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Node Localization in a Network of Doppler Shift Sensor Using Multilateral Technique

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ABSTRACT: Localization is the process of determining the location of a target(s) in a given set of coordinates using a location system.However, due to environmental uncertainty and Doppler effects, mistakes in distance estimations are created in physical situations, resulting in erroneous target location. A range-based multilateration technique is presented to improve localization accuracy. Multilateration is the method of calculating a position based on the range measurements of three or more anchors, with each satellite acting as the sphere's center. The distance between the satellite and the receiver is represented by the sphere's radius. The intersection of four spherical surfaces determines the receiver's position. This study's approach proposes a simple measure for evaluating GRT based on reference node selection. The algorithm utilizes these reference nodes, seeking to determine the optimal location based on ranging error. It calculates GRT values for each of the three node combinations. This study evaluates the performance of range-based localization using the Multilateration Algorithm with a Correcting Factor. The correction factor is applied to both the anchor node and the node to be measured; hence, the localization error is significantly reduced. In terms of how much time and money it takes to run and how much hardware it costs, the new method is better than some of the current methods.

KEYWORDS: Trilateration; dopplershift; multilateration; localization; blind nodes; computational complexity.

1. Introduction

A Wireless Sensor Network (WSN) consists of distributed autonomous sensors that cooperatively monitor physical or environmental conditions such as temperature, sound, vibration, pressure, or motion. Each node in a sensor network is typically equipped with a radio transceiver or other wireless communication device, a small microcontroller, and an energy source, such as a battery. In localization services like battlefield surveillance, the information sensed by a node is of less importance unless the position of the sensor is known. The process of finding the geographical position of such a node is called localization. From the localization point of view, there are two types of nodes in a WSN: anchor nodes and tracked nodes [1]. Anchor nodes are nodes whose geographical position is known, for they are equipped with Global Positioning Systems (GPS). A sensor node can detect a change in the physical quantity for which it is meant to be and can also transfer this information to other nodes. If a sensor node does not know its position, the information sent will not include the geographical region in which the change occurred [2,3]. localization is indispensable for localization-based services. Wireless sensor networks (WSN) are some kinds of new generation networks that are composed of a large number of smart devices, such as smart sensors with sensing, computing, and communicating units. The tiny smart sensors are autonomous and embedded with limited power sources that are not renewable [4,5]. Wireless network, communications, and integration advancements have made this new generation of WSN suitable for a variety of commercial and military applications.The data supplied by the sensors in such applications is frequently trivial in comparison to accurate knowledge of the actual placement of nodes. As a result, establishing the locations of sensors, also known as localization, is a critical challenge in WSNs, not only in and of itself, but also as a prelude to addressing more complex and sophisticated network tasks. Many domestic and international researchers have conducted in-depth investigations into the WSN localization method in recent years. A WSN consists of a node network spatially distributed over a monitoring area where the nodes can be integrated into vehicles or robots with motion in a given environment [6]. Nodes are small, low-cost devices with low processing capacity and low power consumption. Some of their tasks include the collection, processing, and transmission of information; they also carry out cooperation with other nodes [7,8].

2. Review of Literature

The use of a global positioning system (GPS) to locate each sensor appears to be the preferred choice. However, in WSNs, such as interior situations where GPS signals are unreliable, this technique is impractical. Furthermore, GPS receivers are energy-intensive, expensive, and too large for small sensors [9,10]. Hence, to extend the life-time of the network, hardware, communication protocols, and processing algorithms should be designed with low energy consumption [8]. Alternative solutions have been proposed in the literature, considering some sensors, called anchor nodes, having known positions and unknown nodes (blind nodes), which require localization. In practice, anchor node positions can be obtained by using GPS or by installing anchors at positions with known coordinates [11]. The most widely used localization principle of a multilateral process is illustrated in Figure 1.

