

AN AUTONOMOUS UNDERWATER VEHICLE “MAYA”, FOR MONITORING COASTAL WATERS, ESTUARIES, RIVERS AND DAMS

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Abstract:

There has been an increasing use of Autonomous Underwater Vehicles as a new generation ocean data platform [1]. This article demonstrates the use of Maya [2][3][4], for monitoring coastal waters, estuaries, rivers and dams. Maya is a mono hull structure with detachable nose and tail cones. The nose cone is mission specific, and offers the following sensor combinations: (a) dissolved oxygen and fluorometer, (b) conductivity temperature and depth, (c) hyperspectral irradiance, radiance and fluorometer. During a yoyo mission off-Goa in Nov 2006, a sensor suite (option c) was used to simultaneously measure the upwelling radiance (Lu) and down welling Irradiance (Ed) spectra, along with fluorescence Chlorophyll-a. The sampling frequency was 0.1 Hz. All sensors exhibited consistency during the various mission segments, consisting of surface, dive to 2m, cruise at 2m and ascent to the surface. Maya was operated away from the mother ship, so as to decouple the optical measurements from all ship borne disturbances, like ship shadow and vibration of winch wire. Using the Ed and Lu spectra the hyperspectral remote sensing reflectance (Rrs) [5], was derived along the mission track. Both irradiance and radiance, show an exponential decrease and increase respectively during the mission descent and ascent segments. Fluorometer recorded chlorophyll-a values averaged at 0.52 ug/l. Water samples were collected along the path for estimating the Chlorophyll-a pigment using HPLC method. During another expedition to the SUPA dam in Karnataka during January 08, various missions were carried out to study the spatial variations of dissolved oxygen, chlorophyll-a & backscatter. A 3.3km path following, waypoint guided yoyo mission at 1m depth was executed at noon in the east to west direction. Maya was programmed to pop up for a GPS fix every 500m. A similar mission was executed at 2m depth in quick succession but in the west to east direction for a distance of 1.7km. The sensor time series outputs are presented. More recently under the biogeochemistry program, Maya was used to study the spatial (horizontal & vertical) salinity distribution in rivers and estuaries during the onset of tides. An improved path following algorithm [6] was implemented to achieve minimal cross-track errors. Simulations carried out using hardware in loop technique for the deployment sites are presented.

INTRODUCTION

The development of the “Maya” was initiated nearly six years ago [2][3]. Maya is now an effective tool for conducting scientific experiments and underwater surveys in coastal waters, estuaries, rivers and dams.

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Since the initial pool and fresh water dam tests, experiences gained from numerous field tests, technological improvements and continuous engineering development have led to a significant advancement in the vehicles capabilities and reliability. [4][6]. All these developments and the need to measure high resolution light intensity resulted in Maya being considered as an extended arm of the ship for remote sensing applications. In an upcoming field experiment under the biogeochemistry program Maya, equipped with a CTD would be used to monitor and map the salinity distribution during the onset of tides.

VEHICLE DESCRIPTION

Maya is a mono hull structure with detachable nose and tail cones [2]. A standard Maya is 23 cm in diameter and 174 cm long. A magnetically coupled underwater motor placed at the rear provides propulsion to the vehicle. Heading and diving maneuvers are accomplished using four control surfaces. When on surface Maya communicates with the ship using a high speed radio link and uses a Global Positioning System for navigation. During underwater missions it uses an acoustic Doppler Velocity Log (DVL). High energy density Lithium ion polymer batteries offering 182 Wh/kg were used for propulsion as well as sensors and electronics [7]. 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 [8]. Low level tasks like actuation, speed control and power monitoring are carried out using dedicated 8 bit microcontrollers. The iX86 computer and the various microcontrollers are connected to each other using a CAN 2.0B, Controller Area Network 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.

Table 1 lists many of Maya's specifications and features.

Length	1.742 m
Diameter	0.234 m
Nose Shape	Slender Ellipsoid
Hull	Aluminum 6082
Nose and Rear Cones	FRPG/Acetal
Total weight in air	~54.7 Kgf
Drag coefficient	0.35
Depth range	200 m
Propulsion	Brushless motor
Propulsion efficiency	0.26 %

Nominal speed	1.5 m/s
Endurance	~ 6 hrs
Power source	Lithium n polymer
Total average power	130 W
RF communication	2.4 GHz, 115kbaud

Table 1 Specification of Maya

OPTICAL MAYA

A sensor suite consisting of Irradiance (Ed) and Radiance (Lu) radiometers and fluorometer were mounted on the nose cone. (Fig. 1)

