

Use of Marine Robot 'MAYA' for Monitoring the Zuari and Mandovi Estuarine Systems

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Abstract-Autonomous Surface Vehicles (ASVs) are gaining popularity among oceanographic, meteorological and defense research organizations [Motwani, 2012]. The Autonomous Underwater Vehicle, MAYA designed and built at CSIR-NIO [Desa, E et al., 2007] was used to study the spatial distribution of biogeochemical properties in the Zuari and Mandovi Estuarine systems during the onset of tides. MAYA was repurposed as an ASV to tightly follow a path [Maurya, P et al., 2008] along the mid-section of the rivers and water properties ie. Temperature, Salinity, Dissolved Oxygen (DO), Fluorescence and Turbidity were mapped. Surface water samples were simultaneously collected along the path at discrete points and analyzed using conventional laboratory methods (Autosal for salinity, Winkler titration for DO, and fluorometry for chlorophyll *a*) for validation purposes. Salinity and DO values from MAYA sensors and lab analysis agreed within ~1% and ~2% respectively. The Zuari section was about 34 kms in length and was covered in 2 days during February 2015. Salinity along the track varied from 33.79 to 10.25 PSU, indicating that the measurements were made in different sections of the river. The Mandovi section was about 21 kms in length and was covered in a day during June 2015. In both cases MAYA was aided by the upstream tidal currents and cruised at an average velocity of ~1.5 m/sec. Autonomous Vehicles such as MAYA are essential in providing better spatial and temporal coverage of biogeochemical data.

Index Terms---AUV, ASV, Estuarine, Salinity, Dissolved Oxygen, Chlorophyll.

I. Introduction

The last decade has witnessed a surge of interest worldwide in the development of autonomous marine vehicles capable of roaming the oceans freely, collecting data at surface of the ocean and underwater. Representative examples are Autonomous Surface Vehicles (ASVs) and Autonomous Underwater Vehicles (AUVs) [Desa, E et al., 2007] [Motwani, 2012] [Manley, J et al., 2008]. Smaller class of AUV's have been used to study estuarine and coastal environment [Cruz, N et al.] [Chyba, M et al., 2010] [Mascarenhas, A et al., 2012]. As part of the Sustained Indian Ocean

Biogeochemical and Ecological Research (SIBER-India) project it was proposed to use the Autonomous Underwater Vehicle 'MAYA' and the Autonomous Vertical Profiler 'AVP' in coastal waters and estuaries to enable data collection at a very high resolution. This effort would complement the exhaustive sampling effort carried out by the chemistry group and provide an insight as to how the biogeochemical parameters vary during the onset and progress of a high tide cycle starting from the estuarine mouth, along the river and ending upstream. The secondary objective was to validate the path following algorithm of MAYA in the presence of currents.

II. Characteristics of MAYA and path following algorithm

Maya (figure 1) (Table I) is a mono hull structure machined out from a solid block of aluminium alloy. It has detachable nose and tail cones. [Madhan, R et al., 2006]. A magnetically coupled underwater motor placed at the rear provides propulsion to the vehicle. Heading and diving manoeuvres are accomplished using four control surfaces. On surface MAYA communicates with the mother ship using a high speed radio link and uses GPS for navigation. During underwater missions it uses an acoustic Doppler Velocity Log (DVL). High energy density Lithium ion polymer batteries are used for propulsion as well as sensors and electronics. An x486 computer in a PC104 form factor, running Linux OS acquires attitude, heading and velocity data, to perform control, guidance and navigation of the vehicle. Low level tasks like actuation and power monitoring are carried out using dedicated 8 bit microcontrollers. iX86 and the various microcontrollers are connected to each other using a CAN 2.0B, operating at a maximum speed of 1 Mbps. The nose cone is mission specific, and can carry a host of physical, chemical and biological sensors. The specifications of sensor connected to the science node of MAYA for the purpose of Zuari and Mandovi survey are listed in Table II, showing range, accuracy, and the maximum sampling rate. The sensors include an active fluorometer (FLNTUS Wetlabs, St. Philomath, OR) that measures chlorophyll and turbidity, a fast DO sensor (RINKO III, Nishi-ku, Kobe, Japan), and CTD (Seabird Electronics, Bellevue, Washington)



