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INDOOR POSITIONING AND FALL DETECTION SYSTEM DESIGN FOR PEOPLE WITH ALZHEIMER'S AND EPILEPSY DISEASE

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Abstract - Alzheimer and Epilepsy are tremendously increasing neurodegenerative diseases in the world. Alzheimer's disease causes hallucinations, wandering, falls and incidence of getting lost. On the other hand, Epilepsy seizures may occur at any time. Hence, a smart tracking system can help to monitor and locate patients. Although global positioning systems are used in variety of tracking applications, their use is mainly based on outdoor environments and they can provide sufficient accuracy. However, patients are mostly spent their time in indoor environments. Since global positioning system signals are disrupted and attenuated by materials between user and satellite, it is hard to locate user in a building. At this point, there needs to be a different technology for tracking patients in indoor environment for both general and emergencies. In this study, ultra-wideband technology has been chosen for indoor positioning system designbecause of its very low energy consumption, precision rate, robustness and low interference feature. Also, a smart fall detector has been added to the system for emergencies. The created system can differentiate falls with the help of accelerometer and locate patients for intended area. The end product tests showed that the possibility of tracking and detecting falls with an error of 26.23 cm depending on conditions. This value also states that it is an assuring system for various positioning applications.

Keywords - UWB, Indoor Positioning System, Fall Detection, Wireless Sensor Network.

I. INTRODUCTION

The number of older people is increasing day by day around the world. According to the report published by United Nations in 2015, there were 901 million people aged 60 years or over in 2015, an increase of 48 per cent over the 607 million older people globally in 2000 around the world. Also, it is projected that the number of people aged 60 years or over will grow 56 per cent to 1.4 billion between 2015 and 2030 [1]. World Health Organization also stated that between 2015 and 2050, the proportion of the world's population over 60 years will nearly double from 12% to 22% in its fact sheet published in September 2015 [2]. Worldwide, these ratios indicate that population of elders is growing at a much faster rate than past. As populations get older, age-related neurodegenerative diseases such as Alzheimer's Disease (AD) and Parkinson's Disease (PD) have become more common [3]. Epilepsy can also be classified as a brain disorder results from malfunctioning of brain cells and abnormal electrical signal impulse activity [4]. Wandering, gait disorders, hallucinations, Getting Lost (GL), cognitive frailty, memory loss, language problem are the symptoms of AD. Symptoms of AD is very dangerous and it generally results in physical injury and GL [5]. Thus, relatives of people with AD generally make them locked behind the doors to keep them secure. Due to disease, relatives or carers tend to restrict the movement of elders as a preventive measure. However, this is not a solution for the disease and there are researches about importance of physical activity in AD. Regular physical activity increases the endurance of cells and tissues to oxidative stress, vascularization, energy metabolism, and neurotrophin synthesis. They are all important in neurogenesis, memory improvement, and brain plasticity [6, 7]. In addition, an elder should be able to provide his basic needs by himself or take a walk nearby. Thus, assistive technologies became crucial for both patients and his relatives. Assistive health technologies are making important contributions to elder lives especially at home. Assistive monitors can give information about elder or patient continuously. Fall detectors, heat alarms, navigation systems, door monitors and health monitors helps patients for emergencies. These smart systems can also report and generate emergency calls. The study focuses on a problem that Global Positioning System (GPS) cannot supply enough information for indoor positioning emergencies. Although GPS can locate anyone globally, they are not suitable for indoor environments because of the signal attenuation from walls. Therefore, GPS is not suitable in a home, a shopping mall or a hospital environment. Since elder people spends most of their times in indoor environment, the significance of exact location of a person is crucial for immediate help whenever needed.The objective of this study is to create an indoor location positioning system with fall detection capability. The system should be able to detect falls whenever it occurs. In this way, it would be possible to alert caregiver with position data. Accurate data measurement of falls and position is aimed for better estimation of emergencies.

II. THE SYSTEM MODEL

2.1. Accelerometer

Accelerometers are the products of Micro-Electro-Mechanized-Systems (MEMS) technology. MEMS are silicone integrated circuits, but they are mechanical in nature. Similar techniques are used to produce MEMS that are used to make electronics. The difference is that tiny mechanical structures can interface with electronics. They are specifically designed for motion analysis and they have wide application areas from cell phones to planes. For example, motion analysis helps us to create in-outdoor navigation systems, control stabilization, joint angle measurement, camera stabilization systems more precisely.