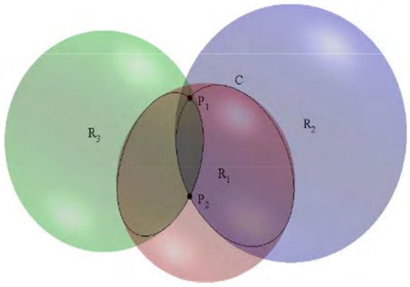

Figure 1. A Visualization of Trilateration for location Estimation

In line with the development trend of mobile computing and its embedded technologies, WSN has become widely used in daily applications such as healthcare, monitoring, natural disaster prevention, and surveillance [12]. Therefore, localization awareness is an important part of network design. Due to the complexity of related algorithms, researchers in this area have made significant progress, but there are still quite a few deficiencies suggested a WSN distributed localization approach based on local spatial constraints, in which a piece of software repeatedly solves a set of local spatial constraints to estimate the coordinates of a sensor node, which is then constantly updated based on the nearby nodes in the communication range. The location estimation approaches mentioned here rely on a large amount of important data that can often only be gathered by distributing and sharing range and node position data across a network [13]. Furthermore, multi-hop distances between unknowns and anchors must be appropriately blended and represented through information exchange. The most difficult aspect of this process is avoiding cumulative errors that result in huge position estimation inaccuracies, which contradicts the findings of this study. Previous study presented the quadrilateral localization approach, which selects the four anchor nodes with the least path loss, performs combination ranging on three of them, and uses the average of the qualified triangles' coordinates as the measurement node's location coordinate [14]. This helps with accuracy to some extent. As a result of this technique, the localization process might quickly become prohibitively expensive in terms of the communications and power required to disseminate the relevant data, which hence does not support the study's suggestion. It can be hard to use the DV-hop and DV distance algorithms from previous study if the network isn't isotropic and there aren't a lot of nodes [15].

Although Euclidean techniques are more resistant to irregular networks, they necessitate a higher degree of degree and anchor density for accurate position estimation [16,17]. I proposed a compressed sensing localization approach based on a deterministic sensing matrix, in which numerous sensor nodes are defined as a sparse matrix in a discrete region, noise measurement is recovered using received signal strength information, and the target is then located. To avoid unnecessary communications and provide scalability to varied network sizes, topologies, and irregularities, these and all other ranging propagation techniques and algorithms must be efficient and robust. To minimize position estimate mistakes, they must also accurately propagate and represent distances from unknowns to anchors. Previous study suggested a cluster-based WSN localization technique that combines the cluster structure and a global system to express the network's logic and lowers measurement errors based on multi-hop probability, improving node localization accuracy. Previous studies recommended utilizing the differential particle swarm optimization technique to optimize the location coordinates of the nodes to be measured, and it proposed using % to adjust the average hop distance of anchor nodes in DV-Hop [3,11,18]. Trilateration fails when a GPS navigator receives inadequate satellite data because it is unable to follow enough satellites [19,20]. Large structures or mountains can also obscure weak satellite signals, making exact location calculations impossible. If the GPS device is unable to deliver accurate position information, it will notify the user in some way [21]. Satellites might also be down for a while. Because of variables in the troposphere and ionosphere, for example, signals may move too slowly. Certain rocks and objects on the Earth may also ping signals, causing some confusion. This study follows the same approach as the previous one, but differs in the area of the error correction factor.

3. Statement of the Problems

Anchor nodes in a WSN are completely aware of their location in the geographical region, making it critical to locate sensor node positions. The positions of the sensor nodes are computed using the anchor node positions [22]. Mobile sensors are unable to provide highly accurate positional data because they require centralized processing that takes too long to complete. Latency is one of the main concerns with mobile sensor networks [23]. Because the sensor's position has changed since the last measurements, a longer period for localization may create a delay. Another issue in mobile WSN, Doppler shift, would have arisen. Furthermore, because the majority of proposed localization algorithms require loss of sight (LOS), measurements of mobile sensor nodes may result in localization in a worsened LOS situation [24]. As a result of the battery voltage deterioration, the power supply to the emitter is lowered. Following that, the emitter sends weaker signals with a lower RSSI. As a result, the sensor-to-anchor-node distance is inaccurate. The implication is that the mistake in distance measuring grows as the battery ages, increasing the computational cost [25]. Only if the reference points' coordinates and distances from the target to the reference points are exact can the target be accurately located. In practice, however, due to multipath and environmental uncertainty, mistakes in distance measuring are introduced, resulting in inaccurate target location prediction. As a result, multilateration is used to calculate coordinates utilizing more than three reference sites to reduce the impact of distance discrepancies. It is commonly recognized that the presence of noisy distance measures will generate a flip ambiguity problem if a node's neighbors are roughly collinear [5].