Fig 1. MAYA cruising on surface

TABLE I**Main specifications of MAYA**

Total Length	1.8 m
Diameter	0.234 m
Max depth rated	200 m
Weight	~54 kgs
Nominal speed	1 m/s
Endurance	~ 8 hrs
Communications	RF 2.4 GHz
Payloads	GPS, DVL, Pressure, CTD, DO, Chlorophyll, Turbidity, Radiometers.

TABLE II**Science sensors interfaced to the science node of MAYA**

Sensor	Range & Accuracy	Sampling	Response
Dissolved Oxygen	0-200% DO(μ M) Linear \pm 2% FS	1s to 255 min (1Hz in MAYA)	~1 s
Chlorophyll	0.02-60(μ g/l)	~8 Hz (4 HZ in MAYA)	<125ms
Turbidity	0-25 NTU		<125ms
Conductivity	0 to 9 S/m \pm 0.0003 S/m	~16 Hz (16 Hz in MAYA)	<65ms
Temperature	-5 to +35 $^{\circ}$ C \pm 0.002 $^{\circ}$ C		<65ms
Depth	0 to 7000dBars \pm 0.1% of full scale range		<65ms

Application driven mission scenarios demand for the control of AUV's to follow spatial curves accurately without stringent temporal constraints in the presence of currents and wave disturbances. This is in contrast to trajectory tracking, where it is required for a vehicle to be at desired points at specific instants of time. MAYA's path following algorithm relies on an inner-outer control loop approach. The outer loop kinematic control generates reference commands and the inner loop heading autopilot accepts and executes the commands using a simple strategy without resorting to explicit current estimation [Maurya, P et al., 2008].

III. In Situ Calibration of Sensors

MAYA sensor suit consisting of DO, Chlorophyll, Turbidity and CTD was validated using conventional laboratory methods (Autosal for salinity, Winkler titration for DO,

and fluorometry for chlorophyll a). MAYA was programmed to execute a continuous, circular surface mission until the availability of battery energy, in a shallow Bambolim bay. Surface water samples were drawn simultaneously at three locations at close proximity between 12.00 noon and 1.00pm using a Niskin water sampler. The average DO and salinity values obtained from sensors (159.32 μM , 34.02 psu) and laboratory method (163.27 μM , 33.98 psu) agreed well. Chlorophyll a values were not in agreement primarily because the waters were highly turbid (7.56 NTU). This campaign was continued throughout the entire mission (figure 2).

