Positioning of Underwater Vehicle using Acoustic Signal

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Abstract — The location the position of the underwater vehicle is a vital task inorder for the autonomous underwater vehicle (AUV) to carry out task for which it is designed for. As the Global positioning system cannot be used to find location of AUV due to degradation of the radio frequencies in water. Acoutic signals are used to locate the position of the vehicle.

In this paper, different positioning methods are described and simulated using matlab simulator when beacons are located at certain distance from the vehicle using time of arrival (TOA) and time difference of arrival (TDOA) technique.

Keywords—Autonomous underwater vehicles, time of arrival (TOA), time difference of arrival (TDOA), navigation.

INTRODUCTION

Autonomous underwater vehicles are gaining more attention and attracting researchers more due to their ability to work autonomously without human interaction for its usability at the same time making its design more interesting and challenging. AUV is loaded with a preplanned path and is able to navigate using acoustic beacons on the seafloor, GPS positioning, and inertial navigation. It is designed to overcome obstacles it faces during the mission. AUV is used in marine geoscience, typically move at a speed of 1.5-2m/s and can be affected by tidal currents and noises in the environment..

In order for AUV to carry tasks in hazarduous situations, it requires accurate navigational ability. While using the Global Positioning System (GPS) within the water, electromagnetic signal decay abruptly with an increase in depth, hence navigation of underwater vehicle cannot rely on GPS. As acoustic signals decay slowly in water as compared to electromagnetic waves, they are used for underwater communication to find the correct location of the underwater vehicle Underwater vehicle navigation systems are often aided by measurements of ranges to beacons or markers. Acoustic navigation uses acoustic beacons present in the AUV mission area, regardless of their operation. AUV's are used in different fields such as reasearch and scientific, Military and commercial purposes with different missions assigned to them.

METHODOLOGY

UNDERWATER POSITIONING SYSTEM USING ACOUSTIC SIGNAL METHODOLOGIES:

Position estimation can be done by considering two perspectives. The first prospective includes the condition when the target wants to know its location by running some algorithm relative to some known positions or coordinates. The second perspective includes the condition when the infrastructure calculates the position of the object and Autonomous Underwater Vehicle (AUV) doesn't know its location. The former is called Tracking and the latter is known as Navigation.

The Techniques used by the autonomous vehicle to calculate its position by finding the distance between the transponder and the transceiver can be classified as follows:

- Position estimation using Time of Arrival (ToA)
- Position estimation using Time Difference of Arrival (TDoA)

3.1 Position estimation using Time of Arrival (ToA)

The Time of Arrival (ToA) method performs ranging based on the arrival time of the transmission. This method presumes that the receiver knows the time during which the signal was transmitted but time at which signal is transmitter is unknown, synchronization is required between transponder and transciever.

ToA calculates distance by using the formula

velocity = Distance / Time or

distance= velocity* ToA

TOA= time at which the signal is received- time at which signal is transmitted

Calculation of the position using time of arrival is done using the following method.

3.1.1 Trilateration

Trilateration is a technique used to solve for the position of a vehicle (T) which can be determined in two dimensions by measuring the distance between T and three fixed beacons (A_1, A_2, and A_3) whose positions are known. Consider coordinates of 3 beacons nodes , distances are calculated using the travel-times of acoustic signals traveling between the fixed object (beacon node) and a target/ underwater vehicle. These measured travel-times are converted to distances by multiplying the travel-times by the speed of sound in the medium in which they travel. Given the distance between T and S1, then T must be located on a circle centered at A_1 with a radius equal to the distance between T and A_1.

$$d_1= \sqrt{\left(x_T - x_{A_1}\right)^2 + \left(y_T - y_{A_1}\right)^2} \qquad \text{.........1}$$

$$d_2 = \sqrt{\left(x_T - x_{A_2}\right)^2 + \left(y_T - y_{A_2}\right)^2} \qquad \text{...........2}$$

$$d_3= \sqrt{\left(x_T - x_{A_3}\right)^2 + \left(y_T - y_{A_3}\right)^2} \qquad \text{.........3}$$

Location of the target can be accomplished by linearizing these equations and solving them iteratively.

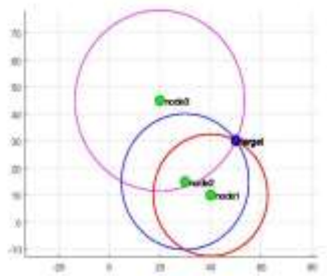

Figure 2. Positioning using Trilateration method

3.2 Position estimation using time difference

Consider coordinates of the beacon nodes which are already known, the time at which the signal from node 1 will reach the target node at time t_1 and time at which the signal from node 2 will reach the target node be t_2

The time at which the signal from node 1 will reach the target node be t_3.

