Anchor selection by geometric dilution of precision for an indoor positioning system using ultra-wide band technology

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Abstract
In wireless localization systems, the performance enhancement of location estimation is an important goal. In recent years, different positioning systems using an ultra-wide band (UWB) technology have been created, and always an evaluation metric to test such systems is needed for ensuring a suitable system for a specified application. Also, a non-line-of-sight (NLOS) identification and mitigation method is needed usually when utilizing the UWB technology. The mean-square-error (MSE) and geometric dilution of precision (GDOP) evaluation metrics are widely implemented as standard for choosing a perfect system. In a harsh environment, a novel algorithm of indoor positioning (IP) system is presented using the UWB technology without implementing any NLOS identification and mitigation technique and the localization accuracy is evaluated online. The UWB is used to communicate a mobile station (M) with \( n \) anchor nodes distributed randomly and clustered by utilizing a combination method to create different groups, and then a conventional linearized least square (LLS) method is utilized by each group for locating \( M \). A weighted GDOP metric is implemented online to assess the positioning accuracy of each group. Then, the group having the lowest positioning error among other groups is selected to relocate \( M \) using a proposed LLS, named modified LLS, for the selected group to enhance the positioning accuracy. The created system outperforms different IP systems in the market for the last decade in terms of time, complexity, and accuracy. The created IP system has a positioning error around 25 cm\(^2\) of MSE in a hard environment, which is less than those of different IP systems created recently in the market.

1 | INTRODUCTION

In indoor localization systems (ILSs), the main goal is to obtain an efficient and precisely sufficient indoor localization technique, flexible to any changes in the conditions of any environment, convenient for expanded areas, and easy to use as possible with complicated tasks. Different techniques like fingerprint and geometric techniques (such as triangulation and trilateration) using specific technologies have been proposed. Depending on these techniques, several ILSs presented indoor location-based services (ILBS) [1]. Nowadays, no commercial indoor positioning (IP) system is convenient to solve the emergency responder's location problems [2]. This is because all solutions need advance calibration, measurements, configuration, and deployment. In scenarios such as emergencies, we do not have sufficient time and flexibility to set up all sensors in a suitable way that may assist in obtaining a precise accuracy to position a mobile target, but command centres need to observe and control the movement of their operational duties, while rescuers are trying to reveal casualties to apply a convenient care. The most suitable people for such cases are the police, firefighters, civilians, and military. We present an IP system in a harsh indoor environment convenient for various statuses including emergency statuses. Indoor environments might be divided as structured or known, semi-structured, and unstructured or unknown based on the control that the ILSs take possession of them [3,4]. In radio frequency (RF) communication network, localization might be distributed into range-based and range-free approaches [5]. The researchers consider that radio signal strength (RSS) is the most known range-free
approach. Experimental or theoretical paradigm of the signal diffusion in this approach is converted into distance or position measurements [6, 7]. The range-based techniques are based on the measurement of distances between transceivers implementing the time of flight, time difference of arrival (TDOA), or two-way ranging–time of arrival (TWR-TOA) [8].

Usually, researchers presumed that some anchor nodes assure the tasks via information sharing and cooperation [9, 10]. However, for different situations, only a limited number of anchor nodes are required to take part in a particular effectiveness. For instance, a walking target may come into the controlling domain of five anchor nodes, but only three of them are sufficient to acquire positioning task simultaneously. In addition, the physical qualifications, such as energy, time, and ability of sensing of wireless sensor network (WSN), ought also to be deemed. Therefore, it is very important to specify how many and which anchor nodes should attend in the cognitive task so as to reduce redundancy information and energy consumption while still providing requisite accuracy [11–13].

The created algorithm operates to avoid setting up all anchors in an appropriate way and only delineate them at random for reducing the time of installation and cost of utilizing a towering number of sensors, and implemented for properly locating a mobile station with positioning error ranging from 10 to 25 cm² of mean square error (MSE) in different indoor circumferences. The created algorithm is utilized experimentally implementing the ultra-wide band (UWB) technology. The main challenge to create an indoor localization system in an indoor environment using the UWB technology is to obtain an appropriate method of non-line-of-sight (NLOS) identification and mitigation. So, in the present paper, using such method is avoided while implementing the UWB technology as explained in the following sections.

