Indoor Localization based on Ultra Wide Band using Deca-Wave

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Abstract - *In this world, industrialization made revolutionary changes in civilization. Tracking in Indoor industrial environments often requires very precise localization. It is the primary objective of this paper. A solution for this purpose is short-range radio technology called Ultra-wideband (UWB) technology using Deca-wave module. This new system consists of 8 Anchor and a Tag plus one Gateway for Indoor localization with UWB (Ultra-wide Band) and a Deca-wave Module with better accuracy. The frames used for the working of anchor-tag system are Deca-wave specific ranging frames, complying with the IEEE 802.15.4 standard data frame encoding. Instead of using RSSI based distance calculation we will be using a more accurate time of arrival (ToA) based distance calculation. This calculated distances are used for x-y co-ordinate calculation using a localization algorithm with translation technique running in a computer or Raspberry Pi. The proposed technique offers better accuracy in indoor environments.*

***Keywords*: Indoor localization, UWB, ToA.**

1. INTRODUCTION

Today, MEMS IC technology and wireless communication uses wireless sensor networks for various applications such as process monitoring, process control etc. Using the small and cheap device called sensors the physical parameters such as temperature, light and pollution are sensed. The data collected is routed to special nodes, called sink nodes (also called Base Station, BS), in a multi-hop basis, as shown in Fig.1. The sink node sends data to the user through Internet or satellite, via a gateway. A gateway might not be needed if, distance between the user and the network can be locally monitored. Monitoring, natural disaster relief, patient tracking, military target and automated warehouses are the different fields where WSNs are used as a wide range solution. WSNs are useful only if sensor nodes are aware of the environment surrounding them compared to the traditional networks. For example, each sensor could only monitor its region and collected data should be sent to the sink node. However, the ability to correlate collected data in time and in space defines the potential of WSNs. This is the reason why localization is a fundamental tool to WSNs [1].

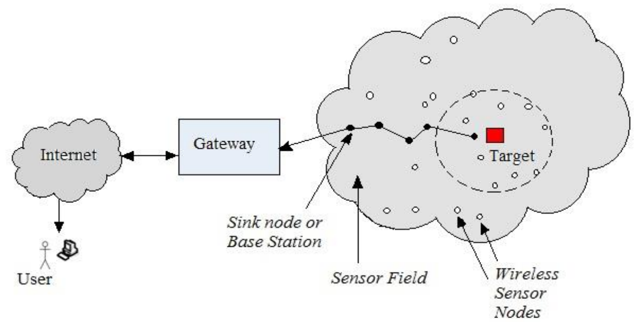


Fig.1. Wireless Sensor Network.

Localization in wireless sensor network is an important area of research that has been addressed through many proposed schemes. It refers to the ability of determining the position (relative or absolute) of a sensor node, with an acceptable accuracy. Based on the dependency of the range measurements these proposal schemes are classified into two major categories: range-based schemes and range-free schemes. However, it is difficult to classify hybrid schemes which combine different methods based on connectivity information and/or range measurement techniques as range-based or range-free schemes. Also, range based schemes and range-free schemes are divided into two types: fully schemes and hybrid schemes. Furthermore, the efficiency of localization schemes is evaluated in terms of accuracy.

Indoor positioning system has a great impact on public safety if deployed correctly. If a responder uses this technology to navigate their way throughout a structure, an operation's personnel can track and monitor the status of those responders as they transverse through the building. This technology could provide quick access to information as to the whereabouts of students and staff in the case of active shooter incidents. The technology can also be leveraged to perform historical analyses (e.g., finding out which employees were in the vicinity of an incident that occurred in the past). There are different techniques for the position finding. Usually, GPS is added to the network for this purpose. But, this is not practically applicable because of high cost, high power consumption and environment constraint

[2]. In addition, the GPS fails in indoors applications, under the ground, or dense forest.

Most technologies support multi-floor structures as they provide calibration techniques to limit signal bleed through and configuration options to assign antennas to floors such as (beacons, access points, LED, etc.). A grid of antennas/detectors is required in each floor. In this field, another method used for Indoor positioning is Wi-Fi triangulation/mapping. This can also be done without beacons. Signals of Wi-Fi enabled devices are needed to capture the Wi-Fi access points. People can self-locate using apps on their smart phones (e.g., the phone determines where it is based on the ambient radio signal it sees, magnetic signature, etc.). The disadvantage on Wi-Fi system is that it can't track a larger amount of tagged assets over a greater distance with more accuracy.

