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Underwater Terrain Mapping with a 5-DOF AUV

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Paper introduces extensive application of a state-of-the-art Autonomous Underwater Vehicle (AUV-150) capable of operating up to a depth of 150 meters, without any human intervention. Considering navigational and guidance issues relating AUV-150 as well as the images obtained on an account of underwater terrain mapping done employing the payload sensors as the pioneer space; the paper also includes the plots generated as a result of post-processing algorithms applied on the raw data obtained from the scanning sensors used typically for seabed mapping.

[**Keywords**: AUV, Seabed Mapping, Navigational Sensors, Payload Sensors, Post-processing algorithms.]

Introduction

AUV-150 is a work-class prototype developed by CSIR-CMERI, Durgapur targeted towards an operational depth upto 150 meters and having seabed mapping as a major objective. Vehicle is embedded with active propulsion, navigation, and control systems apart from a hybrid communication system that uses radio waves while on the surface and acoustic underwater communication system.

Mission trials have been conducted at the Idukki Lake located at Cochin in Kerala, India with AUV-150 from 25.09.10 to 09.10.10. Typical lawnmower, square and straight course missions have been conducted towards effective lake-floor mapping and bathymetry. Navigational autonomy has been achieved on large scale through the effective coordinated operation of controller, navigational sensors, and actuators, altogether governed by a control software architecture running on a dual core x86 processor with a clock frequency of 2.0 GHz. The positional information from INS has been improvised through integration of GPS as well as DVL data. Since, the GPS is non-functional while underwater, therefore positional data inconsistency from INS up to a specified limit has been corrected using dead reckoning technique with DVL data.

Deep survey Side-Scan-Sonar (SSS) is used as a payload sensor of AUV for mapping underwater terrain. Novel algorithm has been adopted for post-processing raw digital data obtained from the lake trails using MATLAB to sort out the positional coordinates and the height informations and to further manipulate these data through Non-Uniform Rational B-Spline (NURBS) modelling using Open GL, with a view towards rendering a 3-Dimensional plot of the seabed-contour.

Materials and Methods

AUV-150: State-of-Art

The AUV-150 (Fig. 1) is a cylindrical-shaped carrier with streamlined fairing to reduce hydrodynamic drag. Weighing 490 kg and having a length of 4.8 meters with just 50 cm diameter. Vehicle is perfectly designed with GPS, INS, DVL, and Altimeter as the key navigational sensors and camera, CTD and Side-Scan-Sonar as the payload sensors for

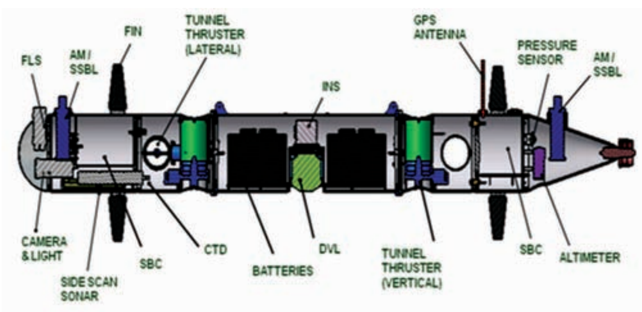

Fig. 1—Cross-Sectional view of AUV-150 exhibiting precise location of all devices within various modules

performing mapping related tasks and oceanographic survey activities. Some of the system specifications are listed in Table I[1]. AUVs have ideally 6-degrees of freedom, but the AUV-150 design; with multi-thrusters actuation for shallow water application; is such as to provide maneuvering capability along pitch, yaw, surge, sway and heave with 5 D.O.F and stable for roll about longitudinal axis.

Altimeter operates upto a depth of 3000 metres at 200 kHz frequency. Vehicle is equipped with a GPS receiver antenna with antenna cable 5 meter long. GPS provides position information in longitudes and latitudes which is integrated with the PHINS system to further obtain the absolute position of the vehicle in terms of Universal Transverse Mercator (UTM) geographical coordinates systems. Fig. 2 shows trajectory followed by the AUV-150 during the mission trail along with the altimeter height information.