4. Research Methodology

In WSN, there are several ways to represent position location information. Geometric description is the most basic sort of spatial description, and it is used in this work. Under a Cartesian coordinate reference system, a geometric description characterizes space by its geometric form and a group of coordinate points. The space model is a solid representation that is frequently used to define an explicit space with coordinates like (x, y, and z). Different geometric shapes physically define a space. A geometric shape can be either a 2D or 3D primitive. In specialized applications, the building of shapes can be extended to more intricate shapes. In terms of the space geometric shape, coordinates are chosen and ordered in a specific way for each space. The geometric shape of a space is strictly tied to the coordinate description. To estimate the position location of a node, the basic concepts of intersection of distinct lines and the right geometric formulation can be used to determine the accurate point in positioning location methods [24]. Time of arrival (TOA), time difference of arrival (TDOA), and received signal strength intensity (RSSI) are among the methods used to calculate the nodes' placement location coordinates (RSSI). These approaches use lines and angles to calculate the position of a node based on geometric considerations. These principles include triangulation, multilateration, and hyperbolic.

4.1. Multilateration Technique

Multilateration is the process of estimating a position based on the range measurements of three or more anchors [25]. Thus, many localization algorithms check to see if the three reference nodes form a triangle with a minimum angle greater than a certain threshold. Given the distance between three nodes (a, b, and c), the Law of Cosines determines the three angles of the formed triangle:

$$a^2 = b^2 + c^2 - 2bc.\cos(A) \tag{1}$$

An example of the cross points of the geometry relationship of the cross points of spheres using 4 anchor nodes is shown in Figure 2. We use multilateral localization to calculate the 3D positions of an unknown node.

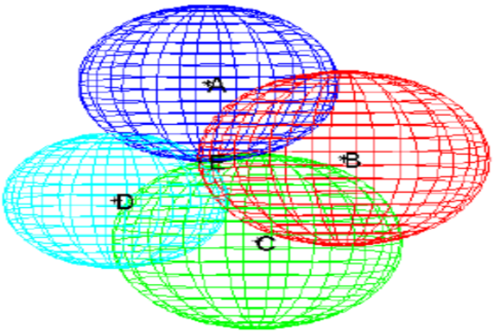

Figure 2. The geometric relationship in 3D localization.

4.2 Algorithm Description

The flow chart of the proposed algorithm is presented in Figure 3. An unknown node forms a reference set of $n-nodes$ based on the RSSI value; $S_{REF} = \{i | RSST_i \in \max_n RSSI\}$, where i is the reference node index. The node generates all possible 3-node combinations of $S_{REF}; that.is.C(n,3) = j$ combinations $\forall(c_1,...,c_n)$. For example, if $n = 5$, the number of combinations $c(5,3) = 10.and.if.n = 4$ then the number of combinations $c(4,3) = 4$.