In this paper, a new approach is proposed based on time of arrival (TOA) using ultra- wideband and IEEE 802.15.4 technology for both LOS and NLOS propagation conditions for short range in indoor environment. UWB is used because it has some significant advantages comparing other schemes. This will give an accuracy of 10-30 cm, which is considerably better than when working with beacons (1-3 meters) or Wi-Fi (5-15 meters). The latency time is very low (position request up to 100 times/second). Also, height differences can be measured accurately. However, the technique is mostly suitable for special industry applications, which requires appropriate components.

2. METHODOLOGY

The proposed Indoor positioning system has four main parts for localisation. They are eight anchors, one Tag, location engine and a gateway as shown by the overall system in Fig.2.

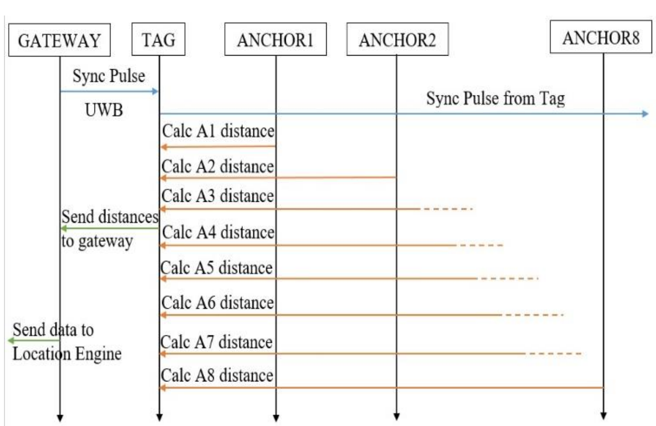


Fig.2. Overall System.

The overall system works on UWB technology. In this system, anchor-tag devices are DWM1000 devices. These devices provide low power consumption and lot of API's (Application Peripheral Interfaces). This will make it simpler for programming. A two way ranging method called ToA is used for calculating distance, where the propagation delay between a well-known positioned nodes, so-called anchor, and unknown position node (Tag) is used to estimate their positions. In ToA, synchronization between the nodes is required to improve the accuracy of localization. The mathematical representation is given below [3].

$$D_i = C * \tau = \sqrt{(x - x_i)^2 + (y - y_i)^2} \qquad 2.1$$

Where (x_i , y_i) represents the position of the anchor 'i' and (x, y) represents the position of the unknown node. D_i is the estimated distance, C is the velocity of light, and τ is the time delay between the anchor 'i' and the node with unknown location. In order to find the location of a node at least three equations involving three different anchors are needed. If the node is mobile more equations are needed.

The Fig.3 represents the two way ranging ToA method for time of flight calculation, ToF or τ [6]. This calculated value is used for distance calculation.

Time of flight is given by [6],

$$ToF = \frac{t_2 - t_1 - t_{reply}}{2} \qquad 2.2$$

Where, ToF is the Time of Flight, t_{reply} is time taken for replying to tag poll message, t1 and t2 are time stamp for transmitted poll message at tag and time stamp for received response message at tag respectively.

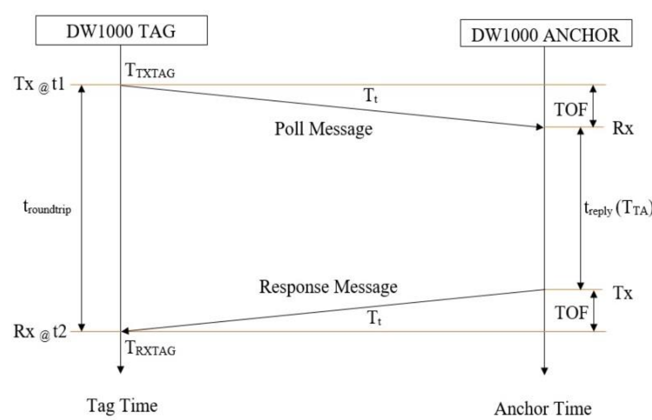


Fig.3. Two Way Ranging.

In the system eight anchors are used to find the time of flight. The basic model for four anchors is given in Fig.4.

The device which is used to move around different points to get the position details are called as tags. The gateway acts as a bridge for transferring distance data to location engine. A location engine is a computer where localisation algorithm runs to find the position of the tag.