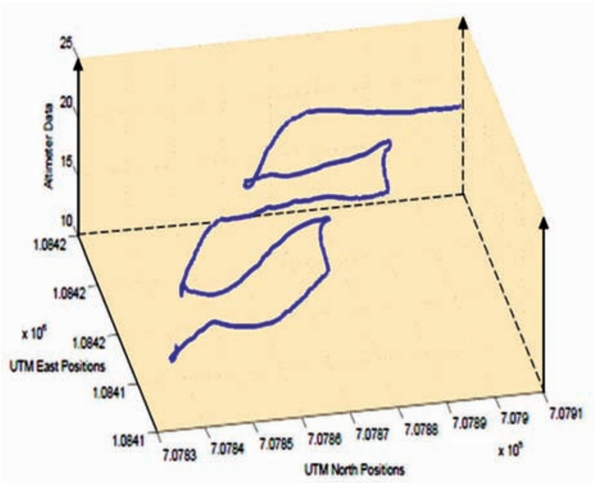

Fig. 2—AUV-150 Trajectory with Height information

Side Scan Sonar: AUV-150 payload sensors

The SSS used in AUV-150 is the Seaking ROV/ AUV mounted Sidescan Sonar system from Tritech International Inc. UK. The SeaKing DST Sidescan Sonar is available with two operating frequencies, typically 325 kHz and 675 kHz. The major specifications of the SSS used are listed in Table 2.

System comprises of two separate transducers (Port and Starboard) connected with interconnect leads to a dual channel electronics pod. These transducers are mounted at an ideal Tilt Angle of 25° below horizontal (Fig. 3).

The system operates continuously in polling mode. Entire pulse transmitted for a particular range along a

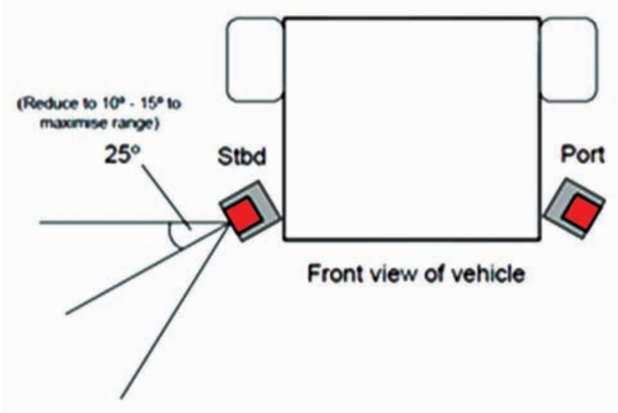

Fig. 3—SeaKing ROV/AUV DST SSS System Vehicle Installation

particular scanning line is divided into small sectors (known as "Bins") and the echoes of objects that reflect sound back to the sonar transducer is used to generate and display image obtained in the proprietary Tritech ".V4Log" format. Sampled intensity data is obtained by the operation of the ADC which is post-processed to generate the seabed map knowing the fact that the length of the shadow reflected from the target is related to the height of the object, its range, and the height of the sonar head.

Post Processing towards Generating 2-D Contour Map

Setting the NBins value for 496 bins, the averaged digital sampled values of the intensity of reflection obtained for each bin has been generated. And the UTM location and the corresponding height information from the altimeter for each time instance are also obtained.

Height and distance for each bin can be obtained as (referring Fig. 4):

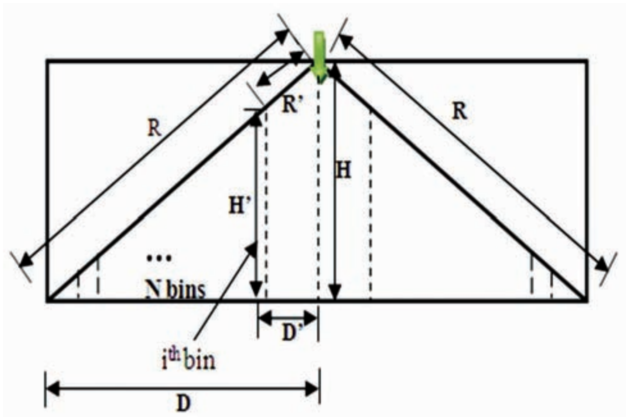

Fig. 4—Height & Horizontal Distance for Bins

Slant Height for i^{th} bin: $R' = (i / N)*R$ .....(1)