TDoA calculates the distance by using the formula

Velocity = Distance* (Time difference) or

v= d * TDoA

Time difference of arrival between node 1 and 2 and node 1 and node 3 is given by

$TDoA_{12}$ =d *(t_1-t_2) 4

$TDoA_{13}$ =d *(t_1-t_3) 5

3.2.1 **Multilateration**

A receiver employing Multilateration measures the times between the first received signal and all subsequent signals. All of the transmitters must transmit simultaneously, or with known delays between them, to measure the TDOAs of the acoustic signals.

Multilateration is referred to as hyperbolic positioning because each TDOA defines a hyperbola on which the position of the receiver must lie. Three Pingers (B_1, B_2, and B_3) whose positions are known, simultaneously transmit ranging signals. A target (T) receiving these signals measures the time between receiving the first signal and all subsequent signals. For a three-beacons system, two TDOA's are measured: the time between receiving the first and second signals ($TDOA_{12}$) and the time between receiving the first and third signals ($TDOA_{13}$).

In order to calculate the position of the underwater vehicle, using time difference of arrival from 3 nodes reduce the coordinate system, figure 5 and 6 show the multilateration before and after.

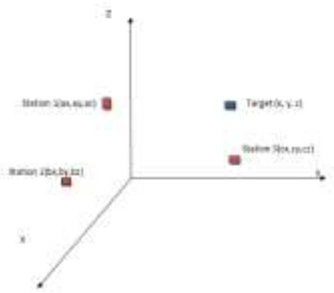

Figure 5 Coordinate system (Before reduction)

After conversion

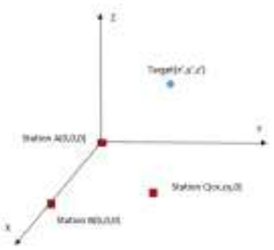

Figure 6 Coordinate system (After reduction)

Fig 6 shows vehicle position relative to three beacons 1, 2, and 3. One of the stations is at the origin, one station is on the axis and another axis is orthogonal to the two station baselines.

Let v be the velocity $T_{12} = t_1 - t_2$ and $T_{13} = t_1 - t_3$ be the difference of time of arrival at the station pairs 1, 2 and 1, 3.

Distance R_{12} is given by,

$$\sqrt{((x')^2 + (y')^2 + (z')^2)} - \sqrt{(x' - b)^2 + (y')^2 + (z')^2} \qquad (6) \qquad {}_{12} = R_{12}$$

Distance R_{ac} is given by,

$$\sqrt{(x')^2 + (y')^2 + (z')^2} - \sqrt{(x' - C_x)^2 + \left(y' - C_y\right)^2 + (z')^2}$$

(7)

$= v^* T_{13} = R_{13}$

Transposing the first terms to the right side of (1) and (2), squaring and simplifying ,

$$R^2_{12} - b^2 - 2bx' = 2R_{12}\sqrt{(x')^2 + (y')^2 + (z')^2} \quad (8)$$

$$R^2_{13} - c^2 + 2C_x x' + 2C_y y' = 2R_{13}\sqrt{(x')^2 + (y')^2 + (z')^2} \quad (9)$$

where b and c= sqrt (c_x^2+c_y^2) are the lengths of the station baselines.

If range R_{ab} is not equal to zero, equating equation (3) and (4) and simplifying,

$$y' = gx' + h \quad (10)$$

where,

$$g = (R_{ac} * (b/R_{ab}) - c_x) / c_y \quad (11)$$

$$h = (c^2 - R^2_{ac} + R_{ac} * R_{ab} (1 - (b/R_{ab})^2))/2\, c_y ; \quad (12)$$

Substituting 5 in 3,

$$z^2 = dx^2 + ex + f \quad (13)$$

where ,

$$d = -(1 - (b/R_{ab})^2 + g^2);$$

$$e = b*\{1 - (b/R_{ab})^2\} - 2*g*h;$$

$$f = (R^2_{ab}/4)*\{1 - (b/R_{ab})^2\}^2 - h^2 \quad (14)$$

Using these, one can calculate the position

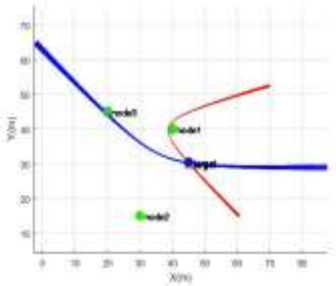

Figure 6. Multilateration

CONCLUSION

Trilateration requires the time during which the signal was transmitted from the transmitter in order to calculate the distance, hence extra hardware is required for synchronization of nodes is also considered which is overcome in case of Multilateration. Multilateration eliminates the extra hardware required as in case of trilateration as time during which signal is transmitted is not required.