Biomedical researches on human movement systems has become a great field of interest. Quantifying falls, movement disorders help to analyze diseases such as Parkinson's disease, AD and epilepsy. Accelerometers are mostly used tool in this area because it is cost effective and gives precise data. Moreover, energy consumption of these devices is very low, so it opens the possibility of long term device projects. Since they are very small sensors, it can be worn comfortably [8]. In contrast to cameras at homes, accelerometers are privacy friendly. Additionally, they can be included in a system with a microcontroller to detect specific events such as incline-decline walking, falls, posture etc. By this way, experts or users can interact with the patient immediately. Mainly, the most useful analysis is made by accelerometers; then some of them uses gyroscopic and magnetomotive data.

In this study, ADXL345 accelerometer has been chosen to monitor the fall detection of patient by detecting acceleration data. The sensor has high resolution (13-bit) and it is a small, thin, ultralow power as low as 23µA device. Since the system needs an alert for elderly care, ADXL345 can provide acceleration information about if there are any injuries happened or not. By this way, it is possible to detect falls by the acceleration data of movement. Communication between integrated circuits which are microcontroller and accelerometer is performed by Inter-Integrated Circuit (I^2C).

2.2. Ultra-Wide Band Transceiver

UWB technology have gained widespread use in a variety of applications and getting more interest day by day because it has many advantages. Very precise location of tagged objects with low cost implementation is the most crucial one. Since UWB systems has noise like properties, it creates little interference to other systems. Thus, they are resistant to severe multipath and jamming, and have very good time-domain resolution allowing for precise location and tracking. Various UWB wireless sensor network applications include locating and imaging of objects and environments, perimeter intrusion detection, video surveillance, in-vehicle sensing, outdoor sports monitoring, monitoring of highways, bridges, and other civil infrastructure, and so on [9]. Moreover, lots of applications exist in medicine which uses UWB to track and locate patients, personnel, assets etc. UWB technique achieves higher accuracy positioning than conventional wireless technologies (e.g. RFID, WLAN etc.) [10]. In this project, location aware wireless sensor network is created by sensors which uses UWB technology. Mentioned sensor which is DWM1000 designed as a transceiver for communication. Some of the key advantages of UWB sensor are relatively low cost, low power, small form and robustness. Low cost sensor provides large number of nodes, so wide range area network can be created inexpensively. Creating small device has the advantage of easy positioning where the sensing actually takes place. Low power consumption property of the device will operate device long times without any maintenance. Robust sensor will be required so that high quality of data communication can be guaranteed. However, the sensor has enough timing resolution capability because of the high frequency. High timing resolution provides positioning capability by using two-way ranging model.

Two-way Ranging Model:Two-way ranging concept can be explained by the data acquisition of sensors. Determining Time of Flight (TOF) of signals between sensors will give the information about distance between them. The distance formula between two objects can be expressed as Eq.1,

$$\text{Distance} = \text{Speed of radio waves} \times \text{TOF} \qquad (1)$$

Timestamping with precise clock is also important factor to calculate precise TOF data. In the study, the anchor starts a transmission of a radio message1 to tag and records its time of transmission (transmit timestamp) t1. Then, tag receives the message and transmits a response message (a radio message) back to anchor after a delay treply. Anchor then receives this response and records a receive timestamp t2. This process is shown in Fig.1.

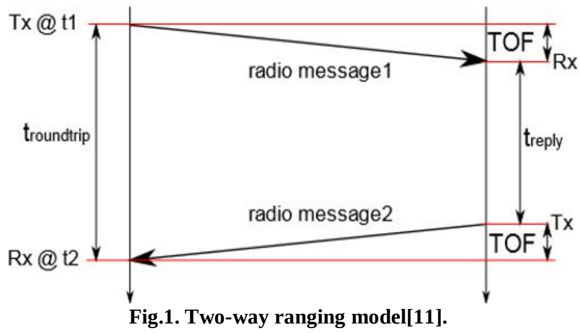

Fig.1. Two-way ranging model[11].