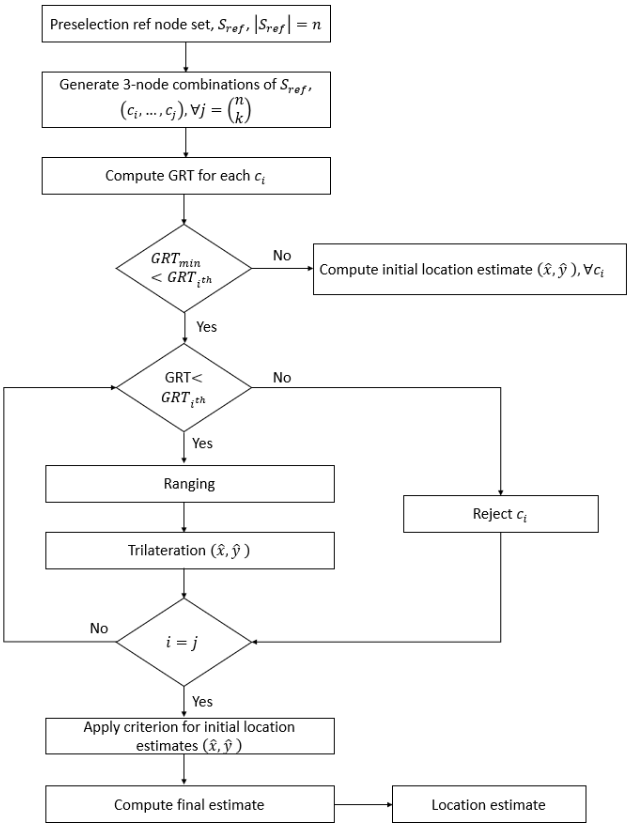

Figure 3. Flowchart of the Algorithma

Using more than five reference nodes increases the number of combinations, hence, the total number of k-combinations of $n-nodes$ is $\binom{n}{k} = \frac{n!}{k!(n-1)!}$. If less than five reference nodes are available, the number of 3-node combinations would be $c(4,3) = 4.or.c(3,3) = 1$, which would probably downgrade the performance. Therefore, for a proper functionality, at least five reference nodes are needed. For trilateration, three reference nodes at the minimum are required. To reduce the computational load, the reference nodes are preselected based on their RSSI value and geometry. The Geometry of Reference Triangle (GRT) values are computed for the 3-combinations in the preselected reference node set. The Algorithm exploits these combinations and aims to find the best ones at a given time for computing the final location estimation of a node. The algorithm is scalable, and can be implemented in low-cost, resource constrained WSN nodes.

4.3. Mathematical Model

As a result, if there are three locations, $(N_1, N_2, \&, N_3)$ as illustrated in Figure 4 below, and the distances between the reference points and object T are known, the point of intersection of the three circles is the presumed location of object T.

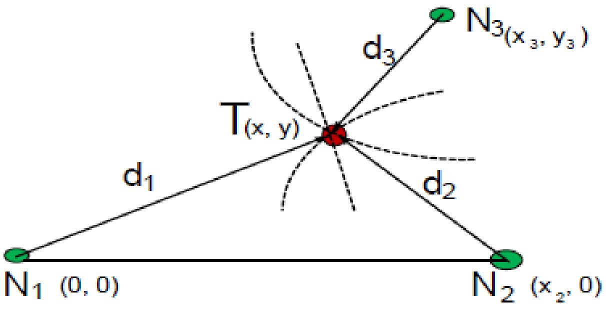

Figure 4. Multilateration principle

The distances ($d_1, \&, d_2$) can be calculated by computing the signal's TOF. The first circle has a radius of (d_1) and the second circle has a radius of (d_2). To get the target T's coordinates, first calculate the distances between reference nodes and the target T using the following equations:

$$d_1 = (t_1 - t_0).c \tag{2}$$

$$d_2 = (t_2 - t_0).c \tag{3}$$

$$d_3 = (t_3 - t_0).c \tag{4}$$

where c is the speed of light, t_0 is the time of signal sent from T, d_1 is the distance between $N_1..and..T$, d_2 is the distance between $N_2..and..T$, d_3 is the distance between $N_3..and..T$, t_1 is the time of arrival of a signal that is sent from $T.to.N_1$, t_2 is the time of arrival of a signal sent from $T..to..N_2$ and t_3 is the time of arrival of the signal sent from $T..to..N_3$. Three intersecting circles with centers at the reference points and radii equal to distance from the target T have the following equations:

$$d_1{}^2 = x^2 + y^2 \tag{5}$$

$$d_2{}^2 = (x - x_2) + y^2 \tag{6}$$

$$d_3{}^2 = (x - x_3)^2 + (y - y_3)^2 \tag{7}$$

where d_1 is the line connecting reference point N_1 and target point T, d_2 is the line connecting reference point N_2 and T, d_3 is the connecting reference point of N_3 and T, the coordinates of the target point T are (x, y), and the coordinates of reference point N_1 are (0, 0), and the coordinates of reference point N_2 are (x, 0). The coordinates of reference point N_3 are (x_3, y_3). The coordinates are found by solving equations (5), (6), and (7):

$$x = \frac{x_2{}^2 + d_1{}^2 - d_2{}^2}{2.x_2} \tag{8}$$

$$y = \frac{x_3{}^2 + y_3{}^2 + d_1{}^2 - d^2{}_3 - z.x.x_3}{2.y_3} \tag{9}$$

The coordinates of the target T can be estimated and the position they define is the only one where all three circles intersect [9].
Using the dot() function, we can calculate Euclidean distance (Python codes)

a) Use the dot() method to calculate Euclidean distance.
b) np import numpy
c) Make the points into arrays.
d) np.array = x
e) y = np.array (()); y = np.array (()); y = np.array
f) # removing the vector
g) temperature = x - y
h) np.dot = sum sqr (temp.T, temp)
i) # Taking the square root and
j) # Euclidean distance printing
k) print(np.sqrt(sum sqr))

In the trilateration procedure, the Received Signal Strength Indicator (RSSI) value and cluster information are used to compute the node position using equation (8) and (9) [15, 20].
The following is an example of a localization error:

$$d_{error} = \sqrt{(x_e - \hat{x})^2 + (y_e - \hat{y})^2 + (z_e - \hat{z})^2} \tag{10}$$

where $(\hat{x}, \hat{y}, \hat{z})$ are the estimated values of the target node? The average localization error is then measured by:

$$E_{avg} = d_{error} / N$$

5. Result and Discussion

At least four or more reference nodes with known coordinates are required for 3D localization. The fundamental mathematical principles for determining the placement location are addressed. The positioning of a target node can be done with high accuracy using this method. The precision of the calculations is unaffected by increasing the distance between the reference node and the target node. The RSSI error has no effect on the x and y positions in the ground node, however the z-position swings with a gap as the RSSI error grows, and the average distance error remains the same. Because the RSSI standard deviation shows three values, all within the range, and has a sufficiently low error rate, this method looks to be a proper localization

5.1. Distance Estimation Error

“Ranging Error” is the difference between the estimated and the time inter-node distance. Ranging error Δd_i for sample i is defined as:

$$\Delta \hat{d}_i = \hat{d}_i - d$$

where $\hat{d}_i .and. d$ are the estimated and the distance respectively. The mean and the standard deviation of the ranging error $\Delta \bar{\hat{d}}_i .and. s\Delta \hat{d}_i$ respectively are defined as:

$$\Delta \bar{\hat{d}}_i = \frac{1}{n}\sum_{i=1}^{n}\Delta \hat{d}_i , s\Delta \hat{d}_i = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\Delta \hat{d}_i - \Delta \bar{\hat{d}}_i\right)^2} \qquad (11)$$

where n is the number of distance estimated samples.

Ranging has a significant role in range based localization, and ranging accuracy impact localization accuracy. Ranging error is probably the most significant and characteristic factor that impairs RSSI based localization accuracy, mainly because of the sensitivity of the RSSI changes [12]. The sources of error in RSSI based ranging can be classified as: propagation environment, weather conditions, interference and so on. Two major sources of error are path loss exponent (PLE) estimation error and temperature change [4,26-28].

5.2. Doppler Effects

The frequency shift of a radio wave caused by relative motion between the relevant nodes (transmitter and receiver) is known as the Doppler Effect [29]. This shift is proportional to the velocity and direction of motion of the nodes in relation to the received wave's arrival direction [7]. The same method is used to calculate the user velocity, which is based on satellite speeds acquired from broadcast data [6,29]. As a result, analyzing the characteristics of wireless sensor network localization in the current era of noisy distance measurements is a difficult research topic.

