2021 International Conference on Electronics, Communications and Information Technology (ICECIT), 14–16 September 2021, Khulna, Bangladesh

Coordinates Determination of Submerged Single Mobile Sensor Using Sensor's Mobility

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***Abstract*—In this paper, a new mathematical model has been designed where the location of a single mobile sensor can be determined from a single beacon node. Because the appropriate coordinates of sensor are very much needed for underwater data analysis. If the sensor moves in any straight direction, its location can be determined through this mathematical model. In this proposed model, the distance from the beacon node to the sensor will be measured from just two positions of the beacon node. This mathematical model calculates the coordinates of the sensor in the perspective of the beacon node using the angle that the direction of mobile sensor creates with the earth's latitude, longitude and altitude line. In order to observe the mathematical model practically, it has been simulated with minimal error.**

Keywords— Single Mobile Sensor, Non-parallel Situation, Single beacon Node, Localization, Acoustic Signal

I. INTRODUCTION

There is no end to knowing the world. The world is constantly being explored. Where two-thirds of the earth is water. Most unexplored areas of the world are under water. Exploring terrestrial area is easy and there are many algorithms. But still some challenges to explore under water. For exploring under water, we need to communicate with sensors. But still some challenges to communicate with sensor, if sensor is mobile and single. For this comprehensive exploring Underwater Wireless Sensor Network (UWSN) is important. It is important to develop an appropriate localization mechanism to collect accurate information. The appropriate localization mechanism will only work when appropriate measurement is possible. To measure the appropriate distance, it is necessary to find out how the speed of the acoustic signal change in the vertical water column. In [1] discussed how temperature, depth, salinity affect the acoustic speed in vertical water column. In [2] UWSN has been discovered new type of sensor. It provides fancy opportunities for design and implementation various new application fields in the water. Through this network (UWSN), various parameters in water such as pH, turbidity, dissolved oxygen and temperature can be measured. In [3] coordinates of sensors have been calculated using cayley-menger determinant. The coordinates of the sensors in parallel situation have been calculated using a single beacon node. The sensors are deployed in parallel position with the water surface. Then measure the distance of the sensor from the beacon node to the sensors from six different position. Since the sensors are static, every time a tetrahedron shape is created. Their base remains the same so their volume remains the same. Then solve the $Ax = \mathrm{b}$, find the value of x and find the coordinates of the sensors. In [4] here also, coordinates of sensors in non-parallel situation have been calculated using cayley-menger determinant. Algorithm has been used after create a parallel situation through projection of non-parallel situation. There are also many localization algorithms that are relevant to Underwater Sensor Network (UWSN). Such as ranged-based schemes, range-free schemes, signal processing schemes. In ranged-based schemes, position is calculated through precise distance and angle [5][6]. Localization related application has improved day by day, such as object positioning, tracking in smart space, personal navigation which is necessary for indoor localization. For indoor Global Positioning System (GPS) application does not work. In that case new localization method is needed. Communication on UWSN is also a main fact that Underwater Wireless Sensor Network (UWSN). Acoustic signal is usually used for long distance. Acoustic waves are considered to be the primary carrier of information transmission, because its frequency band is 20Hz-20kHz. Acoustic waves propagate very fast in fluids than air. In air speed of sound is 343.2m/s. In water acoustic signal propagate 4.3 times faster than air. On the other hand, the range of radio waves is 3kHz to 300kHz. Its frequency is much higher but it travels only 100km to 1mm respectively. Radio in vacuum travel at light speed ($3\text{x}10^8$m/s). In any medium, its speed decreases a bit. And optical signal ranges from 400THz to 900THz. It also has high frequency but it can also travel 1 meter to 10 meters [2]. Localizing underwater mobile sensor can have different characteristic, such as low communication bandwidth, large propagation delay, floating node mobility, high error problem. In that case, localized the mobile sensor through mobile acoustic network protocol design [7]. In [8] introduced a new method for calculate beacon positions based on inter-beacon distance, and linearization of the triangle equation that do not require any preliminary estimates. In [9] introduced a new model for localizing the sensor, if the beacon node is mobile-constrained. And in [10] determined the coordinates of sensors where sensors considered as mobile sensor and their speed and velocity are same.

