# Six Monthly Progress Report of Research Scholars

## Period: July to Dec, 2017

## (DEPARTMENT OF OCEAN ENGINEERING)

1. Name : Awanish Chandra Dubey
2. Roll No : OE13D027
3. Program : PhD
4. Specialization: Unmanned Marine Vehicle
5. Category : Regular
6. Guide(s) :Prof. V. Anantha Subramanian, Dr. Bharat Bhikkaji
7. Date of Joining : July-2013
8. Date of Registration : July 2013
9. Area of Research : Control and Navigation of Unmanned Marine Vehicles
10. Date of Comprehensive Examination: (If applicable)
11. Date of Research Proposal Meeting : (If applicable)
12. Date of Second Seminar : (If applicable)

**Details of Core Courses**

| S.No. | Course No. | Course Name | Semester | Grade |
|---|---|---|---|---|
| 1 | CH5120 | Modern Control theory | Odd 2013 | C |
| 2 | OE5070 | Statics and Dynamics of Marine Vehicles | Odd 2013 | C |

**Details of Elective Courses**

| S.No. | Course No. | Course Name | Semester | Grade |
|---|---|---|---|---|
| 1 | ID6020 | Introduction to research | Odd 2013 | P |
| 2 | OE5030 | Wave hydrodynamics | Odd 2013 | A |
| 3 | EE5730 | Non Linear Control System | Even 2014 | B |
| 4 | EE6417 | Robust Control | Even 2014 | A |
| 5 | OE5310 | Guidance & Control of Marine Vehicles | Odd 2014 | S |

Date :

IIT Madras, Chennai.

Signature of the Guide
(Name)

Signature of the Scholar
(Name)

# Progress Report

## i) Problem Definition: Cooperative control and navigation of unmanned marine vehicles.

**State of Art:** The earliest reference on single-beacon navigation by Scherbatyuk et al. 1995, describes the implementation of a navigation system using range data from one acoustic transponder (from a LBL commercial solution) and yaw and relative velocity measurements from on-board sensors. To estimate the AUV position and the ocean current velocity they implemented a least squares based algorithm. Larsen 2000, presented a similar solution, but that relies on very accurate dead reckoning information and uses the range data from a single transponder only as a periodic position ’fix’. Baccou et.al 2002, propose an algorithm for 2D homing and navigation that relies on range data from a single source and a ’low-cost’ solution for dead reckoning. The algorithm consists of two steps: an initialization phase based on nonlinear least squares and a refinement phase based on an Extended Kalman Filter. They showed convergence and robustness of the navigation system in simulation and post-processing experiments. An important remark is that the algorithm includes maneuvers described as optimal in the sense of the Fisher Information Matrix (FIM), although the analysis leading to those results is not presented. The solution presented by Chitre 2010 considers a moving beacon and multiple AUVs that are able to measure their ranges to the beacon and use that information for self-localization. Moreover, a path planning algorithm is proposed for the moving beacon that should minimize the position errors accumulated in the other vehicles. The performance of the algorithm is evaluated in simulation. Fallon et.al 2010 analyzed the observability of such a system and compared the performance of several estimators. Webster et.al. 2009 described the implementation of a navigation system using a moving beacon and multiple AUVs with synchronized clocks. Thus, the AUVs can measure their range to the beacon from the one-way-travel time of the acoustic signal broadcasted by the moving beacon at periodic intervals. Batista et.al, 2011 addressed the problem of 3D localization using range measurements to a single source and relative velocity measurements, in the presence of unknown constant currents.

In context with the development autonomous system for of scaled ship model/surface vehicle for maneuver and sea keeping tests work done by F. Lopez Peña et.al, 2013, describes a development of self propelled scale ship model for tiwing tests, with the main characteristic of not having any material link to a towing device to carry out the tests.

