = (x_i, y_i, z_i)$ where I = 1,2,3,4 and blind node p (x, y, z) with its distance d_i, where I = 1,2,3,4, then there is the following Eq. 3:

$$\begin{cases} (x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2 = d_1^2 \\ (x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2 = d_2^2 \\ (x-x_3)^2 + (y-y_3)^2 + (z-z_3)^2 = d_3^2 \\ (x-x_4)^2 + (y-y_4)^2 + (z-z_4)^2 = d_4^2 \end{cases} \quad (3)$$

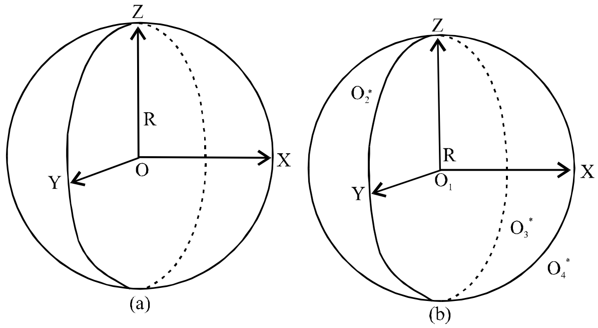

Fig. 1: Error sphere with the position at the center and the error threshold as the diameter

Formula (1) can be translated into Eq. 4:

$$\begin{cases} 2(x_2 - x_1)x + 2(y_2 - y_1)y + 2(z_2 - z_1)z \\ = x_2^2 - x_1^2 + y_2^2 - y_1^2 + z_2^2 - z_1^2 - d_2^2 + d_1^2 \\ 2(x_3 - x_1)x + 2(y_3 - y_1)y + 2(z_3 - z_1)z \\ = x_3^2 - x_1^2 + y_3^2 - y_1^2 + z_3^2 - z_1^2 - d_3^2 + d_1^2 \\ 2(x_4 - x_1)x + 2(y_4 - y_1)y + 2(z_4 - z_1)z \\ = x_4^2 - x_1^2 + y_4^2 - y_1^2 + z_4^2 - z_1^2 - d_4^2 + d_1^2 \end{cases} \quad (4)$$

The equation set can be expressed as Eq. 5:

$$AX = b \quad (5)$$

Where:

$$a = \begin{bmatrix} x_2 - x_1 & y_2 - y_1 & z_2 - z_1 \\ x_3 - x_1 & y_3 - y_1 & z_3 - z_1 \\ x_4 - x_1 & y_4 - y_1 & z_4 - z_1 \end{bmatrix}$$

$$b = \begin{bmatrix} x_2^2 - x_1^2 + y_2^2 - y_1^2 + z_2^2 - z_1^2 - d_2^2 + d_1^2 \\ x_3^2 - x_1^2 + y_3^2 - y_1^2 + z_3^2 - z_1^2 - d_3^2 + d_1^2 \\ x_4^2 - x_1^2 + y_4^2 - y_1^2 + z_4^2 - z_1^2 - d_4^2 + d_1^2 \end{bmatrix}$$

The final result of the Least Squares Estimation can be expressed as Eq. 6:

$$X = (A^T A)^{-1} A^T \quad (6)$$

We can get the unknown point p according to the formula above. However, the distance d_i, where I = 1,2,3,4 which we get with RSSI technology has some error due to the environment noise or multiple reflection. Therefore, the final results of the position also have a certain degree of error. To address this issue, we get different results from different anchor nodes and take the average of these results as the final data, so as to reduce the error to some degree. Besides, we assume that the error for a position is wrapped in a sphere which is centered at that position. Further, we may assume that the error is similar in different directions, such that the diameter of the error sphere can be the error threshold, as shown in Fig. 1a. Therefore, if the distance of two positions is with the error threshold, they will be considered as the same position. For example, having O_1 as the reference position, the position O_2 and O_3 will be considered as the mirror position of O_1 due to the measurement error, while O_4 is another position. When using a low accuracy distance detection method, there will be some error in location detection. Take the Fig. 1b for instance, when one elderly stays at point O_1 for a while then moves to O_4. The detection system may get the inaccurate data and get the mirror locations O_1, O_2 and O_3. The elderly will be recorded to be move from O_1 to O_3, then to O_2 and last stop at O_4. A technique shift happens in such scenario. As there will be 20 cm distance detection error when using RSSI-based measurement, the error sphere will be used to detect the mirror location and reduce the technique shifts.