Using the recorded timestamps t1 and t2, anchor can calculate the round-trip time troundtrip and knowing the reply time in the tag, treply, TOF can be determined by Eq.2,

$$\text{TOF} = \frac{t2 - t1 - t_{reply}}{2} \qquad (2)$$

If the speed of radios waves through air is assumed as same as the speed of light c, then distance between anchor and tag can be calculated by Eq.3,

$$\text{Distance} = c \times \frac{t2 - t1 - t_{reply}}{2} \qquad (3)$$

Spatial coordinates calculation of unknown point from its distances to other three reference points is known as trilateration. Trilateration method leads to find unknown point in 3D plane. The system uses trilateration to calculate the position of tag. In this method, each known point communicates with the tag which is unknown point providing precise details of distances. Once the distance measurements are received by tag, the unknown point of tag is calculated by trilateration. If the unknown point is (x,y), known points will be (x_i,y_i) and distance can be calculated as (r_i). Thus, three set of circle equations with known radius parameters are given inEq.4,

$$\begin{aligned}(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 &= s_1^2 \\ (x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2 &= s_2^2 \\ (x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2 &= s_3^2\end{aligned} \qquad (4)$$

Expanding out the parameters and representing in the matrix form gives Eq.5,

$$\begin{bmatrix} 1 & -2x_1 & -2y_1 & -2z_1 \\ 1 & -2x_2 & -2y_2 & -2z_2 \\ 1 & -2x_3 & -2y_3 & -2z_3 \end{bmatrix} \begin{bmatrix} x^2 + y^2 + z^2 \\ x \\ y \\ z \end{bmatrix} = \begin{bmatrix} s_1^2 - x_1^2 - y_1^2 - z_1^2 \\ s_2^2 - x_2^2 - y_2^2 - z_2^2 \\ s_3^2 - x_3^2 - y_3^2 - z_3^2 \end{bmatrix} \qquad (5)$$

Since the equation is written in the matrix form, the solution of the Eq. 6 provides position of tag.Detailed calculation of the matrix equation system explained in [12].

$$A_0 \,.\, x = b_0 \qquad (6)$$

2.3. Microcontroller
Configuration and addressing of UWB modules must be programmed each time whenever sensors needs to be in use. Also, sending and receiving data times must be acquired and calculated to find out distance. While range data is acquired, fall detection system must work at the same time. Therefore, microcontroller must be added in the system structure to communicate between sensors, calculate position of tag, direct data to intended network. Since ATMega328p microcontroller is low-cost, low power and high-performance chip with sufficient pins for the project, it has been chosen for the application of system. The chip allows I^2C and SPI communication. While SPI connections update about range data in high rates, the accelerometer sends data whenever falls happen.Fig.2 shows tag design including connections with accelerometer and UWB module.Fig.3 shows circuit design of anchor including UWB module.

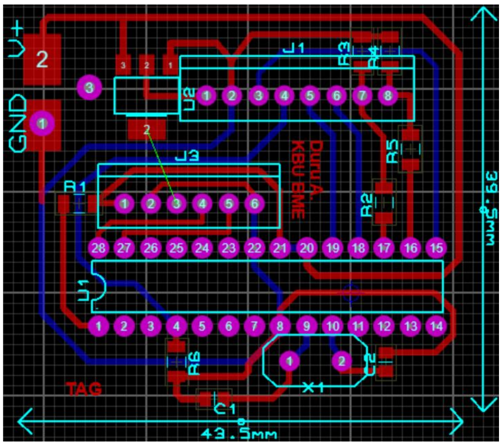

Fig.2. Circuit design of tag.

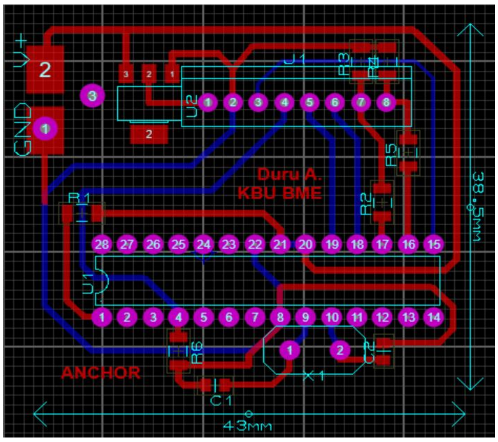

Fig.3. Circuit design of anchor.

III. RESULTS AND DISCUSSION

3.1. Measurement Tests
Distance measurement tests use one tag and one anchor for data collection. 4, 6, 10, 15 and 20meters measurement tests have been applied to the system. Samples include 1800 ranging data. Real distance measurement data has been collected by laser meter with millimeter accuracy. Real measurement data are also checked at least three times to minimize user related error. Performed distance estimations with modules are going test the system accuracy and results are going to show if drift occurs over time. Fig.4 shows the system setup for distance measurement application.