In another context of development of Indoor positioning system, Abdelmoumen Norrdine 2015 proposed a method where the nonlinear elements of the equation systems are treated as additional unknown, which represent simultaneously a constraint.

iii) **Work done before review:** Developing an ultrasonic based Indoor Positioning System(IPS) for the position estimation of the surface vehicle in local coordinate to perform path following and station keeping in wave basin.

**1. Experimental setup of Indoor Positioning System (IPS) :**

The system for indoor positioning is based on the principle of time-of-flight (TOF) of ultrasonic signal to estimate the distance between a receiver node and a transmitter node. Ultrasonic Transducer model no TR40-16OA00 with central frequency of 40 kHz has been used to perform distance calculation by using time of flight method. The above mentioned system is consists of 4 ultrasonic receivers and one transmitter. The transmitter is attached to the target of which position need to be estimated and the four receivers will be mounted at known positions. The transmitter and receiver will get synchronised by using one radio Frequency (RF) module.

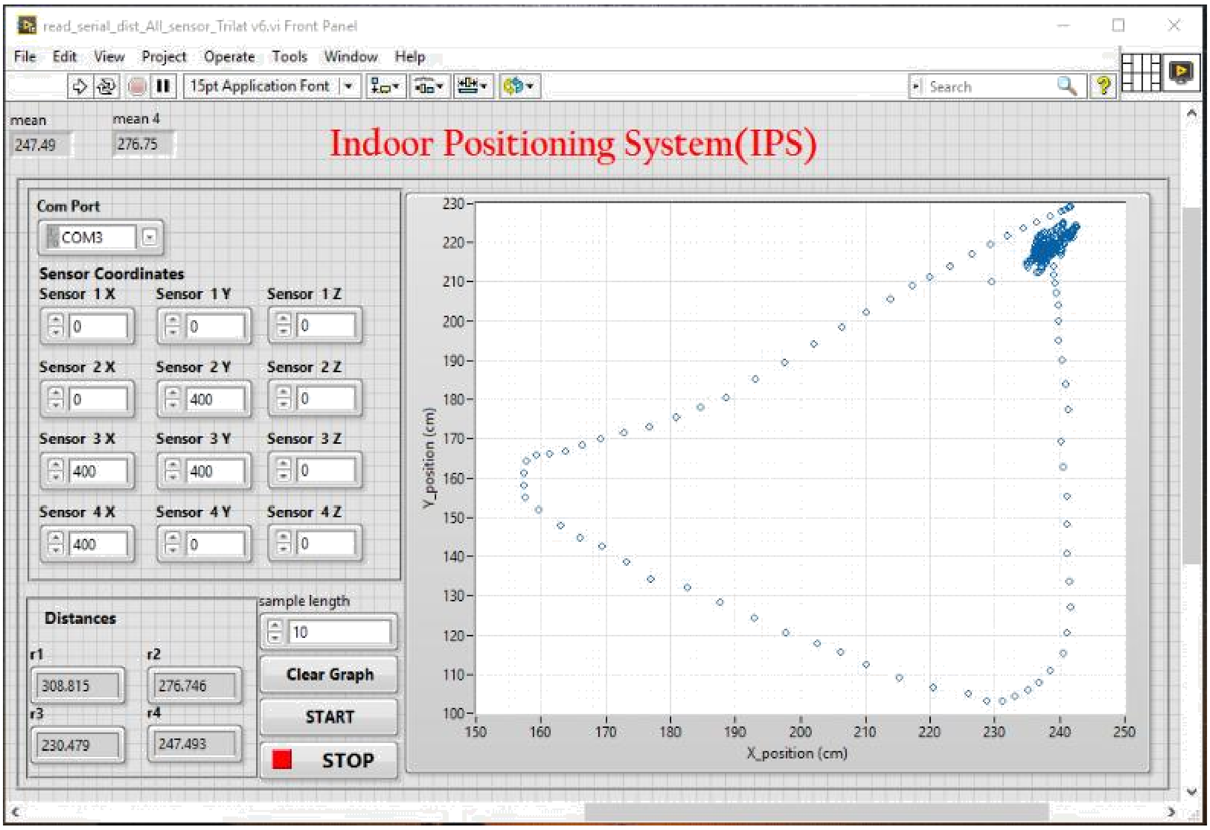


Fig. 2.Graphical User Interface for position estimation using ultrasonic transducers.