The contributions of this work are as follows: (i) cluster the entire anchor nodes into different groups using a combination method and locate the mobile station by each anchor node group using conventional linearized least square (LLS) (create different IP systems), and then, utilize a weighted GDOP (WGDOp) evaluation metric to measure the positioning accuracy of each created IP system. (ii) Create an anchor selection (AS) approach by selecting the appropriate anchor node group that has the lowest WGDOP value obtained from its IP system. (iii) Finally, create a modified LLS method for relocating the mobile station by the selected anchor node group.

A survey of the IP system corresponding to this work is introduced in Section 2. The system model is explained in Section 3. Computation of WGDOP in linearized LS is offered in Section 4. AS and the modified LLS approaches are presented in Section 5. Activities of the experimental and evaluation of the created system are presented in Section 6. Section 7 summarizes the discussion and results corresponding to the experimental activities. Finally, a conclusion is presented in Section 8.

2 INDOOR POSITIONING SYSTEMS SURVEY

For the last 2 decades, the problem of range-based localization system has been studied, particularly in the field of sonar and radar, where distance measurement is obtained from TOA or TDOA [14–18]. Different IP systems utilizing UWB technology are built to locate a mobile station in various indoor environments such as normal or emergency under different measurements. Some of them are stated below.

In 2019, the authors presented a closed-form positioning method for the measurement of multiple TDOAs and single TOA. The presented method approximates the final location result implementing three-step weighted least squares (WLSs). The first WLS tools up a premier location for the last two steps. Therefore, the technique implements two WLSs for estimating the location based on heteroscedastic TOA and TDOA measurements. Additionally, the GDOP of the presented hybrid TDOA and TOA localization has been derived. The analysis of GDOP shows that the created hybrid positioning has lower GDOP than TDOA-only localization. This means the presented hybrid localization has a better accuracy than TDOA-only positioning. The author claims in the simulation setup that the presented positioning approach may have better rendering than the closed-form TDOA-only positioning technique, and the accuracy of positioning may estimate Cramer–Rao lower bound when the TDOA estimation errors are small [19].

The authors of Ref. [2] present an AS method using MSE metric to evaluate the performance of each anchor node group. Computing the MSE metric will need for the true value of the estimated target. Since it is unknown, the authors derived an equation, which is mathematically complicated to compute the MSE without the true value and used the estimated distance instead. So, to enhance the estimated distance, an NLOS identification and mitigation method is needed. First, the anchor nodes are clustered into different groups of two up to n – 1 anchors implementing a combination approach. Each group computes the position of the same mobile station using LLS. After having several positions based on the number of anchor node groups, the created MSE is used to assess the accuracy of positioning of each group, then the group that has less MSE among other groups is selected to be used for relocating the mobile station using the WLS method. The author claimed that they obtained a positioning accuracy with MSE about 50 cm².

In 2017, the authors of Ref. [20] created a modified least square iterated (MLSI) to reduce error and modify the connection of anchors with M. The MLSI utilizes an iteration technique to minimize the error of the traditional LS technique. The authors claim that the MLSI can efficiently enhance the location error rate. When implementing a system of four fixed (anchor) nodes, the medium error is about 0.8 m. But, increase fixed nodes from 4 to 5; the value of error is reduced to 0.48 m. The concept of this technique is to optimize the measurement vector implemented in the main equation of the traditional LLS technique by including the average measurement error. Also, the localization accuracy could be maximized while using more built-up anchor nodes.

The algorithms of the localization performance are discussed by Poulse [21] in terms of the cumulative distribution function and root mean square of localization errors.
The results of the experiment explain the efficiency of various positioning approaches for UWB technology in indoor environments. The fingerprint estimation approach presents better rendering compared to LLS estimation and Weighted Centroid Estimation (WCE) algorithms. Results of the experiment present that the LLS approach has poor rendering for UWB indoor localization. Three different localization algorithms are evaluated in the same situations (LOS and NLOS). These algorithms are the LLS method, fingerprint (FP) method, and WCE. The authors claimed that the FPE approach shows better execution for LOS and NLOS channels. However, the FP complexity and computational time are high as compared to LLS and WCE. The localization accuracy is based on the experiment time. If the experiment time increases, the FPE algorithm presents poor execution when compared to LLS. The LLS approach presents high localization accuracy when the experiment time increases. For some experiment points, the FPE and WCE present the same execution when compared to LLS.