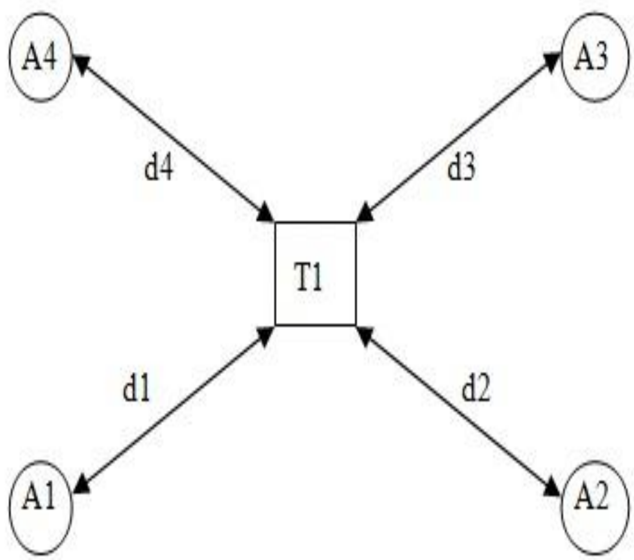


Fig.4. Model of Proposed System.

In the first phase, the basic communication and distance calculation between one Anchor and Tag is implemented. Also, a calibration scheme for the antenna delay which is needed for best accuracy is developed. The frames used for the working of anchor-tag system are Deca-wave specific ranging frames, complying with the IEEE 802.15.4 standard data frame encoding. Here, a poll message is send by the initiator to trigger the ranging exchange and the exchange is completed through response message send by the responder.

During next phase, the time of arrival details are used for calculating the distance between anchor and tag. These distances obtained from anchor-tag system are sent to location engine via gateway device through the serial port communication. Then, the location engine calculates the position of tags using localization algorithm that is running in the system. CCA is a centroid algorithm used for this calculation. It will give better accuracy in indoor environment. The steps involved in overlapping and non-overlapping cases of centroid method are as follows:

1. Every time for location finding the algorithm takes minimum of nearest three anchor distances to the tag.
2. With the distances from anchor to the tag, these nearest anchors will form a circle. The radius of circle will be the distance measured from tag to respective anchors.
3. Thus, circles are formed in which two cases are there,
    - Overlapping.
    - Non-Overlapping.

If the circles overlap,

- ➔ The tag will be most probably seen inside the common overlap area of circles.
- ➔ From which the intersection points of overlapping circles are to be determined.
- ➔ After finding the above mentioned points, create a polygon using this intersection points.
- ➔ From the polygon, we have to find out the centroid of the polygon formed and this centroid point is assumed as the tag position.

For non-overlapping circles,

- ➔ Find out the intersection points by solving the respective circle equations same as that of overlapping case.
- ➔ After getting the intersection points we have to make polygons with all possible combinations of the intersection points.
- ➔ The centroid of the polygon with largest area will give you the position of the tag.

Mostly, the existing techniques uses two dimensional calculations where the height of the tag from ground plane is not considered for co-ordinate calculation. This will affect the accuracy. As a solution to this, a translation method for height is needed. For our experimental analysis we fix this translation height at 4 feet. Here, the distances from the anchors to tag are in 3D plane. We have to translate this 3D distance into 2D plane inorder to get better accuracy. Also, the co-ordinates obtained will be in two dimensional planes.

The test setup for measurement of indoor co-ordinate is shown in Fig.5.

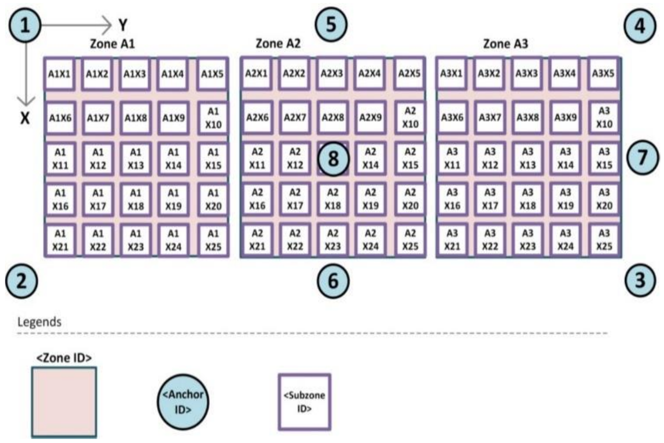


Fig.5. Testing Zone Arrangement.