**2. Path following and trajectory tracking for surface vehicle:**

In order to achieve position of an underwater vehicle using range measurement form single surface vehicle, the vehicle must be able to perform general trajectory tracking to get the information about the range measurement and then able to estimate the position of underwater target. The above will achieve by merging the first to objective of the problem statement.

**i. Mathematical Formulation :** The kinematic equation of the unmanned marine vehicle is given by:

$$\dot{x} = u\cos(\psi) - v\sin(\psi)$$
$$\dot{y} = u\sin(\psi) + v\cos(\psi)$$
$$\dot{\psi} = r$$

In Fig. 3, M is the orthogonal projection of the surface vehicle point P on Ω, and are the normal and the tangent unit vector to the path at M respectively . The kinematic model of the UMV in (s,y) coordinates is given by:

$$\dot{s}_1 = -\dot{s}(1 - c_c y_1) + v_t\cos(\psi)$$
$$\dot{y}_1 = -\dot{s}(c_c s_1) + v_t\sin(\psi)$$
$$\dot{\psi} = \omega_w - c_c\dot{s}$$

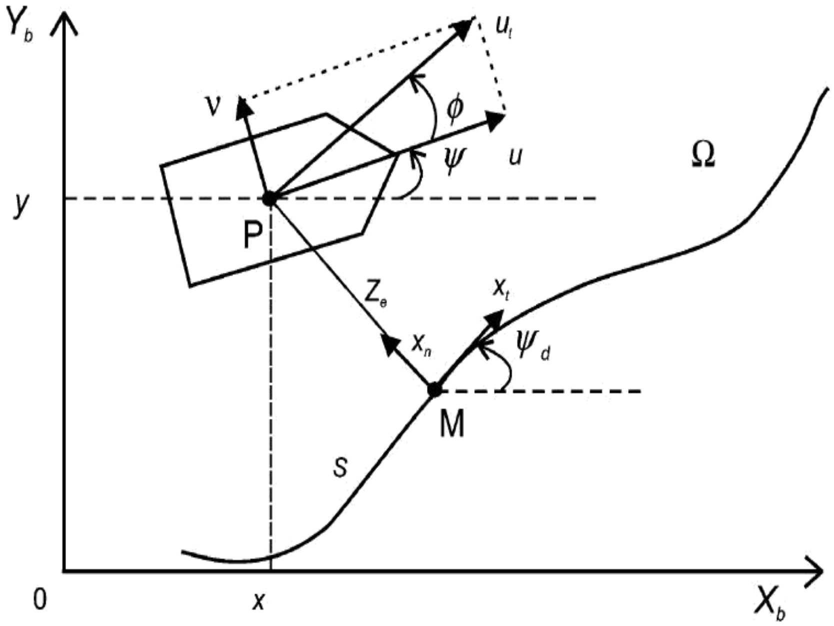


Fig.3 Framework of surface vehicle path following in Serret-Frenet frame.