Height for i^{th} bin: $H' = ((R-R')*H)/R$ .....(2)

Horizontal Distance for i^{th} bin: $D' = (R'*D)/R$ .....(3)

where,

R = Range of sonar beam

H = Vehicle Altitude

D = Horizontal distance of the farthest bin (Pythagoras Theorem).

Each bin returns intensity of the echo generated from the surface encountered by the sonar transmitter beams. Target height off the sea floor can be obtained using Eq. 2 (Fig. 5). In Fig. 6 the AUV with bearing in the 1st quadrant is observed and the generic formula to obtain coordinates for the Bins has been established which would be applicable for AUV bearing in all the four quadrants:

$$x' = x+\Delta x \quad ...(4)$$
$$y' = y-\Delta y \quad ...(5)$$
$$x'' = x-\Delta x \quad ...(6)$$
$$y'' = y+\Delta y \quad ...(7)$$

where,

Θ = bearing

$\Delta x = D' \sin\Theta$

$\Delta y = D' \cos\Theta$

An algorithm for selecting the Bins of interest reflecting echoes with intensity greater than that of predefined threshold intensity has been obtained. Cartesian Coordinates for all the relevant Bins selected was then obtained from the available bearing & UTM coordinates information.

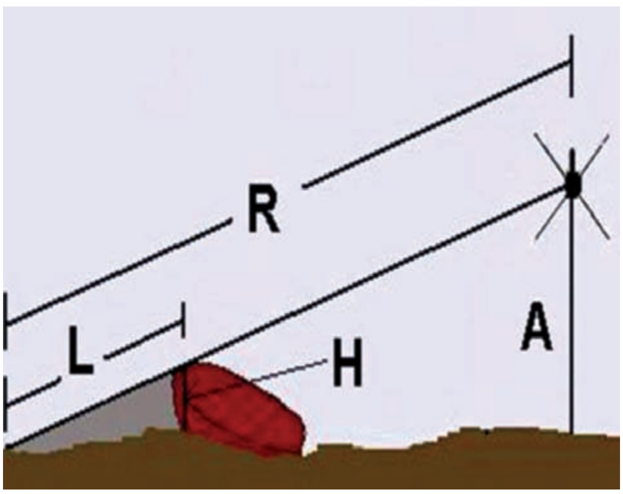

Fig. 5—Target encountered by SSS pulses

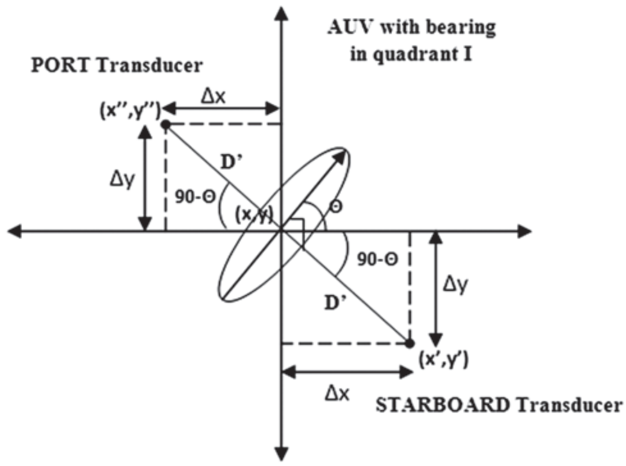

Fig. 6—Cartesian Coordinates for Bin with relevant echo intensity

These Cartesian coordinates obtained for the path traversed by the AUV-150 & the region mapped by the two channel transducers of the SSS integrated with the vehicle has been used to plot the 2-D view of the complete region mapped using various color pallet. Region is indicated by its UTM coordinates taking the initial UTM coordinate as (0,0) and all other coordinates with respect to it. Defined color pallet is given as a legend to indicate the height information for each coordinate.