II. PROPOSED MODEL DISCUSSION

A. Algorithm Design

If we have a circle and if we have placed a straight directed object on each position of the circumference of the circle. The angle is formed by the direction of the object with the radius

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of the circle on the object will remain the same in pair of positions but in different direction with radius. Moreover, it will be different with others.

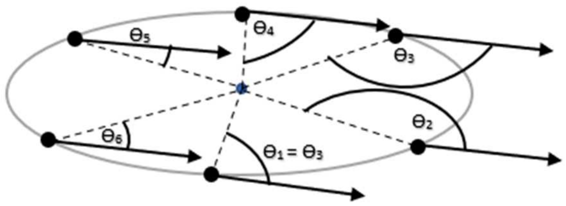

Fig. 1. Proposed model

Assume,

$\Theta_i = \{\Theta_1, \Theta_2, \Theta_3, \Theta_4, \ldots\ldots\ldots$ for each position on the circumference}
Where, I = 1, 2, 3, 4, ...

There are pair of angles whose values are same.
If, $\Theta_1 = \Theta_3$
$\Theta_1 \neq \{\Theta_2, \Theta_4, \Theta_5, \ldots\ldots\ldots\}$ and $\Theta_3 \neq \{\Theta_2, \Theta_4, \Theta_5, \ldots\ldots\ldots\}$
If, $\Theta_1 = \Theta_4$
$\Theta_1 \neq \{\Theta_2, \Theta_3, \Theta_5, \ldots\ldots\ldots\}$ and $\Theta_4 \neq \{\Theta_2, \Theta_3, \Theta_5, \ldots\ldots\ldots\}$

B. *Sensor Discription*

The sensor needs to be mobile sensor whose direction is straight and speed is constant. It could even be a submarine, deep diving vehicle or robotic vehicle.

III. Methodology

A. *Distance Measurement*

Distance can be measure in different ways. For example, through radio and acoustic signal, acoustic signal or synchronous clock. Despite the limitation of acoustic signal Fig. 1 show the existing method that how distance can be measure through acoustic signal. It can be measured by other signals. Here acoustic signal has been chosen, because radio waves do not travel well through salt water. The beacon node and sensor must have the ability to generate and receive acoustic signals.

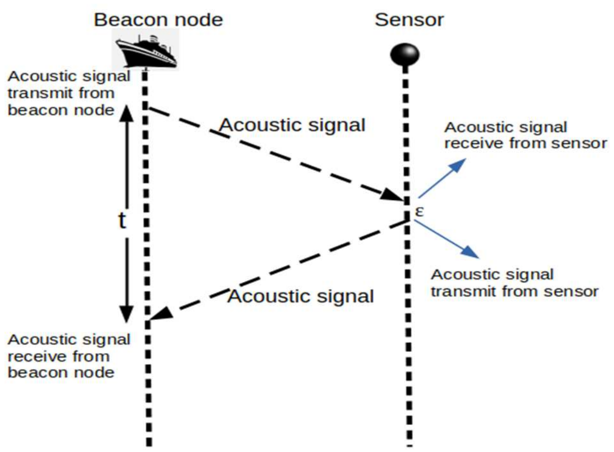

Fig. 2. Distance measurement

Here beacon node will transmit the acoustic signal. Then sensor will receive this acoustic signal. When sensor will receive the acoustic signal, sensor will transmit acoustic signal back. And beacon node will receive this acoustic signal.

So, distance from beacon to sensor = $\left(\frac{t-\varepsilon}{2}\right) v$

Where,

t = Time between transmitting and receiving the acoustic signal of the beacon node.

ε = Time between receiving and transmitting the acoustic signal of the sensor.

v = Velocity of acoustic signal in water.

B. *Coordinates Computation*

This algorithm calculates the co-ordinates of the sensor based on the speed of the sensor. For this algorithm the sensor needs to be mobile and the sensor needs to be straight directed and the constant speed. Here the direction of the sensor finds the coordinates of the sensor with the angle it creates with Earth's latitude longitude and Altitude line.