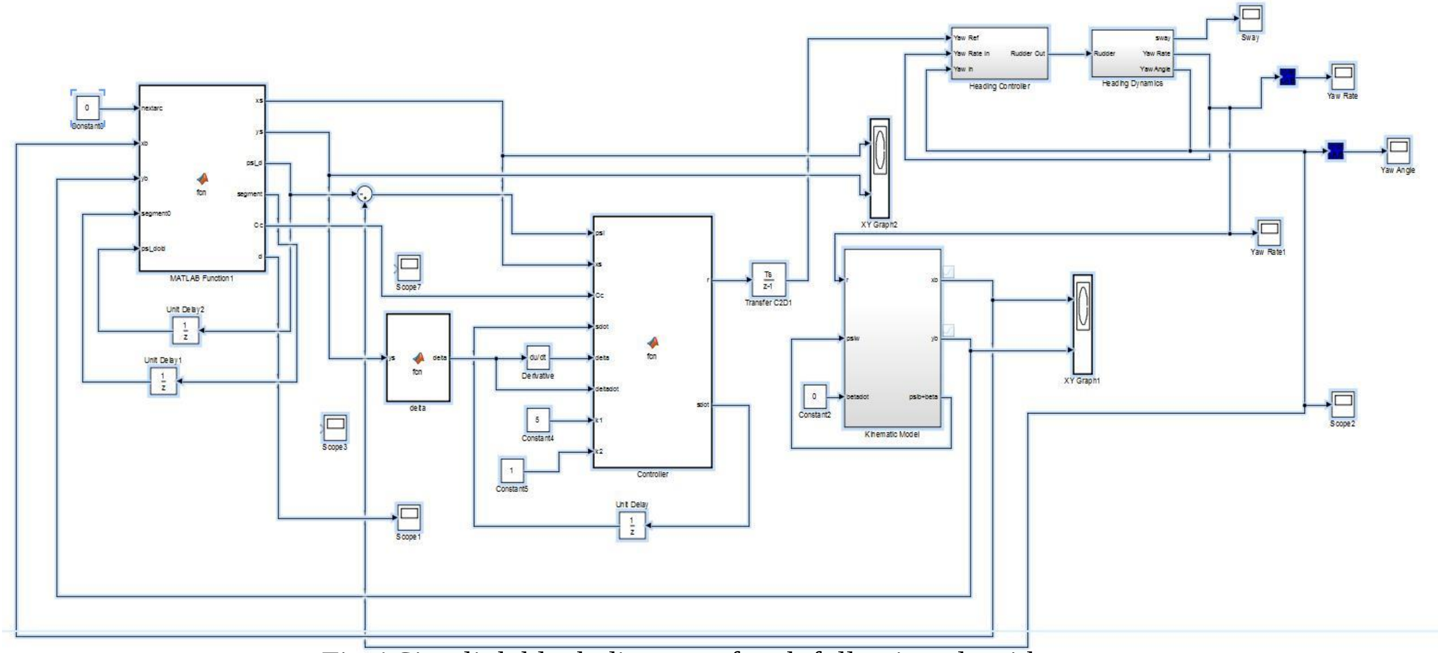

Fig.4 Simulink block diagram of path following algorithm

The Path Following (PF) algorithm has been simulated in MATLAB by using the dynamics model of existing AUV (MAYA) developed at National Institute of Oceanography (NIO) Goa. The PF algorithm uses the non linear controller for the kinematics control and Linear Quadratic Regulator (LQR) controller is used for the dynamics control.