The test area is divided into three major zones A1, A2 and A3. Each major zone consists of 25 subzones. In Fig.5. We can see that the overall testing zone is surrounded by anchors. There are 8 anchors fixed at different positions of the testing zone. We increased the anchor density in order to get better multilateration results. For the calculation of co-ordinates, eight anchors are fixed in the indoor environment. Out of which one will be assigned as origin. Other anchors are fixed in respective positions with respect to the origin.

For taking test data, we fixed different tag locations in the test area as shown in Fig.6.

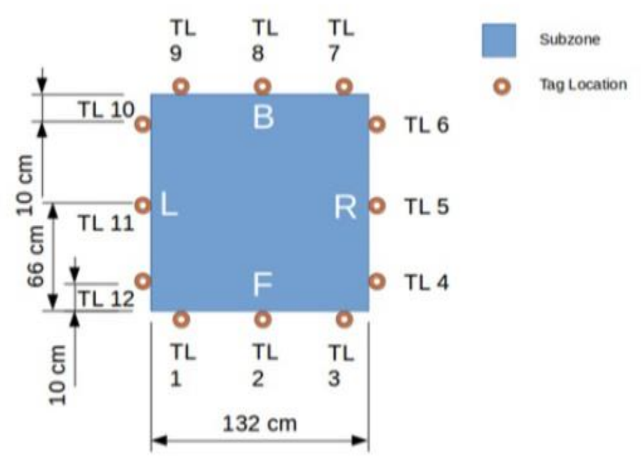


Fig.6. Reference Image of a Subzone.

To take test data we fixed tag locations TL1 to TL12, around each subzone. We have taken test data at this fixed locations at heights 2 feet, 5 feet, 8 feet and 11 feet. And, the entire subzones of every zones are filled with cardboard stacks of different heights. The maximum height of stack in the test area is 12 feet.

3. EXPERIMENTAL RESULTS

Problems and the difficulties in indoor localization are discussed in this section with solutions to them is proposed.

The Fig.7 shows the percentage accuracy of locations of each subzones at different zones. The subzones where zero is denoted are locations where data is not collected.

A1X..	1	2	3	4	5
	41.67	27.08	29.17	43.75	45.83
6	22.92	16.67	20.83	25	35.42
11	6.25	0	27.08	25	29.17
16	12.5	2.08	0	0	27.08
21	27.08	12.5	14.58	16.67	25

Overall Accuracy A1 24.24

A2X..	1	2	3	4	5
	37.5	56.25	79.17	72.92	0
6	27.08	33.33	47.92	37.5	0
11	37.5	35.42	35.42	20.83	0
16	31.25	27.08	45.83	52.08	0
21	19.44	2.08	29.17	43.75	0

Overall Accuracy A2 40.5

A3X..	1	2	3	4	5
	64.58	50	54.17	60.42	0
6	58.33	60.42	58.33	56.25	0
11	37.5	35.42	52.08	58.33	0
16	25	29.17	39.58	47.92	0
21	12.5	22.92	10.42	25	0

Overall Accuracy A3 42.92

Fig.7. Percentage Accuracies with all heights.

For data collection we fixed the translation height to 4 feet. The Fig.7 shows percentage accuracies of subzones considering all 2 feet, 5 feet, 8 feet, and 11 feet heights. Because of considering all heights and fixing the translation height to 4 feet the locations given at 8 feet and 11 feet are very much erroneous. Inorder to handle this situation we need an automating translating height algorithm. It is because of this erroneous results the overall accuracy of the zones are less.

The Fig.8, Fig.9, and Fig.10 shows the graphical representation of percentage accuracy of A1, A2, and A3 considering all heights.

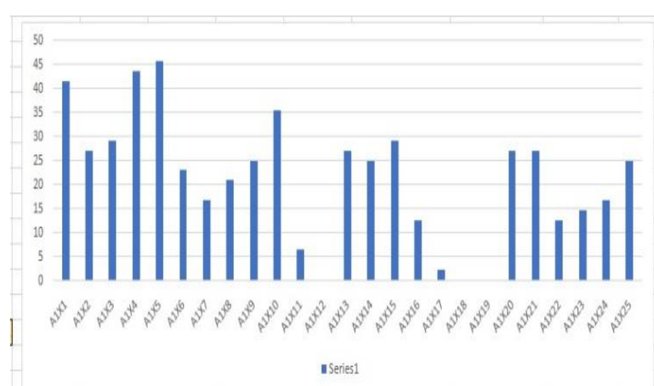


Fig.8. Graph of A1 Zone with all heights.