3-D Terrain Simulation using NURBS methodology

NURBS, a graphics tool, used to create the 3-D view of the path traversed by the AUV. Base of NURBS is Bezier curve which is a polynomial and parametric curve with basic components as control points, knot vector and a basis function.

A NURBS curve definition as a function of parameter '*u*' parametric direction can be represented as in Eq.8[2].

$$C(u) = \frac{\sum_{i=0}^{n} N_i^p(u) w_i P_i}{\sum_{j=0}^{n} N_i^p(u) w_i} \quad ...(8)$$

where,

P_i s are the control points and

N^p_i is the B-Spline basis function of degree p given by Equation 9.

$$N_i^0(u) = \begin{cases} 1 & \text{if } u_i < u < u_{i+1} \\ 0 & \text{otherwise} \end{cases} \quad ...(9)$$

$$N_i^p(u) = \frac{u - u_i}{u_{i+p} - u_i} N_i^{p-1}(u) + \frac{u_{i+p+1} - u}{u_{i+p+1} - u_{i+1}} N_{i+1}^{p-1}(u)$$

In the basis functions definition:

u_is are the ith components of the knot vector &

w_is are the weights of each control point.

The denition of the basis function is recursive.

NURBS surface is fully dened by a control point mesh and two knot vectors: one for the u parametric direction and the other for the v parametric direction. A general NURBS surface can be of different degree in the '*u*' and '*v*' directions. Its definition for two parametric directions can be written by modifying Eq. 8 as

$$S(u,v) = \frac{\sum_{i=0}^{n}\sum_{j=0}^{n} N_i^p(u) N_j^p(v) w_{ij} P_{ij}}{\sum_{i=0}^{n}\sum_{j=0}^{n} N_i^p(u) N_j^p(v) w_{ij}} \quad ...(10)$$

Northing & Easting positional information from UTM data and the corresponding altitude information are manipulated for small regions and 16 control points (x, y, z) are set to create a BSpline surface. For ground level points z=0 and rest with z=scaled down altitude data. These points forms control point mesh. Control points are interpolated using Eq. 9 which is a generalized BSpline polynomial basis function to draw a smooth curve. Interpolated points in both u and v direction will form a smooth surface applying Eq.10; as depicted step-wise in Fig. 8.

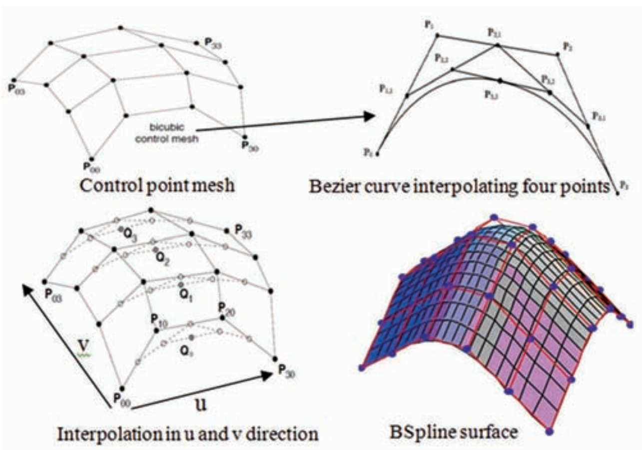

Fig. 8—Formulation of smooth BSpline surface using Bezier curves

Results & Discussion

The generated 2-D plot after applying the post processing-algorithm is represented in Figure 7. Actual path followed by the AUV-150 lying between 707837.2N–707867.9N & 1084130E – 1084142E UTM positions is represented by the pixels coloured with black and the regions mapped during the course of navigation is represented following a color legend for range of altitudes and applying interpolation algorithm. Region represented by the blue color represents features with altitude lying between 9.0-12.0 meters. This algorithm utilizes the raw intensity values directly obtained from the SSS for generating a planar view in graphical mode with color legends.