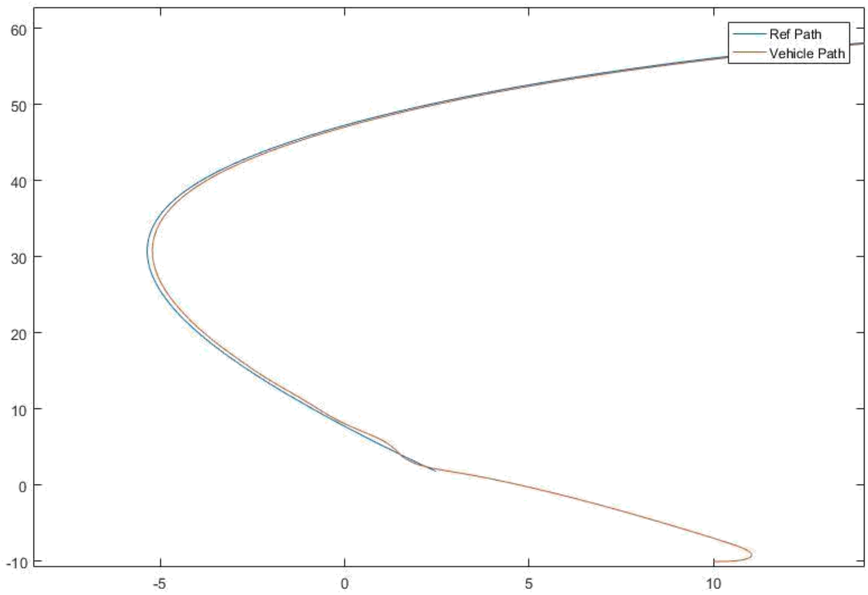


Fig. 5 Simulation result of path following system

**Work done during review**

**Increase the range of IPS:** The range depends primarily on how far the wave can travel with minimal scattering. The range can be increased by either increasing the power of the transmitter or by increase in directivity. In this case, the range is increased by increasing the power of the ultrasonic transmitter. The chirp signal is amplified using power amplifier (OPA552) in inverting mode and then fed to the transmitter. The omnidirectional transmitter consist of eight ultrasonic sensor placed at the interval of 45 degree. Multiple power amplifier used for each set of sensor to avoid overloading of to the amplifier. The amplifier gain is set as per the sensor requirement by choosing the proper value of $R_f$ & $R_1$

$$V_0 = -V_{in} * \frac{R_f}{R_1}$$

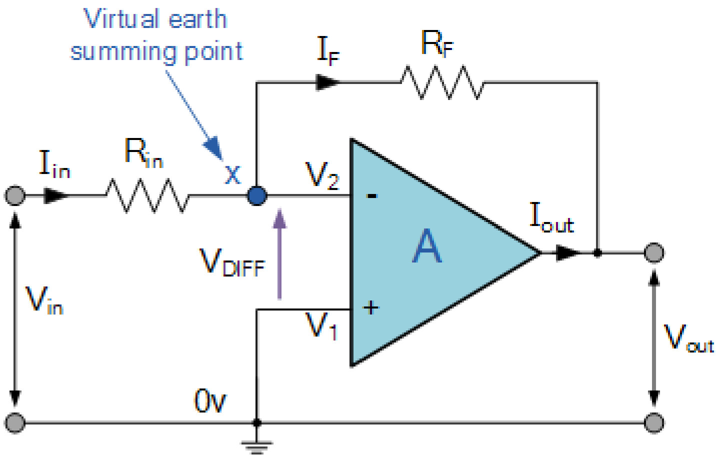


*Figure 1 Amplifier Circuit*

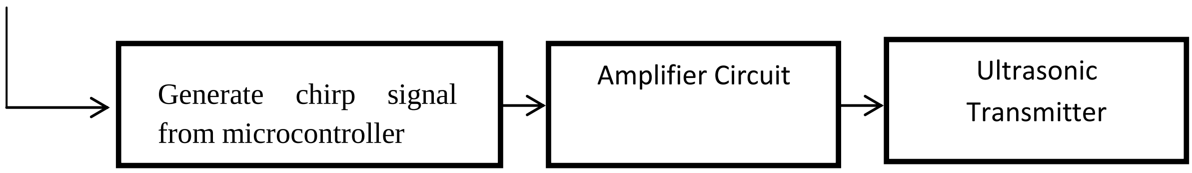


*Figure 2 Block Diagram of ultrasonic transmitter*

**Increase in number of receivers:**

In order to achieve maximum accuracy, and range the number of receivers are increased to 12. Each receiver is tuned to a particular range such as Long range (7-16 meters) and short range (1-9 meters). There are six short range receiver and six long range receivers to cover the long arena (~ 25mx 25m).