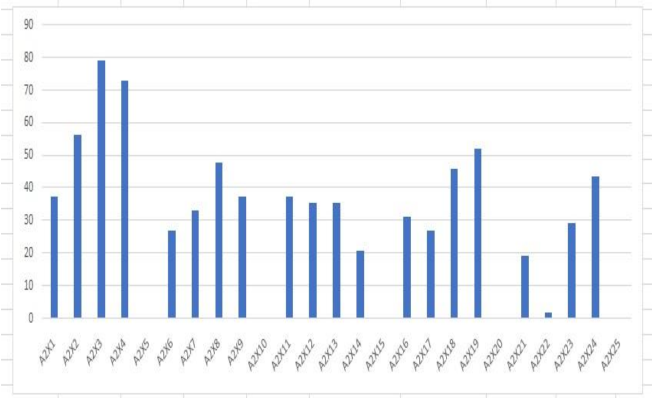


Fig.9. Graph of A2 Zone with all heights.

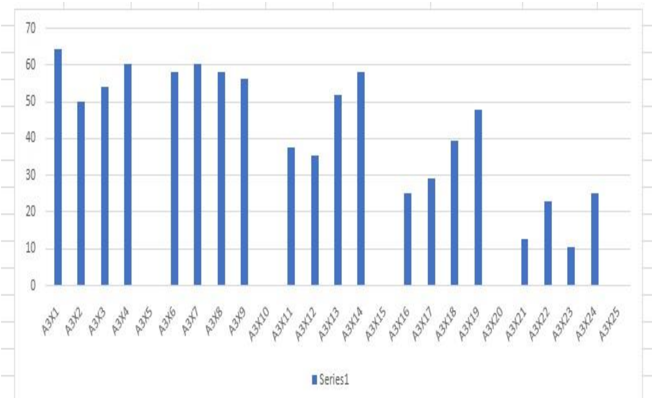
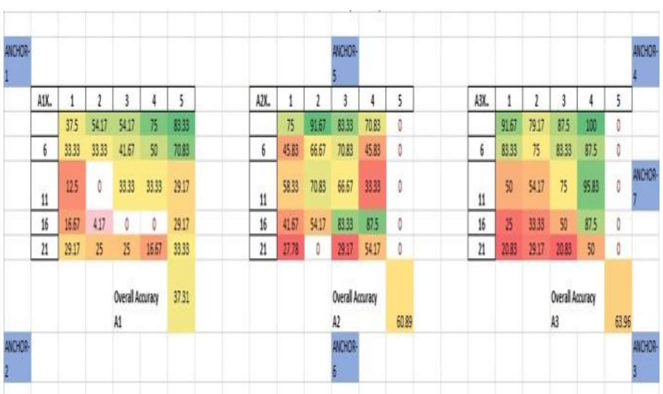


Fig.10. Graph of A3 Zone with all heights.

By considering only 2 feet and 5 feet height, the percentage accuracy for each zone is as shown in Fig.11.



A1X.	1	2	3	4	5
	37.5	54.17	54.17	75	83.33
6	33.33	33.33	41.67	50	70.83
11	12.5	0	33.33	33.33	29.17
16	16.67	4.17	0	0	29.17
21	29.17	25	25	16.67	33.33
			Overall Accuracy A1		37.31

A2X.	1	2	3	4	5
	75	91.67	83.33	70.83	0
6	45.83	66.67	70.83	45.83	0
11	58.33	70.83	66.67	33.33	0
16	41.67	54.17	83.33	87.5	0
21	27.78	0	29.17	54.17	0
			Overall Accuracy A2		60.89

A3X.	1	2	3	4	5
	91.67	79.17	87.5	100	0
6	83.33	75	83.33	87.5	0
11	50	54.17	75	95.83	0
16	25	33.33	50	87.5	0
21	20.83	29.17	20.83	50	0
			Overall Accuracy A3		63.96

Fig.11. Percentage Accuracies with 2 Feet and 5 Feet heights.

The corresponding graphical representation for this are shown in Fig.12, Fig.13 and Fig.14. Here, we can see that the percentage accuracies of each zones and subzones has been increased compared to the above plotting with all heights.