In 2015, the WGDOP metric is created to choose the measurement units to enhance the location accuracy [22]. In this work, a WGDOP calculation algorithm using matrix operations easy for hardware implementation is presented. In addition, the created technique is can be utilized when more than four measurements exist. Even when utilizing the all-in-view approach for localization, the presented approach can minimize the computational overhead. The presented WGDOP technique with less computation is compatible with the global positioning system, WSN, and cellular communication systems. The created WGDOP calculation with matrix operations provides an accurate WGDOP calculation and it is very convenient to utilize in practical hardware equipment.

From the aforementioned literature, we can observe significant impacts, which are time consumption and complexity of the created systems. In most literature using UWB technology, an appropriate NLOS identification and mitigation method is needed to proceed with their algorithms. Also, all literature except [2] are not able to evaluate the created system online, but, usually, the positioning accuracy of the created system will be computed offline when the estimated position will be compared to the true position. An IP system that has lower time and complexity than the aforementioned literature is presented. We created an IP system utilizing UWB technology without using the NLOS identification method and compared online different positioning accuracy obtained by different anchor node groups and select the best group that has less positioning error among all other groups and then used this group to relocate the mobile station using the created modified LLS.

3 | SYSTEM MODE

The created system contains different steps as shown in Algorithm 1 starting with anchor node distribution ending to locate the mobile station using the selected group having best positioning performance, then using the created LLS algorithm to relocate the mobile station. In this algorithm, as shown in Figure 1, we start with installing randomly $n$ anchor nodes inside an indoor environment having 27 m length and 25 m width. In this area, there are two types of walls, concrete and hollow; and a mobile station M should move around the walls. UWB radio technology is used to communicate M and anchor nodes. The UWB commercial device used in this experiment is called DW1000-EVK 1000. We cluttered all anchor nodes into different groups, where each group may have 4 to $n-1$ anchor nodes as shown in Equation (13). Then, the M position is computed using the conventional LLS method by each group of anchor nodes. So, we obtain several measurements of M position, and then, the WGDOP metric is used to measure the positioning accuracy of each group. Then, the group having less positioning error among all other groups is selected (anchor selection) to recompute the M position using the created LLS (modified LLS) method to enhance the positioning accuracy. The following subsections briefly explain the proposed algorithm.

Algorithm 1 Positioning system

1: **procedure** INSTALLATION OF ANCHORMODES  
Create different anchor node groups.
2: **procedure** CLUSTERING NODES

$$p(n) = \binom{n}{4} + \binom{n}{5} + \ldots + \binom{n}{\hat{n}}$$

where $\hat{n} = n - 1$
3: **end procedure.**

1: **procedure** LLS METHOD Locate the mobile station

$$\hat{M} = \begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix} = \left( A^T A \right)^{-1} A^T b + \begin{bmatrix} A_{x1} \\ A_{y1} \\ A_{z1} \end{bmatrix}$$

3: **end procedure.

1: **procedure** NLOS MITIGATION >Select the optimum anchor group performance.
2: **procedure** WGDOP

$$WGDOP = \sqrt{\text{tr} \left( G^T K^{-1} G \right)}^{-1}$$
3: **end procedure.

1: **procedure** RELOCATE THE MOBILE > Use Modified LLS
2: **procedure** CREATED MODIFIED LLS

$$\hat{M} = \begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix} = \left( A^T A \right)^{-1} A^T (\hat{b} - T) + \begin{bmatrix} A_{x1} \\ A_{y1} \\ A_{z1} \end{bmatrix}$$
3: **end procedure.
3.1 | Installation of anchor nodes

In the anchor distribution phase, randomly \( n \) anchor nodes in an area with 25 m width and 27 m length were installed. This area includes two concrete walls (3 m apart) with 20 m thickness, and also has three hollow walls with 12 cm thickness. Also, the mobile station moves in this area. Figure 1 illustrates anchor nodes installation phase. In this figure, we can observe the estimated distance \( d, \) blue line \) between the mobile station (red dot) and each anchor node (black square). This distance has an error varies based on signals travel from the anchor nodes to the mobile station. Some signals travel directly from the anchor nodes and some are obstructed by different number and type of walls. The yellow line presents the selected anchor group using the WGDOP metric.