Algorithms for the elderly travelling pattern capture: The travelling of the elderly in the smart home can be recognized as a sequence of movement from one position to another position. In this research, we assume that there will be some danger if the elderly stay at one position beyond the duration he or she used to stay. Therefore, we are trying to solve two problems, what's the travelling pattern of the elderly in the smart home and how to identify the safety status of the elderly by monitoring the activities of the elderly. Since we don't need to care much about the positions where the elderly stayed for a very short time, these positions can be filtered out and only those positions with long residence time will be monitored and analyzed. Such positions are named as Hot Space in this paper as shown in Fig. 2.

Figure 2 demonstrates an example of the travelling pattern of the elderly in the smart home. The elderly may stay in the living room at one place (Node H in Fig. 2) watching TV for most of the daily time. When it's time for the lunch or dinner, the elderly will stand up and go to washing room (Node G in Fig. 2) to wash the hands before cooking (Node A in Fig. 2). After the cooking, the elderly will stay in the dining room (Node B in Fig. 2) to enjoy the food and wash the dinnerware in the kitchen (Node C in Fig. 2) after the lunch or dinner. The elderly will return to the living room to have a rest (Node E in Fig. 2). The elderly may read book or surf the Internet in the study room (Node F in Fig. 2). The elderly may wash the clothes in the washhouse (Node D in Fig. 2) as well. The travelling network will be different for different elderly and different smart home. Therefore, it's very important for us to capture the travelling pattern for each individual and monitor the personal safety accordingly.

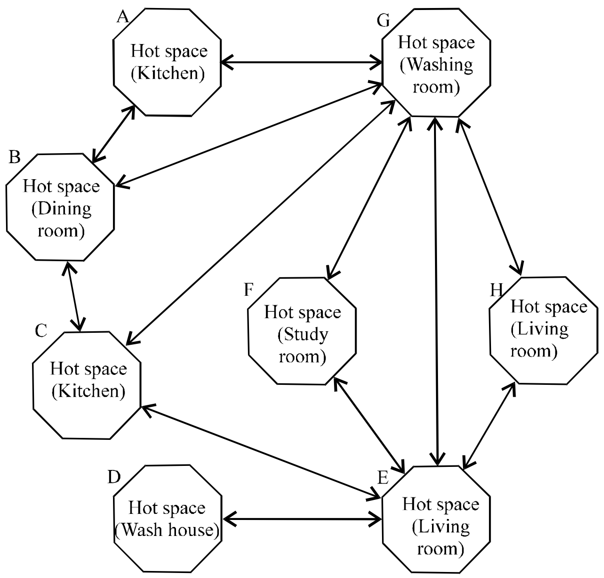

Fig. 2: A travelling network of the elderly in the smart home

Definition 1: Hot Space. The hot spaces are the positions with long residence time. A hot space can be a room or part of a room when the residence time for different parts is different in the room. Hot space is defined as S = <sid, x_1, y_1, z_1, x_2, y_2, z_2>, where sid is the identification no of the space; x_1, y_1, z_1 and x_2, y_2, z_2 indicate a cube which is wrapped by the planes $x = x_1$, $y = y_1$, $z = z_1$, $x = x_2$, $y = y_2$ and $z = z_2$.

Definition 2: Hot Space Cluster. Hot space cluster is a group of hot spaces which have the similar residence time in the smart home. It is defined as SC = <scid, hsc>, where hsc is set of hot spaces <S>, such as s_1, s_2, ..., s_n.

Definition 3: Movement record. Movement record is the record of movement of the elderly in the smart home. It's defined as MR = <T, x, y, z>, where T is the time for the record, x, y and z is the location of the elderly. All the locations will be detected by the location estimation algorithm, so the movement record contains all the movements of the elderly in the smart home. But only the hot spaces will be captured, analyzed and used to identify the personal safety of the elderly.

Definition 4: Living Pattern. Living Pattern is defined as LP = <sc, minD, mediumD, maxD, alertD>, where sc is the space cluster, minD, mediumD and maxD refers to the minimal, medium and maximal duration the elderly has ever stayed at the hot spaces in the space cluster each a time. All these durations are measured and refined in the training. The alertD is the threshold duration for the elderly to stay at the space cluster and the system would alert the related persons for this unsafe situation. Living pattern in this paper has been simplified and demonstrated as some mapping rules which are defined on the basis of space cluster. In order to calculate the medium duration, the summary SumD and count CD of the duration for this space cluster will be calculated at first and the value of mediumD is the factor of the SumD and CD (medium = SumD / CD).

Definition 5: Safety checking system. Safety checking system is defined as SACHS = <S, SC, MR, LP, F, Default>, where S is a set of spaces, SC is a set of space clusters, MR is the movement record, LP is the living pattern which indicates the rules, F is a serial of algorithms including the algorithms for location estimation, hot space detection, space cluster manual merging and safety checking. Default contains the default parameters including the pre-defined inferior limit (PIL: unit s), pre-defined upper limit (PUL: unit s) and the error of location estimation (ELE: unit m).