**Sensor orientation**

Since we made the prototype work in large scale (22*22mts), we planned to use 12 sensors. The sensors are kept at a distance of 5.5 metres apart such that there are 3 sensors on each side. This gave us a more accurate location of where the vehicle is. We tried various methods of sensor orientation to figure out the method that had maximum sensors in range at any given point. We decided to make half the sensors long range and the other half short range such that the long range sensors range from 6m to 17m and the short range sensors range from 1m to 9m.

In the first approach, we placed short range sensor between two long range sensors on the all sides. When plotting such a configuration it was found that there were many areas in the plot where very few sensors were in range of the vehicle. This conclusion gave us more insight to obtain a better form of orientation.

In the second approach, we placed the long and short range sensors in alternate fashion. When the following configuration was plotted, we found a much better plot where 4 or more sensors were found to be in range thereby providing us with better range values for location calculation.

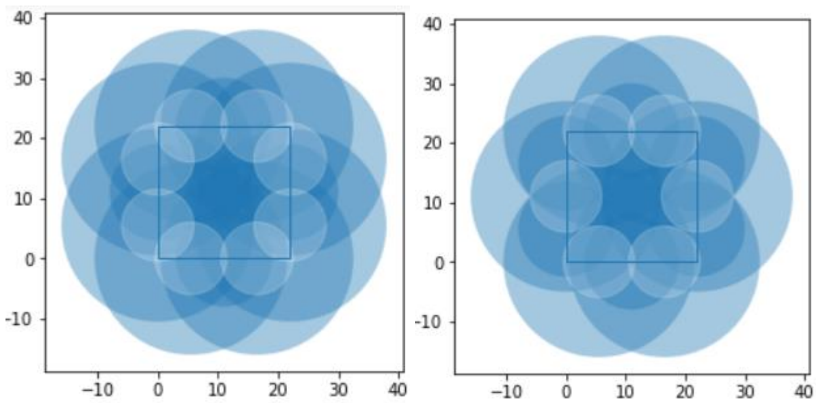


*Figure 3 Ultrasonic receivers configuration*

**Range estimation**

The range measurements obtained from the sensors are corrupted by noise such as multipath reflection, atmospheric condition etc. To estimate the range close to the true value certain estimation algorithms are implemented.

The N - sample mean of the range measurements were taken to minimize the uncertainty. This approach is inefficient in removing the outliers caused by external factors.

So, a combined approach of mean and Machine Learning (ML) model called linear regression was used to improve the accuracy of the range measurements. Linear regression model form a relationship between the obtained sensor data and the true value. A dataset of range measurements for every 1.5mts was acquired and plotted vs true value, where the slope of the line is given by:

$$\frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sum_{i=1}^{n}(x_i-\bar{x})^2}$$

It was found that the model helped us achieve better values at the extreme ranges provided by the ultrasonic sensor.

**Position Estimation**

For the calculation of the correct location of the vehicle, we devised 2 approaches.

The first approach was by the method of trilateration/ multilateration which had been implemented before.

In the second approach, a ML method called k-means clustering was used. In this method, every 2 range values from the receivers are taken and the two points of intersection are obtained.

This can be done without any trigonometry at all. Let the equations of the circles be

$$(x-x_1)^2+(y-y_1)^2=r_1^2, \quad (1)$$

$$(x-x_2)^2+(y-y_2)^2=r_2^2. \quad (2)$$

By subtracting the two equations and expanding, we in fact obtain a *linear* equation for $x$ and $y$; after a little rearranging it becomes

$$-2x(x_1-x_2)-2y(y_1-y_2)=(r_1^2-r_2^2)-(x_1^2-x_2^2)-(y_1^2-y_2^2).$$

(If the circles intersect, this is the equation of the line that passes through the intersection points.) This equation can be solved for one of $x$ or $y$; let's suppose $y_1-y_2\neq 0$ so that we can solve for $y$:

$$y=-\frac{x_1-x_2}{y_1-y_2}x+\dots. \quad (3)$$

Substituting this expression for $y$ into (1) or (2) gives a quadratic equation in only $x$. Then the $x$-coordinates of the intersection points are the solutions to this; the $y$-coordinates can be obtained by plugging the $x$-coordinates into (3).