5.3. What is the Doppler Shift Formula, and how does it work?

$$f = \left(\frac{c \pm v_r}{c \pm v_s}\right) f_0 \qquad (12)$$

where C is the medium's wave velocity, V_r is the receiver's velocity relative to the medium (positive if the receiver is travelling towards the source, negative if the receiver is moving away from the source), V_s is the source's velocity relative to the medium (positive if the source is moving away from the receiver and negative if in the opposite direction); f_0 is the frequency that was observed and f is the frequency that was emitted. When the speed of the source and receiver is slower than the velocity of the waves in the medium, the Doppler shift or Doppler Effect formula is used to define the relationship between perceived frequency and emitted frequency.

Observed frequency:

$$f = \left(1 + \frac{\Delta_v}{c}\right) f_0 \tag{13}$$

Change in frequency:

$$\Delta f = \frac{\Delta_v}{c} f_0 \tag{14}$$

where, $\Delta f = f - f_0 \Delta_v = v_r - v_s$ is the velocity of the receiver relative to the source (positive when the source and the receiver moving towards each other) [30,31].

5.4. Step-by-step derivation of Doppler Effect

There are two conditions that must be addressed in order to derive the Doppler effect: Moving Source and Stationary Observer where the Wave travels with the Source:

$$C = \frac{\lambda_s}{T} \tag{15}$$

where

$c - is.the.wave.velocity$

λ_s – wave length of the source

T – time taken by the wave

$T = \frac{\lambda_s}{c}(after.solving.for.T)$s

$d = \frac{V_s}{T}$ (Representation of distance between source and stationary observer)

where:

V_s – Velocity with the source is moving towards stationary observer.

d – distance covered by the source

$\lambda_0 - \lambda_s - d$ (observed wave length)

$T = \left(\frac{\lambda_s}{c}\right) d = \frac{V_s \lambda_s}{c}$ (Substituting for T and using the equation of d)

$\lambda_0 = \frac{(\lambda_s - V_s)}{c}$ Substituting for d

$\lambda_0 = \lambda_s\left(1 - \frac{V_s}{c}\right)$ Factoring

$$\lambda_0 = \left(\lambda_s\left(c - \frac{V_s}{c}\right)\right) = \lambda_s - \lambda_0\lambda_0 \ = \lambda_s - d\Delta\lambda = \left(\lambda_s - \frac{vd_s}{c}\right) = \left(\frac{V_s\lambda_s}{c}\right)$$

$$\lambda_0 = \lambda \ \lambda_s(c - V_s)c\Delta\lambda = \lambda_s\frac{V_s}{c}$$

5.5. Moving Observer and Stationary Source

$$f_0 = c - V_0\lambda_s \tag{16}$$

where

f_0 – is the observed frequency

V_s – Observed velocity

$f_0 = c\lambda_0$ Where,

f_0 – is the observed frequency

V_s – observed velocity

$f_0 = c\lambda_0$

$$c\lambda_0 = c - V_0\lambda_s\left(\frac{\lambda_0}{c}\right) = \frac{\lambda_s}{c}(c - V_0)\lambda_0$$

$$= \lambda_s\left(c - \frac{V_0}{c}\right)\lambda_0$$

$$= \lambda_s cc - V_0(multiplying.by.c)$$

$\lambda_0 = \lambda_s\left(1 - \frac{V_0}{c}\right)\Delta\lambda = \lambda_s - \lambda_0$ (Change in wavelength)

$\Delta\lambda = \lambda_s - \lambda_s cc - v_0$ Substituting for λ

$\Delta\lambda = \lambda_s - \lambda_s cc - V_0$

$$\Delta\lambda = (\lambda_s(c - V_0) - \lambda_s c)c - V_0\Delta\lambda = \lambda_s V_0 c - V_0$$