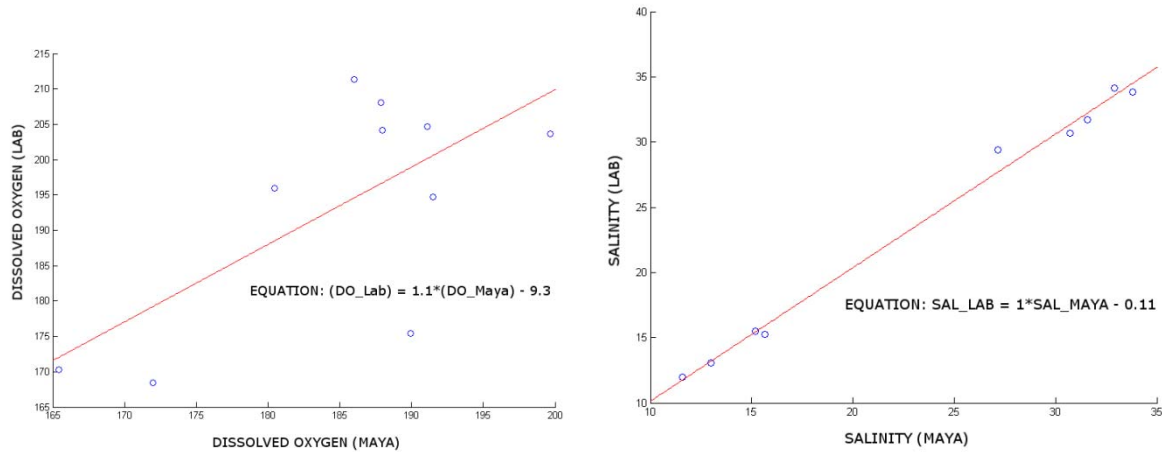


Fig 2. Validation of DO and CTD sensors

IV. Mission Planning

MAYA AUV executes a mission based on a script file ".mis". All the commands are encoded and saved in ".mis". The user plans the mission using the intuitive Google earth application. Google earths "Line Tool" is used to create a path (figure 3) and a ".kml" file is generated based on the planned mission. This ".kml" file is then parsed by the "generate.exe" program to retrieve latitude and longitude information of the path, obtain the corresponding Universal Transverse Mercator (UTM) co-ordinates using the user defined reference point and generate the "SetXYZ" mission commands. NIO headquarters was the reference point for the Zuari and Mandovi missions. As per user requirement missions were generated to run MAYA on surface along the axis of the rivers Zuari and Mandovi coinciding with the onset of high tide. In both cases the mission lasted for 2 days beginning at the mouth, cruising through intermediate sampling points and ending upstream. The tidal currents aided MAYA's movement in the forward direction, however due to the presence of a strict path following algorithm its side-ways movement was restricted.

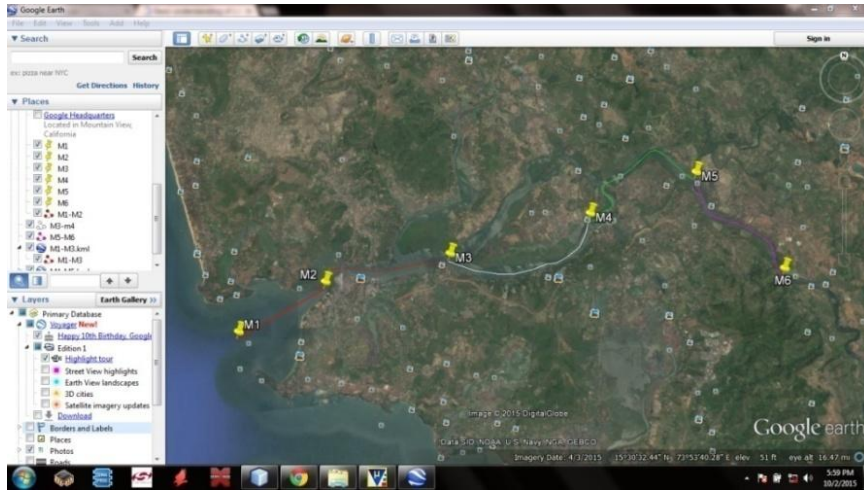


Fig 3. Generation of kml file for the Mandovi track.

V. Mission execution and results

Zuari survey was conducted on 26th & 27th Feb 2015. MAYA was towed from Hawaii beach in Dona Paula to the starting point Z1 (mouth) and the mission was executed at 12.00 noon. MAYA followed the assigned path intersecting sampling points Z1A, Z1B, Z2 (Cortalim), Z2A, Z3, Z3A, Z3B, Z4, Z4A, Z5 (Rachol). Salinity, DO, temperature and turbidity along the track are presented (figure 4).