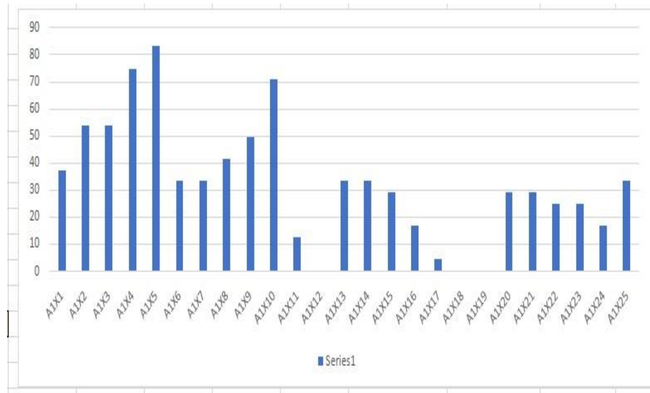


Fig.12. Graph of A1 Zone with 2 Feet and 5 Feet heights.

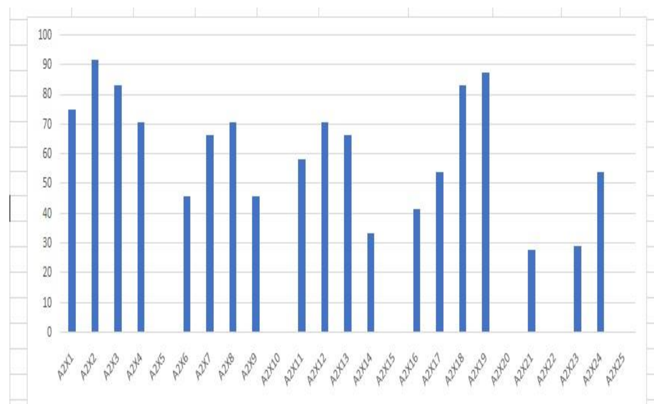


Fig.13. Graph of A2 Zone with 2 Feet and 5 Feet heights.

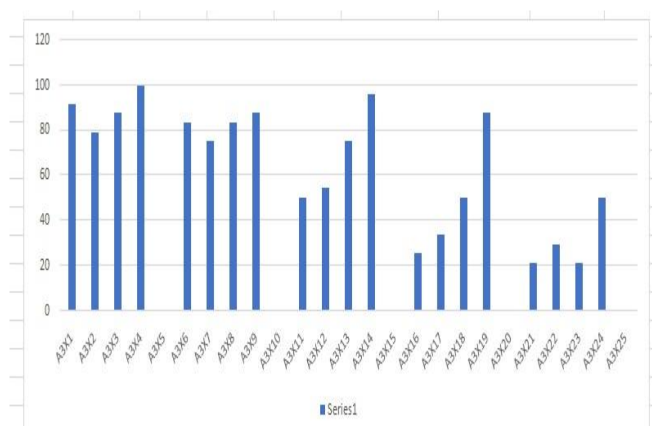


Fig.14. Graph of A3 Zone with 2 Feet and 5 Feet heights.

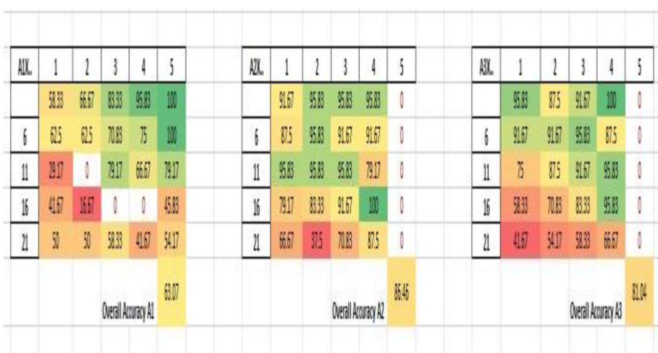
The percentage accuracy of results falling into neighbouring subzone is shown in Fig.15 and Fig.16. The Fig.15 considers the results at all heights while Fig.15 considers the results at 2 feet and 5 feet only. Here we can see that the overall accuracy is very much better than previous plots. For zone A2 and A3 it is more than 80% while considering 2 feet and 5 feet heights.