Here d_i is considered as the subset of the different position of the sensor, where i = 1, 2, 3. And B_j is considered as the subset of different position of beacon node. Where j = 1, 2, 3. In Fig. 3 we can see there are three positions of beacon node. By using this proposed model, the output position of sensor will take place in two positions. Therefore, the beacon node will be moved in the position of B_2 or B_3. First of all, we need to project the sensor into a parallel plane. here S_2' is the projected sensor of sensor S_2. So, the distance from B_1 to S_2' is

$$d_2' = \sqrt{d_2^2 - h_2^2 + h_1^2}$$

The horizontal distance from B_1 to S_1 is

$$d_{h1} = \sqrt{d_1^2 - h_1^2}$$

The horizontal distance from B_1 to S_2' is

$$d_{h2}' = \sqrt{{d_2'}^2 - h_1^2}$$

d_{12} is the distance from S_1 to S_2. So, the distance from S_1 to S_2' is

$$d_{12}' = \sqrt{d_{12}^2 - (h_2 - h_1)^2}$$

By using law of cosines formula, the angle between d_{h1} and d_{12}' is

$$\theta_2 = \cos^{-1}\left(\frac{d_{h1}^2 + d_{12}'^2 - d_{h2}'^2}{2 d_{h1} d_{12}'}\right)$$

$$\theta_2 = \cos^{-1}\left(\frac{(\sqrt{d_1^2 - h_1^2})^2 + d_{12}'^2 - (\sqrt{{d_2'}^2 - h_1^2})^2}{2(\sqrt{d_1^2 - h_1^2})d_{12}'}\right)$$

$$\theta_2 = \cos^{-1}\left(\frac{(\sqrt{d_1^2 - h_1^2})^2 + d_{12}'^2 - (\sqrt{(\sqrt{d_2^2 - h_2^2 + h_1^2})^2 - h_1^2})^2}{2(\sqrt{d_1^2 - h_1^2})d_{12}'}\right)$$

A line from centre creates two angles with the x axis. One is clockwise positive angle and another is clockwise negative angle. Here Θ_1 is the clockwise positive angle of d_{12}' with the x-axis from S_1 to S_2'.

So, the clockwise positive and negative angle of d_{h1} with the x-axis from a S_1 to B_1' is

$$\theta_3 = \theta_1 \pm \theta_2$$

$$\theta_3 = \theta_1 \pm \cos^{-1}\left(\frac{(\sqrt{d_1^2 - h_1^2})^2 + d_{12}'^2 - (\sqrt{(\sqrt{d_2^2 - h_2^2 + h_1^2})^2 - h_1^2})^2}{2(\sqrt{d_1^2 - h_1^2})d_{12}'}\right)$$

And the clockwise positive and negative angle of d_{h1} with the x-axis from a B_1' to S_1 is

$$\theta_4 = \theta_3 - 180$$

$$\theta_4 = \theta_1 \pm \cos^{-1}\left(\frac{(\sqrt{d_1^2 - h_1^2})^2 + d_{12}'^2 - (\sqrt{(\sqrt{d_2^2 - h_2^2 + h_1^2})^2 - h_1^2})^2}{2(\sqrt{d_1^2 - h_1^2})d_{12}'}\right) - 180$$

So, applying cosine and sine function,

$$x = d_{h1} \cos \theta_4$$

$$x = d_{h1} \cos(\theta_1 \pm \cos^{-1}\left(\frac{(\sqrt{d_1^2 - h_1^2})^2 + d_{12}'^2 - (\sqrt{(\sqrt{d_2^2 - h_2^2 + h_1^2})^2 - h_1^2})^2}{2(\sqrt{d_1^2 - h_1^2})d_{12}'}\right) - 180)$$

$$y = d_{h1} \sin \theta_4$$

$$y = d_{h1} \sin((\theta_1 \pm \cos^{-1}\left(\frac{(\sqrt{d_1^2 - h_1^2})^2 + d_{12}'^2 - (\sqrt{(\sqrt{d_2^2 - h_2^2 + h_1^2})^2 - h_1^2})^2}{2(\sqrt{d_1^2 - h_1^2})d_{12}'}\right) - 180)$$