Algorithm 1: Hot space detection algorithm. Hot space is a kind of space where the elderly stays for a long duration more than a pre-defined inferior limit. Hot space detection is a training algorithm.

```
Input: MR, SACHS
Output: Hot spaces
Sort MR in the order of T;
ele = SACHS.Default.ELE, pil = SACHS.Default.PIL, pul = SACHS.Default.PUL;
FOR (each mr in MR) {
BeginT = MR.T;
beginL.x=MR.x, beginL.y=MR.y, beginL.z=MR.z;
DO
fetch next mr in MR;
WHILE (square(beginL.x-MR.x)+square(beginL.y-MR.y)+square(beginL.z-MR.z)< ele)
IF (MR.T - BeginT > pil) {
tempSid = SACHS.Default.newSpaceID(beginL.x, beginL.y, beginL.z);
IF(a validate tempSid is found) // the space has been created already
tempscid = SACHS.SC.findBySpace(tempSid);
ELSE {
SACHS.S.add(-tempSid, beginL.x-ele, beginL.y-ele, beginL.z-ele, beginL.x+ele, beginL.y+ele, beginL.z+ele)
tempscid = SACHS.Default.newSpaceClusterID();
SACHS.SC.add(tempscid, temps);
}
lp = SACHS.LP.findBySC(tempscid);
IF(lp is not available)
SACHS.LP.add(tempscid, MR.T – BeginT);
ELSE
SACHS.LP.update(tempscid, MR.T – BeginT);
}
}
```

In the training model, when a hot space hs is detected by the algorithm, a related space cluster will be generated which only contain the item hs. Such space cluster can be refined or merged to some similar space cluster late manually. SACHS. Default.newSpaceID is used to generate a new space id if there not exists any space contain the input location, considering the error ele. SACHS.LP.add is used to add the tempscid into the living pattern, init the minD, mediumD, maxD, SumD with the input duration and init the CD with 1. SACHS.LP.update will update the related living pattern with input duration accordingly.

Algorithm for the elderly safety monitoring: Algorithm 2. Elderly Safety Monitoring Algorithm.

```
Input: MR, SACHS, Hot spaces and related rules
Output: Alert or warning messages.
1 Sort MR in the order of T;
2 ele = SACHS.Default.ELE, pil = SACHS.Default.PIL, pul = SACHS.Default.PUL;
3 FOR (each mr in MR) {
4 BeginT = MR.T;
5 beginL.x=MR.x, beginL.y=MR.y, beginL.z=MR.z;
6 DO
7 fetch next mr in MR;
8 WHILE (square(beginL.x-MR.x)+square(beginL.y-MR.y)+square(beginL.z-MR.z)< ele)
9 IF (MR.T - BeginT > pil) {
10 tempSid = SACHS.S.findByPosition (beginL.x, beginL.y, beginL.z);
11 IF(tempSid is predefined) { // the space is already defined with rules
12 IF (MR.T – BeginT > tempSid. alertD)
13 SentAlertmessage(beginL.x, beginL.y, beginL.z, MR.T – BeginT, tempSid. alertD);
14 ELSE IF (MR.T – BeginT > tempSid.maxD)
15 SentWarningmessage(beginL.x, beginL.y, beginL.z, MR.T – BeginT, tempSid. maxD);
16 } // the space is already defined with rules
17 ELSE // the space is not defined with rules
18 SentWarningmessage(beginL.x, beginL.y, beginL.z, MR.T – BeginT, pil);
19 }
20 }
21 }
```

SACHS. S. find by position at line 10 is used to fetch the hot space from the pre-defined hot space list which contains the position. The warning or alert message will be sent out according to the pre-defined rule. If a position doesn't have any rule pre-defined but the resistance time is larger than the threshold, a warning message will be sent out.

VALIDATION IN THE SIMULATION

Movement record was simulated by a program which provided random duration, random 3-D movement (x, y and z). The program generated the record in 5 sec period.

Table 1 lists the hot spaces detected by the algorithm. AlertD is assigned with the maxD plus 300 sec.

For each space, it is recognized as safe if the elderly stay within the maxD, unsafe is the elderly stay beyond the maxD but no exceed alertD. If the elderly stay more time than the alertD, the system assumes that there is a danger. Any observation on non-hot space but with duration more than the PIL will be recognized as abnormal as no hot space could be detected. Because the data volume is small, manual calibration is easy and enabled all the time. The space cluster can be manually merged when there are of similar rules. For example, in Table 1, space cluster 2, 7 and 8 could be merged to one space cluster. In such way, the rules could be reduced though the spaces remain the same.