A1X..	1	2	3	4	5
	56.25	33.33	47.92	56.25	54.17
6	43.75	31.25	35.42	37.5	58.33
11	20.83	0	58.33	50	62.5
16	33.33	16.67	0	0	43.75
21	39.58	25	31.25	35.42	41.67
			Overall Accuracy A1		41.48

A2X..	1	2	3	4	5
	50	66.67	93.75	95.83	0
6	47.92	50	64.58	62.5	0
11	58.33	54.17	58.33	50	0
16	54.17	45.83	54.17	62.5	0
21	47.22	29.17	58.33	68.75	0
				Overall Accuracy A2	58.61

A3X..	1	2	3	4	5
	66.67	58.33	64.58	77.08	0
6	66.67	77.08	77.08	62.5	0
11	56.25	68.75	68.75	66.67	0
16	47.92	62.5	60.42	60.42	0
21	31.25	45.83	41.67	45.83	0
				Overall Accuracy A3	60.31

Fig.15. Percentage Accuracy Including neighboring Zone with all heights.



A1X..	1	2	3	4	5
	58.33	66.67	83.33	95.83	100
6	62.5	62.5	70.83	75	100
11	29.17	0	79.17	66.67	79.17
16	41.67	16.67	0	0	45.83
21	50	50	58.33	41.67	54.17
			Overall Accuracy A1		63.07

A2X..	1	2	3	4	5
	91.67	95.83	95.83	95.83	0
6	87.5	95.83	91.67	91.67	0
11	95.83	95.83	95.83	79.17	0
16	79.17	83.33	91.67	100	0
21	66.67	37.5	70.83	87.5	0
				Overall Accuracy A2	86.46

A3X..	1	2	3	4	5
	95.83	87.5	91.67	100	0
6	91.67	91.67	95.83	87.5	0
11	75	87.5	91.67	95.83	0
16	58.33	70.83	83.33	95.83	0
21	41.67	54.17	58.33	66.67	0
				Overall Accuracy A3	81.04

Fig.16. Percentage Accuracy Including neighboring Zone with 2 Feet and 5 Feet heights.

The main problem faced in an indoor localization is the co-ordinate accuracy. So, accuracy is the first goal during distance measurement in LOS and NOS to find the co-ordinates. If no precision is there the data collected will be useless. So by observing the test results we can see that the percentage accuracy of zones are very much better for 2 feet and 5 feet heights. And also, by observing the percentage accuracies of co-ordinates falling into neighboring zone we can see that the accuracy is increasing considerably. This is because the translation height used is 4 feet which is closer to 2 feet and 5 feet heights. So by automating this translation height we can get better accuracy in co-ordinates.

We propose a technique for automating this translation height. In the proposed method, height of the tag and anchor from the ground is required to find x and y co-ordinates in 2D plane. For this consider the below given example in Fig.17.

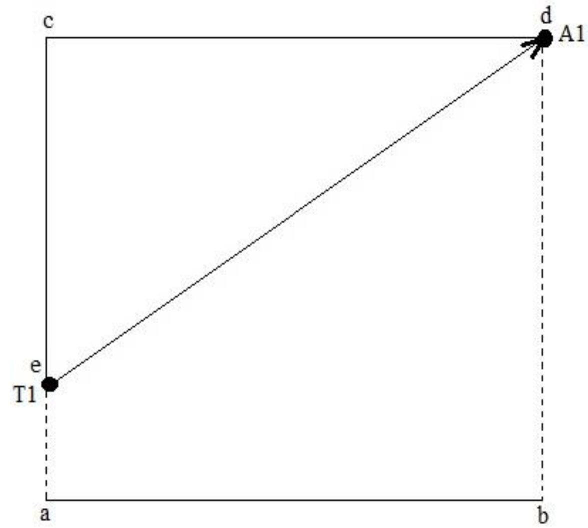


Fig.17. Tag-Anchor Plane.

The figure describes position of tag and anchor in which 'ab' represents ground plane whereas 'cd' is the anchor plane. Similarly, 'ae' is the height of tag from ground plane, 'bd' is the height of anchor plane from the ground and 'ed' is the distance between anchor and tag represented as $R_{distance}$. For co-ordinate calculation we need the distance between tag and anchor i.e., 'd'. For the calculation of 'd' value, ToA method is used. The equation for this is given as,

$$d = \sqrt{R_{distance}^2 - (height\ of\ tag\ from\ anchor\ )^2} \qquad 3.1$$

Whereas, height of tag from anchor plane is the difference between height of anchor plane from ground and the height of tag from ground. So, the equation 3.1 can be written as,

$$d = \sqrt{R_{distance}^2 - (bd)^2 - (ae)^2} \qquad 3.2$$

The problem arises here is variation in the height of tag from ground plane. To make a better calculation, we are using an algorithm to find out height of tag from anchor plane. In this algorithm three anchors which are closest to the tag are chosen as reference anchors as shown in Fig.18.