$$\lambda_0 = \lambda_s cc - V_0\Delta\lambda = \lambda_s V_0 c - V_0$$

5.6. Research Simulation (Doppler Effect)

The configuration of the spread spectrum sound-based locating system used is shown in Figure 5. The suggested system uses an inverse-GPS design, with four microphones set as fixed nodes at known locations and one omni-directional speaker on a mobile platform (mobile station). Silicon microphones (Knowles Electronics, Tokyo, Japan), a speaker (Fostex Company, Tokyo, Japan), a sound interface (Octa-Capture, Roland Corporation, Hamamatsu, Japan), an amplifier (Kama Bay Amp Rev. B, Scythe Inc., Ichikawa, Japan), and a personal computer (Kama Bay Amp Rev. B, Scythe Inc., Ichikawa, Japan) were among the items used (Windows XP, Core 2 duo processor 2.66 GHz and 3 GB RAM). A wired system was employed here for simplicity's sake. A digital thermometer is installed in each microphone and mobile station to monitor the ambient temperature [32,33].

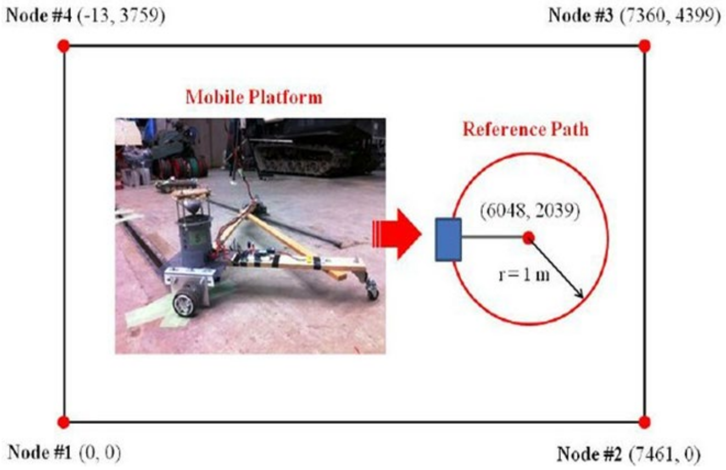

Figure 5. Spread spectrum sound-based local positioning system configuration [32]

The carrier frequency, sequence length, and number of carrier cycles per code chip were the major parameters of the transmitted signal (chip rate). The sampling frequency and sampling bit, as well as other parameters, were set as stated in Table 1 for signal detection. To synchronize signal reception for all microphones, particularly for the arrival time computation, a trigger signal is delivered at the same time as the speaker delivers the spread spectrum sound, as shown in Figure 6.

Table1. Property of spread spectrum sound

Property	Value/Remark
Number of sound wave	1
Sampling frequency	96 kHz
Sampling bit	16 bits
M-sequence length	1,023
Modulation	BPSK
Carrier wave frequency	24 kHz

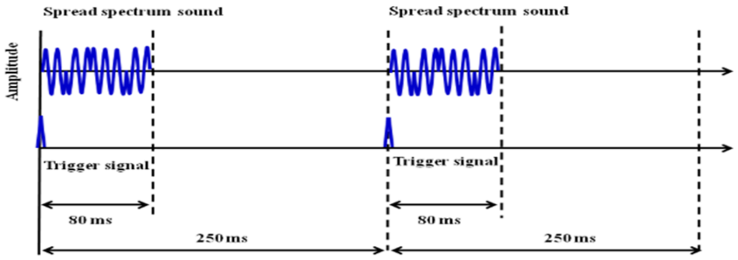

Figure 6. Spread spectrum sound emission and trigger signal for synchronization

6. Conclusion

In varying environmental and weather conditions, achieving location estimates that are accurate and precise is challenging. However, because of multipath and environmental uncertainty, inaccuracies in distance measuring are introduced in practical scenarios, resulting in erroneous target location prediction. To improve localization accuracy and precision, we propose a range-based multilateration algorithm. The algorithm aims to find the best reference node combinations for an unknown node at a given time and space based on the geometry of the reference triangles. The result of the study indicates that the localization error of the algorithm considerably reduces localization error and that it outperforms the often used nearest-neighbors technique. The algorithm can change with the times and find the best reference node combinations for a given situation.

Competing Interest

The authors declare no financial or non-financial competing interests.

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