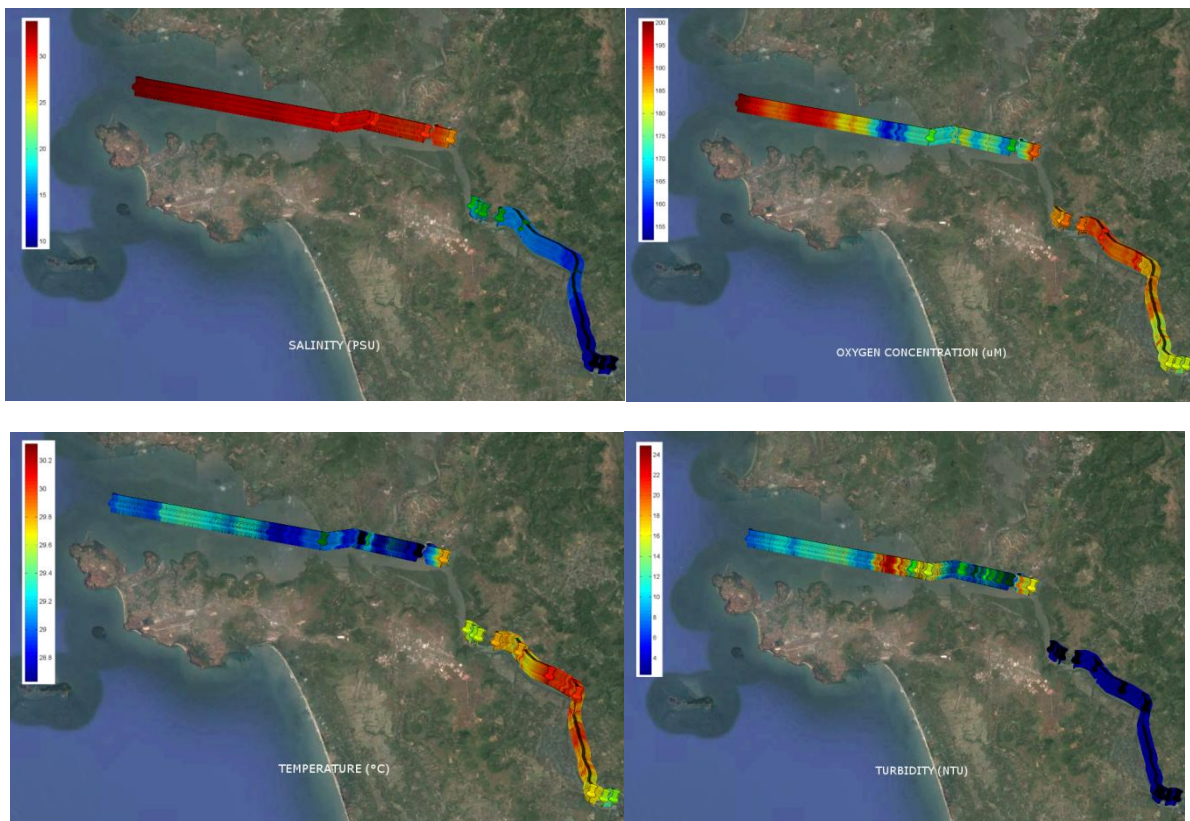


Fig 4. Variation of salinity, DO, temperature and turbidity along the Zuari

Mandovi survey was conducted on 8th & 11th June 2015. In all 4 missions were generated and executed as follows;

M1(Mouth) to M3 (Ribandar) of length 10.5 km, M3 to M4 (Old Goa) of length 7.22 km, M4 to M5 (Amona) of length 7.25 km and M5 to M6 (Volvoi) of length 6.1 km. During the first leg ie: M1 to M3 MAYA was towed due to heavy traffic. This mission extends to after the Mandovi bridge. MAYA ran in autonomous mode from M3 to M6 covering 20.57 km in 2 days and strictly followed the assigned path. Figure 5 shows the actual path against the desired path in the M5 to M6 segment of Mandovi. Salinity, DO, temperature and turbidity along the entire track shown in figure 6.