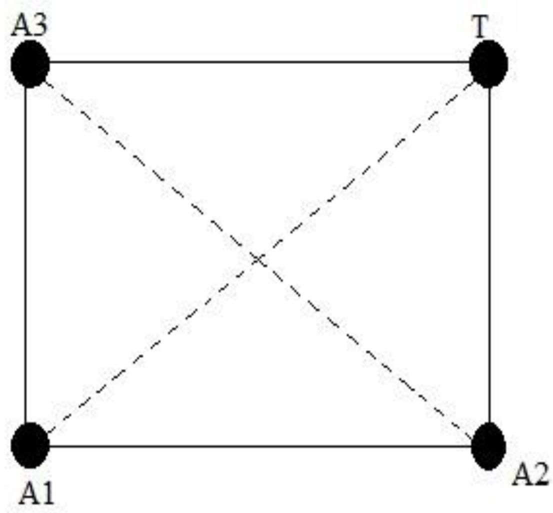


Fig.18. Tag and Reference Anchor System.

Suppose A1, A2, A3 are the reference nodes and 'T' be the tag whose height from ground plane has to be determined. The co-ordinates of A1, A2, A3 and T are (0, 0, 0), (X_2, 0, 0), (X_3, Y_3, 0) and (X, Y, Z) respectively.

Let the distance between the anchors A1 and A3 is 'a' and, the distance between the anchors A1 and A2 is 'b' then, the distance between the anchors A2 and A3, 'c' is given by the equation,

$$c^2 = a^2 + b^2 - 2 * a * b * \cos(\alpha) \qquad 3.3$$

Using the equation 3.3, the angle of distance vector from origin A1 with respect to x axis called 'α' is determined. In the next step, co-ordinates of anchor A3 is calculated by the equation,

$$A3(X_3, Y_3, 0) = A1(0,0,0) + a * (\cos(\alpha), \sin(\alpha), 0) \qquad 3.4$$

Let the tag co-ordinate be (x, y, z) then the distances from each anchors to the tag gives three different equations. This is mentioned as equations from 3.5 to 3.8.

$$(x-0)^2 + (y-0)^2 + (z-0)^2 = d_1^2 \qquad 3.5$$

$$i.e., \quad x^2 + y^2 + z^2 = d_1^2 \qquad 3.6$$

$$(x-x_2)^2 + (y-0)^2 + (z-0)^2 = d_2^2 \qquad 3.7$$

$$(x-x_3)^2 + (y-y_3)^2 + (z-0)^2 = d_3^2 \qquad 3.8$$

The equations from 3.5 to 3.8 are solved for three unknowns and the value for 'z' is determined. Remember to not take these x and y co-ordinates for further calculation. Because, these x and y values are used only for the calculation of height of tag from the ground plane i.e., 'z'. The 'z' value is then substituted in the equation 3.1. Thus, the equation changes to,

$$d = \sqrt{R_{distance}^2 - z^2} \qquad 3.9$$

This translated distance between tag and anchor in two dimensional plane is substituted in the CCA algorithm, from which the original x and y co-ordinates of tag is obtained.

Then some test points are assigned in this environment. The real values of these test points are calculated using distance measurement device and the same is calculated with our own device. Difference between these values will give the accuracy. Accuracy obtained in x and y coordinate lies in between -30 cm and +30 cm. Also, the antennae delay after calibration is 32860 DTU (where, one DTU is equal to 15.65ps).

4. CONCLUSION

The proposed technique is a good technique for indoor localization using UWB and Deca-Wave module. Experiment shows that the Anchor – Tag combination setup by Deca-Wave module is giving an accuracy of 10-30cm in distance measurement using ToA two way ranging method and with proper antenna delay calibration. Antenna delay plays a crucial role in giving better accuracy in distance because it is a factor which affects the time of flight value. Distances were measured using time of flight obtained from two way ranging and time difference obtained from time of arrival method. Deca-Wave DWM1000 module was used as anchor, tag and gateway. They were used as they provided sub one meter accuracy. The positioning algorithm along with proposed translation method will give better co-ordinate accuracy. Since we are using DWM1000 devices better power management is possible. The proposed system will give us better accuracy in indoor coordinates but, since the system depends on certain interferences and signal loss due to stack heights and metallic objects, there is much scope for future work.

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