And,

$$z = h_1$$

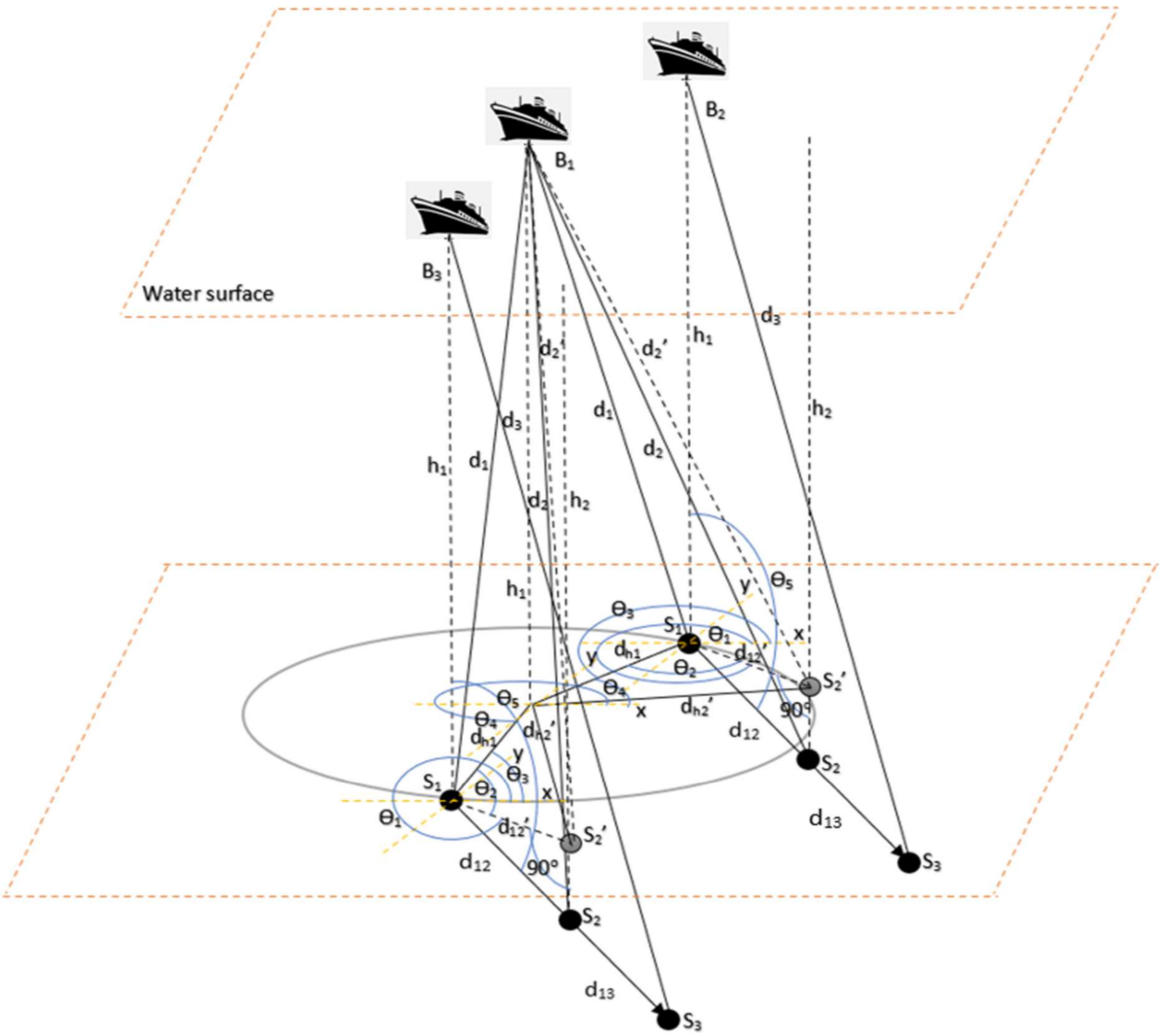

Fig. 3. Determination of coordinates

TABLE I. COORDINATES OF THE SENSOR

Coordinates of sensor	
x	$d_{h1}\cos(\theta_1 \pm \cos^{-1}(\frac{(\sqrt{d_1^2 - h_1^2})^2 + d_{12}'^2 - (\sqrt{(\sqrt{d_2^2 - h_2^2 + h_1^2})^2 - h_1^2})^2}{2(\sqrt{d_1^2 - h_1^2})d'_{12}}) - 180)$
y	$d_{h1}\sin((\theta_1 \pm \cos^{-1}(\frac{(\sqrt{d_1^2 - h_1^2})^2 + d_{12}'^2 - (\sqrt{(\sqrt{d_2^2 - h_2^2 + h_1^2})^2 - h_1^2})^2}{2(\sqrt{d_1^2 - h_1^2})d'_{12}}) - 180)$
z	h_1