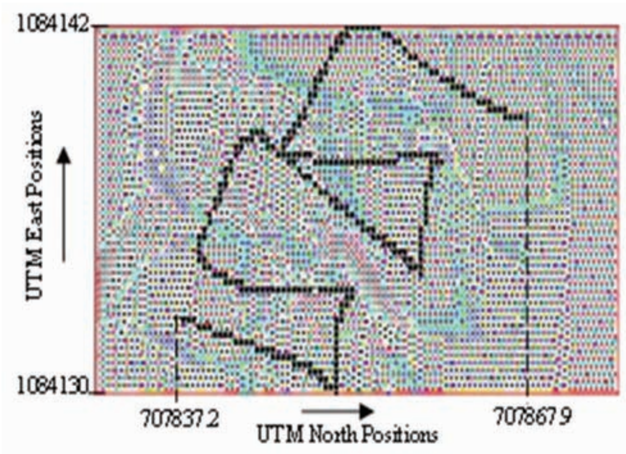

Fig. 7—2-D Plot generated applying post-processing algorithm on side scan sonar data with color legend

Fig. 9 shows the 3-Dimensional view of the path traversed by the AUV-150 indicated by its UTM north and east coordinates along with the height for each coordinate. Simulation techniques can be further improved in order to depict the features around the path traversed by the vehicle and plot an estimated result.

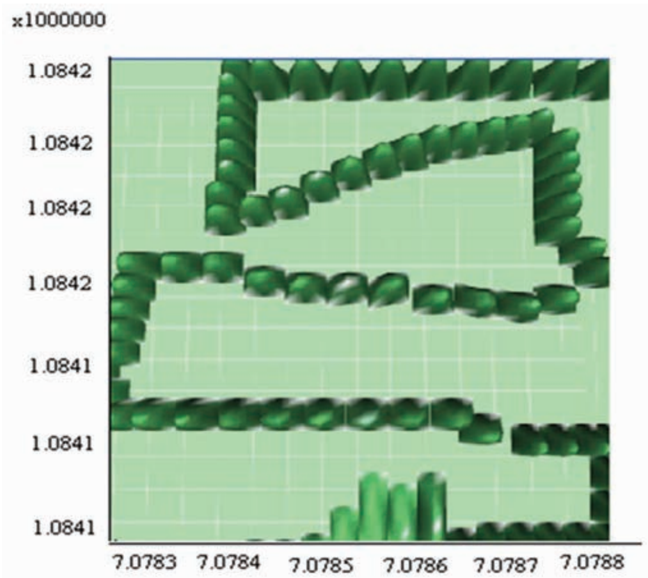

Fig. 9—3-D View of path traversed by AUV obtained using NURBS modelling

Table 1—Important Specifications of the SeaKing SSS System

Features	Particulars	
Operating frequency	325kHz	625kHz
Beam width, vertical	50°	50°
Beam width, horizontal	1°	0.5°
Data communication rate	RS232: 115.2kbaud	
Standard Operating Depth	4000 metres	
Power Requirements	18-36V@12VA	
Data Sampling Rates	5-200 μs	
Data Resolution	4-8 bits	

Table 2—AUV-150 Specifications

AUV-150	Specifications
Operating depth	150 m
Max. operating speed	upto 4 knots
Endurance/mission time	4-6 hours
D.O.F	5 (Stable against Roll)
Energy System	Lithium Polymer Battery

Conclusion

The conceptual features and design aspects of the novel AUV-150 has been discussed along with the major sensors associated with it to carry out one of its major objective of seabed mapping. The work was performed offline in the institute using the data obtained from the mission trails and the results obtained (shown as the 2-D and 3-D plots) were quite satisfactory and in accordance with the seabed mapped by the AUV-150. Procedure for implementing the algorithm on real-time mission surveys is being carried out in order to obtain the seabed features during the course of trails itself.

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