Fig 5. Actual and desired path of MAYA

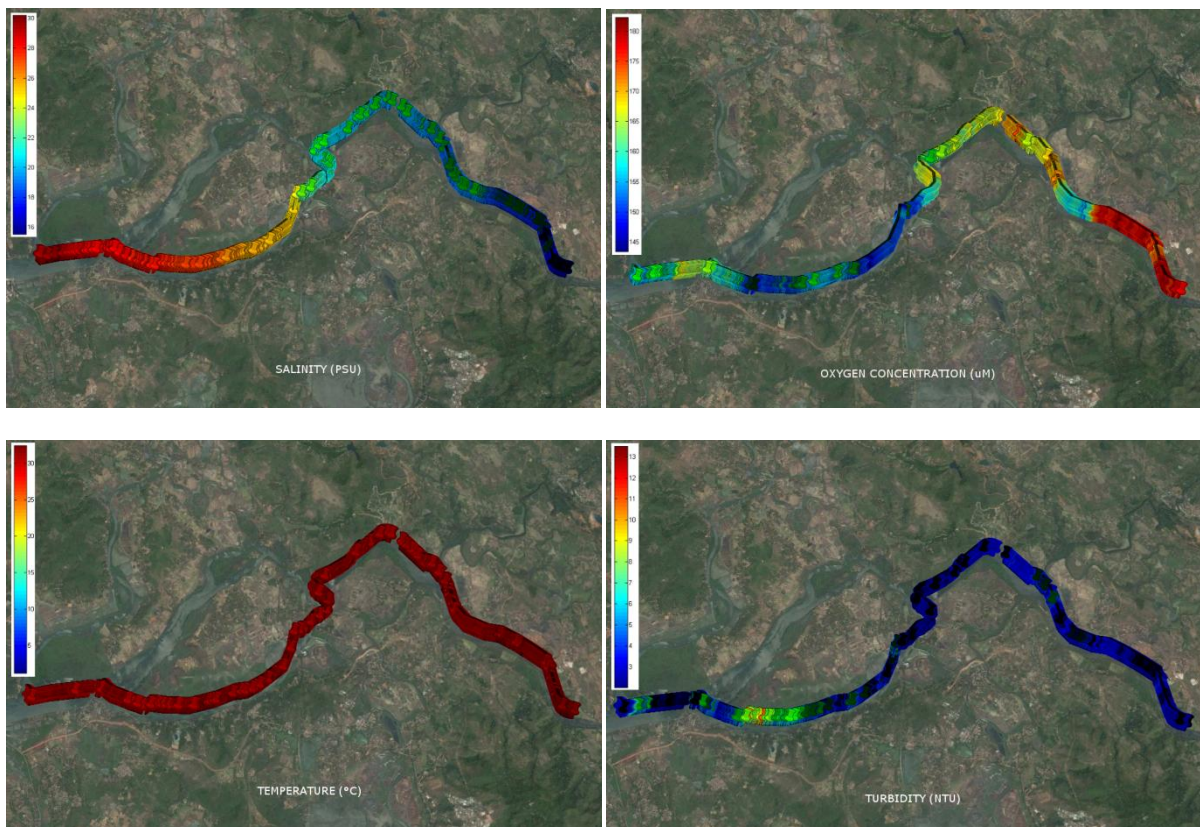


Fig 6. Variation of salinity, DO, temperature and turbidity along the Mandovi

VI. Conclusion

MAYA was successfully used to acquire high resolution physical, chemical and biological water properties of surface waters in the Zuari and Mandovi estuaries. Salinity along the Zuari and Mandovi estuary varied from 33.79 to 10.25 PSU and 30.00 to 15.50 PSU respectively. The error in the path ranged from a few centimetres to 1.5 meters due to strong currents along the path. Speed of MAYA was between 0.8m/s to 1.2m/sec and the endurance was about 6 hours.

VII. Acknowledgement

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