A list of possible points were calculated using equations(1 & 2) where x1 y1 and x2 y2 are the receivers known location and r1, r2 are the ranges obtained through linear regression. By obtaining various groups of points, it was found that each group of points had one point as the approximate location. The implemented algorithm creates clusters of the list of points obtained and takes the largest cluster center as the probable location of the vehicle.

## v) Future Plans:

- Perform Path following and trajectory tracking for surface vehicle.
- Problem formulation for Autonomous Underwater Vehicle (AUV) position estimation using range only measurement.
- Propose numerical solution for the position estimation of AUV using single Autonomous Surface Vehicle (ASV).
- Formation Control for the ASV.

## v) Visible Research Output-NA

**a) Paper(s) Published in Refereed Journal(s)-** WI-FI ENABLED AUTONOMOUS SHIP MODEL TESTS FOR SHIP MOTION DYNAMICS AND SEAKEEPING ASSESSMENT IJMRD Volume 1 Issue 2 ISSN: 2456-7035

**b) Paper(s) Published in Conference Proceeding(s) as Full Paper:** Development of Autonomous System for Scaled Ship Model for Seakeeping Tests in Oceans '16 MTS/IEEE Conference Sep (19-23)-2016, Monterey CA **ISBN:** 978-1-5090-1537-5

**c) Paper(s) Presented in Seminars/Workshops/Conferences (oral/poster)-NA**

## v) Any Other Information (Academic achievements, awards received, etc.)

## References:

[1]. Further Advances in Unmanned Marine vehicles by G.N Roberts and R. Sutton

[2]. A. Scherbatyuk, "The auv positioning using ranges from one transponder lbl," in OCEANS '95. MTS/IEEE. Challenges of Our Changing Global Environment. Conference Proceedings., vol. 3, Oct 1995, pp. 1620–1623 vol.3.

[3]. M. Larsen, "Synthetic long baseline navigation of underwater vehicles," in OCEANS 2000 MTS/IEEE Conference and Exhibition, vol. 3, 2000, pp. 2043–2050 vol.3.

[4]. P. Baccou and B. Jouvencel, "Homing and navigation using one transponder for auv, post processing comparisons results with long base-line navigation," in Robotics and Automation, 2002. Proceedings.

[5] M. Chitre, "Path planning for cooperative underwater range-only navigation using a single beacon," in Autonomous and Intelligent Systems (AIS), 2010 International Conference on. IEEE, 2010, pp.1–6.

[6]. M. F. Fallon, G. Papadopoulos, J. J. Leonard, and N. M. Patrikalakis, “Cooperative auv navigation using a single maneuvering surface craft,” The International Journal of Robotics Research, p. 0278364910380760, 2010.

[7]. S. Webster, R. Eustice, H. Singh, and L. Whitcomb, “Preliminary deep water results in single beacon one-way-travel-time acoustic navigation for underwater vehicles,” in Intelligent Robots and Systems, 2009. IROS 2009. IEEE/RSJ International Conference on, Oct 2009, pp. 2053–2060.

[8]. P. Batista, C. Silvestre, and P. Oliveira, “Single range aided navigation and source localization: Observability and filter design,” Systems I& Control Letters, vol. 60, no. 8, pp. 665 – 673, 2011.

[9] F. Lopez Peña, M. Miguez Gonzalez, A. Deibe, D. Pena, F. Orjales “An Autonomous Scale Ship Model for Towing Tank Testing” 7th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications 12-14 September 2013, Berlin, Germany.

[10]. Abdelmoumen Norrdine “An Algebraic Solution to the Multilateration Problem” 2012 International Conference on Indoor navigation.