3.2 | Target Localization using LLS

Approximating a node position in three-dimensions requires distance information from at least four anchor nodes. We present a three dimensional localizations analysis in a harsh indoor environment. Let \( M = [x_i; y_i; z_i] \) denote the position of the mobile station in Cartesian coordinates. Also, \( A_i = [Ax_i; Ay_i; Az_i] \) presents positions of the anchors. \( i = 1, \ldots, n \), expresses the anchor index and \( n \) expresses the total number of anchor nodes. So, we are able to calculate the Euclidean (true) distance \( r \) between \( M \) and anchor nodes in a common way as presented in Equation (1).

\[
r_i^2 = ||A_i - M||^2 = (Ax_i - x)^2 + (Ay_i - y)^2 + (Az_i - z)^2.
\]  

(1)

A positioning approach should be utilized once the ranges to various anchors are computed to calculate the mobile node location. The most generic localization method implemented for RSS-based positioning is the hyperbolic positioning algorithm [23]. As aforementioned, \( r \) expresses the true range and let \( d \) express the estimated range taken away by a wireless sensor as then the error could be calculated as shown in Equation (2).

\[
e_i = r_i - d_i
\]

(2)

The estimated location could be computed as presented in Equation (3) iteratively utilizing a straight gradient method as an example.

\[
\hat{M} = \begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix}_{k+1} = \begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix}_k - \alpha \begin{bmatrix} \frac{\partial \epsilon}{\partial x} \\ \frac{\partial \epsilon}{\partial y} \\ \frac{\partial \epsilon}{\partial z} \end{bmatrix}
\]

(3)

where \( \sigma \) is a scalar chosen to reduce \( \epsilon \). Also, \( \hat{x}, \hat{y}, \hat{z} \) are the measured coordinates of the \( M \) which denotes the mobile station. In this approach, a premier value of the localization estimation is required. To modify this non-linear problem into linear, the hyperbolic localization approach is utilized by the least square technique [24, 25] as explained in the following subsection.

3.3 | LS linearization

In the collection of all sub-equations in Equation (1), to linearize the LS problem, a member of this collection is chosen as
a reference equation and deducted from all other members in
the main equation (Equation 1).
We specify the distance between anchor node 1 and the
mobile station mentioned in Equation (1) as the equation
reference (Equation 4) shown below:
\[
r_1^2 = (Ax_1 - x)^2 + (Ay_1 - y)^2 + (Az_1 - z)^2
\]  
(4)

\[
\begin{bmatrix}
Ax_2 - Ax_1 \\
Ax_3 - Ax_1 \\
\vdots \\
Ax_n - Ax_1 \\
Ay_2 - Ay_1 \\
Ay_3 - Ay_1 \\
\vdots \\
Ay_n - Ay_1 \\
Az_2 - Az_1 \\
Az_3 - Az_1 \\
\vdots \\
Az_n - Az_1
\end{bmatrix}
\]

A = 

\[
b = 0.5 \begin{bmatrix}
(Ax_2 - Ax_1)^2 + (Ay_2 - Ay_1)^2 + (Az_2 - Az_1)^2 + d_1^2 - d_2^2 \\
(Ax_3 - Ay_1)^2 + (Ay_3 - Ay_1)^2 + (Az_3 - Az_1)^2 + d_1^2 - d_3^2 \\
\vdots \\
(Ax_n - Ax_1)^2 + (Ay_n - Ay_1)^2 + (Az_n - Az_1)^2 + d_1^2 - d_n^2
\end{bmatrix}
\]

(5)

Thus, the estimated mobile position \( \hat{M} \) will be as presented in
Equation (10).
\[
\begin{bmatrix}
\hat{x} \\
\hat{y} \\
\hat{z}
\end{bmatrix} = (A^T A)^{-1} A^T \hat{b} + \begin{bmatrix}
Ax_1 \\
Ay_1 \\
Az_1
\end{bmatrix}
\]

(10)

4 | WEIGHTED GDOP

As stated in our work for anchor selection [2], the derived MSE
must have the enhanced distance measurement to be able to
work conveniently for comparing the performance of the
created systems, so proper NLOS identification and mitigation
method are needed. The main goal in the proposed algorithm
is to avoid using the NLOS identification method, so, we
implement the WGDOP metric. The WGDOP is computed as
shown below.