Here we have got two coordinates of the sensor. Then the beacon node will be taken once in ($d_{h1}\cos((\theta_1 + \cos^{-1}(\frac{\left(\sqrt{d_1^2-h_1^2}\right)^2 + {d'_{12}}^2 - \left(\sqrt{\left(\sqrt{d_2^2-h_2^2+h_1^2}\right)^2-h_1^2}\right)^2}{2\left(\sqrt{d_1^2-h_1^2}\right)d'_{12}})) - 180), d_{h1}\sin((\theta_1 + \cos^{-1}(\frac{\left(\sqrt{d_1^2-h_1^2}\right)^2 + {d'_{12}}^2 - \left(\sqrt{\left(\sqrt{d_2^2-h_2^2+h_1^2}\right)^2-h_1^2}\right)^2}{2\left(\sqrt{d_1^2-h_1^2}\right)d'_{12}})) - 180), 0$) position considered as B_2 and once again in ($d_{h1}\cos((\theta_1 - \cos^{-1}(\frac{\left(\sqrt{d_1^2-h_1^2}\right)^2 + {d'_{12}}^2 - \left(\sqrt{\left(\sqrt{d_2^2-h_2^2+h_1^2}\right)^2-h_1^2}\right)^2}{2\left(\sqrt{d_1^2-h_1^2}\right)d'_{12}})) - 180), d_{h1}\sin((\theta_1 - \cos^{-1}(\frac{\left(\sqrt{d_1^2-h_1^2}\right)^2 + {d'_{12}}^2 - \left(\sqrt{\left(\sqrt{d_2^2-h_2^2+h_1^2}\right)^2-h_1^2}\right)^2}{2\left(\sqrt{d_1^2-h_1^2}\right)d'_{12}})) - 180), 0$) position considered as B_3 and the measure the distance from B_2 to S_3 and B_3 to S_3. Here h_1 and distance from S_1 to S_3 that considered as d_{13} create an angle Θ_5. Here d_{13} is known because of known velocity of the sensor. And Θ_6 is considered as the angle of sensor's direction create with the earth's altitude line.

So, $\theta_5 = \cos^{-1}((h_1^2 + d_{13}^2 - d_3^2)/2h_1 d_{13}$.

Here Θ_5 will be created in two places. $\Theta_{5_k} = \{\Theta_{5_1}, \Theta_{5_2}\}$. Where, k = 1, 2.

$$\text{So, } \Theta_6 = \begin{cases} \Theta_{5_1}, \textit{where } \Theta_{5_2} \textit{ will be rejected} \\ \Theta_{5_2}, \textit{where } \Theta_{5_1} \textit{ will be rejected} \end{cases}$$

If $\Theta_6 = \Theta_{5_1}$, the co-ordinates of the sensor are

TABLE II. COORDINATES OF THE SENSOR

Coordinates of sensor	
x	$d_{h1}\cos(\theta_1 + \cos^{-1}(\frac{(\sqrt{d_1^2 - h_1^2})^2 + d_{12}'^2 - (\sqrt{(\sqrt{d_2^2 - h_2^2 + h_1^2})^2 - h_1^2})^2}{2(\sqrt{d_1^2 - h_1^2})d'_{12}}) - 180)$
y	$d_{h1}\sin((\theta_1 + \cos^{-1}(\frac{(\sqrt{d_1^2 - h_1^2})^2 + d_{12}'^2 - (\sqrt{(\sqrt{d_2^2 - h_2^2 + h_1^2})^2 - h_1^2})^2}{2(\sqrt{d_1^2 - h_1^2})d'_{12}}) - 180)$
z	h_1

If $\Theta_6 = \Theta_{5_2}$, the co-ordinates of the sensor are

TABLE III. COORDINATES OF THE SENSOR

Coordinates of sensor	
x	$d_{h1}\cos(\theta_1 - \cos^{-1}(\frac{(\sqrt{d_1^2 - h_1^2})^2 + d_{12}'^2 - (\sqrt{(\sqrt{d_2^2 - h_2^2 + h_1^2})^2 - h_1^2})^2}{2(\sqrt{d_1^2 - h_1^2})d'_{12}}) - 180)$
y	$d_{h1}\sin((\theta_1 - \cos^{-1}(\frac{(\sqrt{d_1^2 - h_1^2})^2 + d_{12}'^2 - (\sqrt{(\sqrt{d_2^2 - h_2^2 + h_1^2})^2 - h_1^2})^2}{2(\sqrt{d_1^2 - h_1^2})d'_{12}}) - 180)$
z	h_1

IV. RESULTS AND DISCUSSION

We can see very little change in the x, y coordinates of the sensor which is being created due to the error of distance measurement and we have got the z coordinate which is given from the depth sensor. The more accurate the distance measurement gives the more accurate the coordinates of the sensor. Therefore, if take the more accurate distance measurement, the more precise coordinates can be found

A. Error Generation

A slight error has been added in the distance measurement of the sensor from the beacon node while doing the simulation. Because in fact if we measure the distance through acoustic signal, we will not get accurate distance. Some error will be added. In this proposed model, if we get the exact distance, we will get the output accurate.