Table 1: Hot spaces detected by the algorithm

Space cluster	Coordinate (m)		MinD (sec)	MediumD (sec)	MaxD (sec)	AlertD (sec)
1	(1,6,1)	(1.5,6.5,1.5)	60	300	500	800
2	(4,5,1)	(4.5,5.5,1.5)	60	600	1200	1500
3	(0,4,1)	(0.5,4.5,1.5)	60	600	1740	2040
4	(1,4,1)	(1.5,4.5,1.5)	60	600	7200	7500
5	(3,4,0.5)	(3.5,4.5,1)	60	1200	2400	2700
6	(4,4,0.25)	(4.5,4.5,0.75)	60	14400	28800	29200
7	(4,6,1)	(4.5,6.5,1.5)	60	600	1200	1500
8	(5,6,1)	(5.5,6.5,1.5)	60	600	1200	1500

Table 2: Elderly personal safety checking

Observation	Location	Time	Safety checking
1	(1.25,6,1.25)	12:10	Safe in space cluster 1
2	(0.25,4.25,1.25)	12:15	Unsafe in space cluster 3
3	(1.25,4.5,1.25)	12:45	Unsafe in space cluster 4
4	(4.5,4.5,0.25)	14:45	Safe in space cluster 6
5	(3,4,0)	15:50	Abnormal space cluster NA
6	(3,4,0.5)	16:00	Safe in space cluster 5
7	(4,5,1)	16:40	Danger in space cluster 2
8	...	17:20	...

Table 2 shows the checking results on some test cases. All these test cases were designed after the hot spaces had been detected. For the observation 1, 4 and 6, the elderly stayed in space cluster 1, 6 and 5. Since the durations (300, 3900 and 2400 sec) were no more than the related maxD (500, 28800 and 2400 sec), these three observations are safe. For the observation 2, the elderly was in space cluster 3, however the duration is 1800s which is between the maxD (1740s) and alertD (2040 sec), the situation is unsafe. For the observation 7, the elderly stayed in space cluster 2 for 2400 sec which is larger than alerD (1500 sec), it is assumed to be danger. Observation 5 indicated that the elderly stay in some other places other than available hot spaces and is recognized as abnormal.

DISCUSSION

The suggested personal safety monitoring approach may identify the possible danger in the smart home in a simple and straight way. Such method may detect the danger when the elderly is narcoses and doesn't move for a relative long time. There is significant advancement when comparing it to the current available manual danger reporting systems.

However, the suggested approach couldn't detect the danger very quick for some scenarios where the elderly is used to stay for a very long period. For example, if the elder used to sleep for most than 5 h and don't have any significant movement (some movements may be ignored due to the detection error). The suggested approach can only detect the danger after 5 h. To solve such issue, more accurate location detection method can be used so as to detect the small movement. In such way, the elder will be detected with significant movement from time to time and the danger will be detected in a very short duration. Here in this research, we assume that there is only one elderly in the smart home. When there are several elderly live together, the individual identification should be enhanced so as to distinguish different elderly. Otherwise, there will be some conflicts when analyzing the movement record which is the mixture of different movement sequence of the elderly. he communication protocol should be implemented so as to achieve such identification.

CONCLUSION

Elderly personal safety has become a social problem globally due to the increasing ratio of elderly. Smart home has been suggested to solve such problem. Different with other research, here in this paper, an economic solution for elderly personal safety checking has been proposed in this paper. ZigBee and RSSI based location estimation technique have been suggested; however, other research may choose some expensive solutions to get accurate location. Space, space cluster, movement record, living pattern and SACHS system have been defined while living pattern has been simplified so as to reduce the data volume of the rules and enable better calibration of the rules. Hot space has been used to indicate the locations where the elderly prefer to stay and checking rules have been defined as 4 levels of duration including minimal, medium, maximal and alert duration. Different status could then be recognized, such as safe, unsafe, abnormal and danger.

The main contributions of this research are two folders. First, an error tolerant location method is suggested to reduce the impact of detection error. In such way, the low accuracy but economic detection is enabled to be used in indoor environment while there is less technique shifts. Second, an efficient and effective method for personal safety monitoring method is suggested to report the possible danger in a timely mode. It's the enhancement to the currently available manual reporting mechanism.

Though the error of the location detection has been considered in this research and a parameter name *ele* has been introduced in the hot space algorithm, the impact of error is still there. The more accurate location detection results in more accurate safety checking. Due to the cost of infrastructure, smart home may not deploy with some expensive location detection solution. Our group will try to design better accurate location detection solution with reasonable cost in the future research.

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