Commonly, WGDOP is utilized to select the convenient
measurement unit’s subset among all obtainable ones by
defining the geometric impact of their disposition. Each
measurement is assumed to have the same variance of error. If
the unit of measurement subset has the lowest value of GDOP,
the subset will be utilized as the most accurate one for
localization. We define \((x, y, z)\) and \((Ax_1, Ay_1, Az_1)\) as the
locations of the mobile station and anchor nodes respectively.
The GDOP is an accuracy measurement for localization sys-
tems and relates closely with the geometry matrix (G) [22].
Since we deal with three dimension positions, the element of
matrix G is as shown below.
\[
f_{i1} = \frac{\hat{x} - Ax_i}{d_i}, \quad f_{i2} = \frac{\hat{y} - Ay_i}{d_i} \quad \text{and} \quad f_{i3} = \frac{\hat{z} - Az_i}{d_i}
\]

where \( \hat{x}, \hat{y}, \hat{z}, i \) denote the estimated coordinates of the mobile station and the index number of an anchor node respectively. Also, \( d \) denotes the estimated distance. So, the \( G \) matrix will be expressed as shown below:

\[
G = \begin{bmatrix}
  f_{1,1} & f_{1,2} & f_{1,3} & 1 \\
  f_{2,1} & f_{2,2} & f_{2,3} & 1 \\
  \vdots & \vdots & \vdots & \vdots \\
  f_{n,1} & f_{n,2} & f_{n,3} & 1 \\
\end{bmatrix}
\]

Then, the GDOP is expressed as shown in Equation (11).

\[
GDOP = \sqrt{\text{tr}(G^T G)^{-1}}
\]  

(11)

Usually, each distance measurement has different variance in a real environment. A significant example is the combination of different positioning systems. \( K \) is a diagonal matrix and expressed as a weighted matrix.

\[
K = \begin{bmatrix}
  \sigma_1^2 & 0 & 0 & \ldots & 0 \\
  0 & \sigma_2^2 & \vdots & \ldots & 0 \\
  0 & 0 & \sigma_3^2 & 0 & 0 \\
  \vdots & \vdots & 0 & \ddots & 0 \\
  0 & 0 & 0 & \ldots & \sigma_n^2 \\
\end{bmatrix}
\]

\( \sigma^2 \) and \( n \) are the variances of the estimated distance and the total number of anchor nodes respectively. So, the WGDOP is given by Equation (12).

\[
WGDOP = \sqrt{\text{tr}(G^T K^{-1} G)^{-1}}
\]  

(12)

5 | ANCHOR SELECTION AND MODIFIED LLS

As mentioned in Section 3.1 regarding the use of the combination method for clustering the anchor nodes into different groups as explained in the following subsection, the LLS method is used to compute the estimated location of \( M \) for each anchor group. Then, the WGDOP algorithm is used to assess the localization accuracy of every anchor group. Also, we should mention that the WGDOP metric is computed and compared for groups having the same number of anchor nodes when the number of these groups is between 4 and \( n - 1 \). The group having the lowest WGDOP is then selected and all other anchor groups are taken away. Then, the created algorithm (modified LLS) is implemented to relocate the mobile station as presented in the following subsection.

5.1 | Anchor selection

The authors clustered \( n \) anchor nodes into different groups using the combination method. Every group may have 4 to \( n - 1 \) anchor nodes. The probability of the total number of anchor groups is computed using a combination method as shown in Equation (13).

\[
p(n) = \binom{n}{4} + \binom{n}{5} + \ldots + \binom{n}{\hat{n}}
\]  

(13)

where \( \hat{n} = n - 1 \) and \( n \) denote the aggregate number of the selected anchors and the total number of the entire anchors respectively. Every group will compute the position of the mobile station using a conventional LLS, then a WGDOP metric is used to evaluate the performance of all groups to find the best positioning accuracy that a group can have among all other groups. Then, the system will select and use the group that has the best performance to relocate \( M \) utilizing the modified LLS.