B. Simulation Result Analysis and Discussion

To evaluate the proposed mathematical model, the proposed method has been implemented in python. First position of sensor is deployed at (3, 2, -5) meter and the second position of sensor is deployed at (4, 1, -6) meter with respect to the position of beacon node. With respect to the plane of the beacon node, the movement of sensor is non-parallel. Then the distance has been measured from the beacon node to the sensor positions where beacon node is deployed at (0, 0, 0) meter. While assuming the position of sensor with respect to the position of beacon node, here the sensor is considered as mobile in underwater. Fig. 4 is shown the calculated coordinates of the sensor when reading being taken from the beacon node.

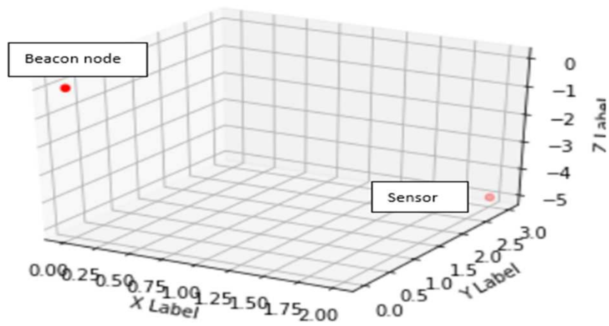

Fig. 4. Calculated sensor's position with proposed method

50 iterations have been taken to calculate distance error where different input of coordinates of the sensor has been taken for every iteration and got different error which is very negligible. Errors have been calculated for 50 iterations and mean error have been calculated which is shown in fig. 5.

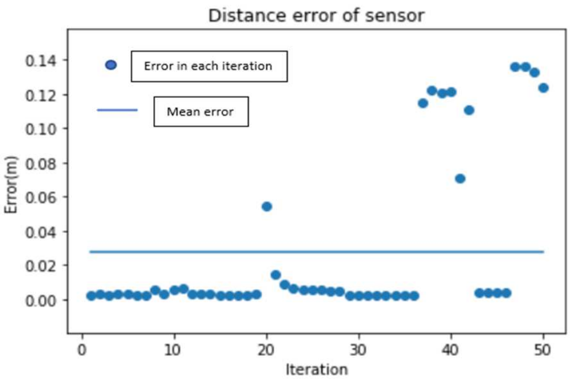

Fig. 5. Distance error of sensor from original position

Table. II show the mean error of distance error for 50 iterations which is negligible and validate the proposed mathematical model. Table. II also show the standard deviation of error distribution.

TABLE IV. GENERATION OF ERROR

Mean error	Standard deviation of error distribution
0.02790646286886686m	0.04727481241629411m

V. Limitation

This proposed mathematical model has some limitation. For static sensor this proposed mathematical model will not work and if the direction of the sensor is not straight line, it will also not work. And it is difficult to follow always straight line for sensor in under water. The sensor should be able to receive, generate and transmit the acoustic signal. And also, the sensor should be able to calculate its directional angle create with the earth's latitude, longitude and altitude line and able to calculate its depth from depth sensor.

VI. Conclusion

In this paper, a new mathematical model has been presented to calculate the coordinates of a single mobile sensor through a single beacon node by exploring Underwater Sensor Network. Ignoring all the challenges of underwater communication, a new mathematical model has been set up which can determine the coordinates of the mobile sensor where the movement of the mobile sensor can be parallel or non-parallel with the plane of the beacon node. This mathematical model has reduced the abundance of beacon node and abundance of reading of beacon node. By simulating this proposed mathematical model, its acceptability with negligible error has been proved. Finally conclude that it can be a reliable mathematical model for coordinates determinant. Through this, underwater environment exploring and monitoring can go further.

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