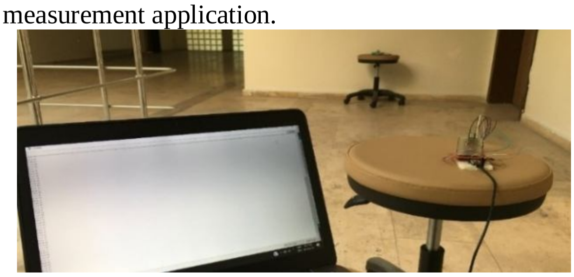

Fig.4. UWB based distance measurement system.

Results are gathered to see the variation among values. Table 1 shows five different measurements with minimum, maximum, range, standard deviation properties. Minimum and maximum properties states peak data values in given test. Range is the difference between peak data measurements. Since mean data difference from real value has been calibrated, the offset value was stated. Standard deviation and Mean Absolute Error performance features are also added to the Table 1. Thus, results of measurement tests can be compared with given parameters.1800 samples taken for each distance estimation test.

Table 1: Distance measurement test results.

	4-meters	6-meters	10-meters	15-meters	20-meters
Min. (m)	3.932 m	5.919 m	9.890 m	14.910 m	19.870 m
Max. (m)	4.092 m	6.069 m	10.080 m	15.140 m	20.400 m
Range (m)	0.160 m	0.150 m	0.190 m	0.230 m	0.530 m
Offset (m)	-0.698 m	-0.611 m	-0.810 m	-0.920 m	-0.790 m
Standard dev. (cm)	2.64 cm	2.28 cm	2.32 cm	3.37 cm	5.77 cm
MAE (cm)	2.14 cm	1.79 cm	1.83 cm	2.65 cm	3.67 cm

3.2. Position Estimation with Fall Detector System

Fall detector system working principle can be adjusted with twodifferent versions. First one includes activity detection. The accelerometer tries to detect activities all the time when its powered. If there is no activity within threshold value, then system calculates position for fast navigation of emergency. On the other hand, the system can be programmed to detect free-falls. This type of activity recognition compares new data with the previous one. Thus, if there is a difference above given threshold value, then system can detect falls. In this system, activity is checked and reported every 10 seconds. The reporting time can be adjusted for different applications. After system configuration, fictional falls are held to test the system. Three anchors have been placed at the corners of 4x11 m rectangle hall to apply trilateration algorithm which is mentioned in Section 2.2. A scenario includes falls at random positions, then these calculated positions compared with real measurements. The obtained graphic can be seen in the Fig.5.

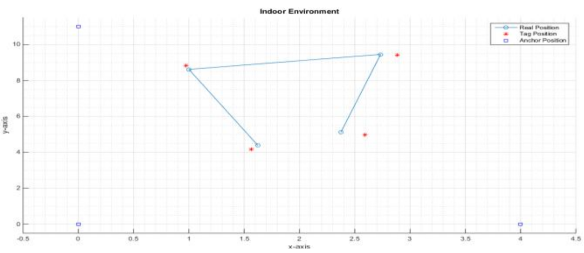

Fig.5. Comparison of real position vs. measured position.

Table 2 shows various error measurements with respect to real position.

Table 2: Error measurement results.

	Distance Errors
Min.	15.49 cm
Max.	26.23 cm
Average	21.15 cm
Standard dev.	4.41 cm

CONCLUSIONS

Measurements are carried out with 5 different distances which are 4, 6, 10, 15, 20m. Results showed that range between minimum and maximum values stays less than 23cm except for the 20m test. Also, offset value does not change much for all the measurements, but offset calibration must be done to converge correct distance. As the Table 1 shows maximum error is19cm up to 10m which is a good resolution. However, there are multiple error sources of measured data which can be explained. The primary source of error is antenna delay in hardware. The capacitance of the hardware may cause nanosecond level delays in transmission. Also, the clock drift causes the distance measurement errors. Received signal level has effect on ranging accuracy. This correction depends on the ranging accuracy of the desired application. Increasing distance returns worse results as seen in 20m test. 20m test resulted larger peaks than the other tests which means there may communication problems in greater peaks. Thus, signal strength should be increased and better antenna can be used for larger positioning plans or the number of modules can be increased.However, test results showed that UWB chips provide promising positioning results and the accelerometer can detect falls. All in all, createdsystem design is capable for emergency cases.

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