5.2 | Modified LLS

When using the UWB technology in an indoor environment, the very first issue that should be taken into account is to determine the type of propagation channel (LOS or NLOS) between the transmitter and receiver, then to mitigate the NLOS channels to obtain a precise measured distance. The precise estimated distance allows creation of an accurate IP system. But, obtaining such a goal is a difficult task due to not common that we can identify the propagation channel accurately and to obtain the correct error of the measured distance to mitigate the NLOS. For selecting the appropriate anchor group, the NLOS identification and mitigation method using the WGDOP is avoided. Then, for relocating the mobile station, a modified LLS algorithm is created using only the variance of the measured distance online to. So, Equation (10) is modified using the vector of variance of measured distances expressed in Equation (14).

\[
T = \alpha \begin{bmatrix}
  \sigma_1^2 & - \sigma_2^2 \\
  \sigma_1^2 & - \sigma_3^2 \\
  \vdots & \vdots \\
  \sigma_1^2 & - \sigma_n^2 \\
\end{bmatrix}
\]  

(14)

where \( \alpha \) is a scalar specified based on the type of environment.
Then, modifying Equation (10) with new vector of $T$, the modified estimated position of a mobile station is computed as shown in Equation (15).

$$\dot{M} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix} = (A^T A)^{-1} A^T (\dot{b} - T) + \begin{bmatrix} A_{x1} \\ A_{y1} \\ A_{z1} \end{bmatrix} \quad (15)$$

6 | EXPERIMENT SETUP

A real experiment using UWB technology is implemented to evaluate and validate the proposed system in an indoor environment. In this experiment, two different trajectories of a mobile station moving around the presented area are shown in Figure 1. The UWB device utilized in this experiment is called Decawave 1000 (DW 1000-EVK 1000) manufactured by Decawave. The characteristics of this device are explained briefly in Ref. [26]. In an indoor environment, the UWB technology is one of the robust technologies, but it requires a method of NLOS identification and mitigation to obtain a precise IP system [27]. We avoid the challenge of the NLOS identification method by creating an AS method using WGDOP and creating a modified ILS method to locate the mobile station.

In this experiment, two different scenarios for a moving target in a harsh indoor environment are designed to assess the created system implemented for a mobile station in various directions and measurements. The indoor environment area has two concrete walls, two hollow walls, and office furniture. Every concrete wall has 20 cm thickness, also, these walls are separated with a distance of 6 m. The hollow walls have a thickness of 12 cm and are too far separated from each other. The form of this area is rectangular with 27 m length, 25 m width, and 0 m height. Figure 1 illustrates the indoor environments. The anchor nodes are randomly installed and their coordinates in these scenarios are as mentioned below:

A. $A_1 = (-10; 10; 0), A_2 = (2.5; 10; 0), A_3 = (5; -15; 0), A_4 = (10; 0;0), A_5 = (2; 2; 0)$, and $A_6 = (10; 7.5; 0)$, as shown in Figure 2.

B. $A_1 = (-5; -10; 0), A_2 = (-5; 10; 0), A_3 = (5; -15; 0), A_4 = (10; 0; 0)$, and $A_5 = (-10; 2; 0)$, and $A_6 = (0; 5; 0)$, as shown in Figure 3.

where $A_i$ expresses the sensor nodes in the network.

The standard deviation and variance of the measured distance used in the WDGOP algorithm and the modified ILS respectively are computed online from eight distance measurements extracted every 1 sec from the aforementioned device [28]. Also, the Bias is used to enhance the distance measurements used in the two algorithms [2, 20] compared to the proposed system. Table 1 shows the values of the variance, and bias of the measured distances ranging from 2 m to 26 m.

7 | RESULT AND DISCUSSION

As mentioned in Section 2, all aforementioned literature require an appropriate NLOS identification and mitigation method to execute their algorithms. Also, usually, these systems cannot be evaluated online. So, the complexity and time
**FIGURE 3** The mobile station moves through the indoor environment (Scenario 2)

**TABLE 1** Experimental data base needed for systems [2, 20] compared to the created system, where $r, d, \sigma^2$ expresses the true, measured, and variance of the distances, respectively, for LOS, soft NLOS, and hard NLOS channels and $Av$ express rate of the bias of the estimated distance.

|       | LOS          | HNLOS         | SNLOS         |
|-------|--------------|---------------|---------------|
| $r(m)$ | $d (m)$      | $\sigma^2 (m^2)$ | $\sigma^2 (m^2)$ | $\sigma^2 (m^2)$ |
| 2     | 2.08         | 0.08          | 0.00          | 4.16          | 0.16          | 0.06          |
| 4     | 4.11         | 0.11          | 0.00          | -             | -             | -             |
| 6     | 6.03         | 0.03          | 0.01          | -             | -             | -             |
| 8     | 8.07         | 0.07          | 0.06          | 9.31          | 1.31          | 0.09          |
| 10    | 10.06        | 0.06          | 0.01          | 10.78         | 0.78          | 0.08          |
| 12    | 12.07        | 0.07          | 0.02          | 12.57         | 0.57          | 0.09          |
| 14    | 14.07        | 0.06          | 0.02          | 15.02         | 1.02          | 0.09          |
| 16    | 16.05        | 0.05          | 0.00          | 16.95         | 0.95          | 0.05          |
| 18    | 18.07        | 0.07          | 0.06          | 18.45         | 0.45          | 0.12          |
| 20    | 20.07        | 0.07          | 0.08          | 20.70         | 0.70          | 0.14          |
| 22    | 22.09        | 0.09          | 0.02          | -             | -             | -             |
| 24    | 24.07        | 0.07          | 0.00          | -             | -             | -             |
| 26    | 26.05        | 0.05          | 0.01          | -             | -             | -             |

$AvBias$ $0.052$ $0.822$ $0.279$

Abbreviations: NLOS, non-line-of-sight.

consumption when using these systems are the main impacts. The main goal in this contribution is to obtain a precise positioning system having less error in position while the mobile moves through a harsh indoor environment. Also, the created system should be simple and not complicated with less time of performance. The contributions of this work can be explained as follows: (i) to avoid using any NLOS identification method; (ii) no requirement of predefined data such as distance bias as needed in the works of [2, 20] compared to the created work, but using the variance of the estimated distance extracted online from the UWB device will help in the design of such systems which are much more reliable to be used in the commercial market; and (iii) modify the conventional LLS by creating and adding a vector of variance distance (T) to the
vector of the estimated distance (b) as shown in Equation (15) to improve the localization accuracy. Two different scenarios are implemented using the UWB device (DW1000-EVK1000). The mobile station is restricted to move through different wall types as illustrated in Figures 2 and 3. After the experimental activity, the empirical cumulative distributed function (ECDF) of the MSE for the proposed system and systems created by Albaidhani et al. [2] and Hao et al. [20] between the approximated and real positions is computed and compared. Figures 4 and 5 present the ECDF for the aforementioned system for scenarios 1 and 2, respectively. The ECDF of the proposed system, and the systems described in Ref. [2, 20] in the two scenarios shows that the MSEs are around 25 cm², 50 cm², and 2.5 m², respectively.

8 | CONCLUSION

This study presents a novel algorithm corresponding to localization systems, especially in indoor environments. The created algorithm is divided into two main phases. In the first phase, n anchor nodes are randomly installed in a harsh environment and clustered into different groups of 4 to n – 1 of nodes communicated to the mobile station by the UWB technology. Each group implements a conventional LLS method to locate the mobile station. Then, a WGDOP metric is used to select the best-performing anchor node group among the other groups. We avoid using any NLOS methods to save consumption time and minimize the system complexity. In the second phase, we relocate the mobile position by the selected group utilizing the created LLS (modified LLS) by adding a vector of variance of measurement distance online to the measurement distance vector in the prime equation of the traditional LLS. The obtained positioning accuracy is about 25 cm² of MSE which is much better than that of other IP systems created in the literature in the last decade. In future, we plan to integrate the created system with internet of thing technology, and to use it for helping to locate elderly people, especially in large hospital and males.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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