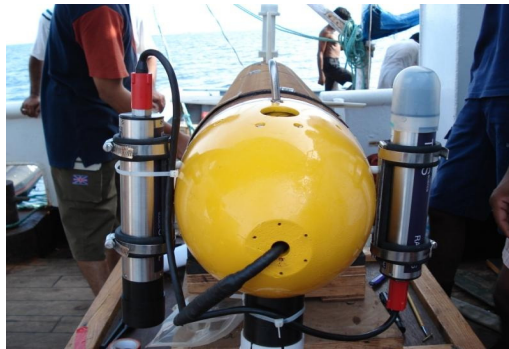


Fig. 1 Maya fitted with sensors

The radiometers are placed 240mm apart. The fluorometer is oriented to ensure that the blue light does not enter the field of view of the radiance sensor. The placement of the sensors on the sides and right in the front and ensures, that they are away from the vehicle shadow and always touch virgin waters. In order to establish the reliability of Maya to carry out optical measurements, small yoyo missions were carried out in coastal waters off GOA, with station depth of about 27m and with position co-ordinates, 15⁰30'6" N and 73⁰39' E respectively, between 12:23:09 hrs to 12:32:19 hrs. A typical mission is as follows

- A) Set the heading to 270 degrees
- B) Move on the surface for 50 sec
- C) Dive to a depth of 2m
- D) Cruise at 2m for 100 sec
- E) Surface up and repeat steps B to E two times

All along the mission track irradiance and radiance spectrums are recorded every 10 sec along with chlorophyll measurements. The chlorophyll values recorded on the surface were smaller than the ones recorded at 2m depth. This trend was observed in all the three segments of the yoyo mission. (Fig. 2) Maya was stable during the entire mission. (Fig. 3)

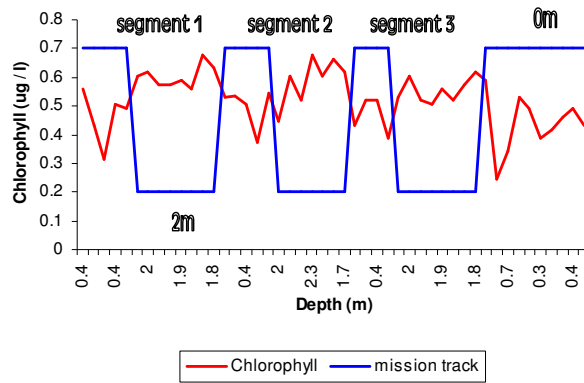


Fig. 2 Chlorophyll-a during a yoyo mission



Fig. 3 Maya cruising on surface

RESULTS

3-D aerial views of the light field as Maya, moves in a yoyo mission is

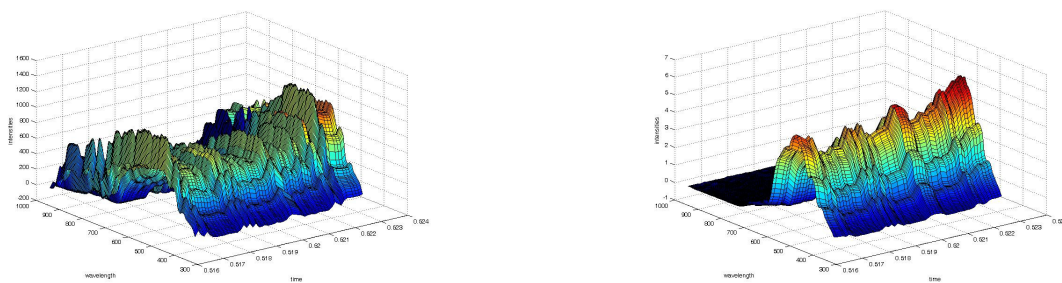


Fig. 4 3-D views of Ed and Lu during the yoyo mission

During the entire mission lasting for approx 500 seconds, 47 spectrums were recorded. As expected the amplitudes of irradiance and radiance sensors were significantly higher when Maya moved on the surface (Fig. 5 & 6)

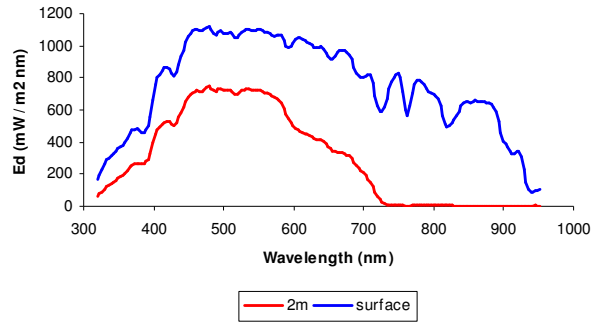


Fig. 5 Averaged Ed spectra

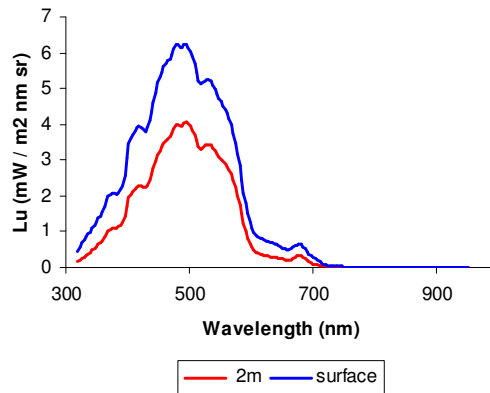


Fig. 6 Averaged Lu spectra

For remote sensing applications, the Remote sensing reflectance (R_{rs}) is essential and is defined as,

$$R_{rs} = L_w / E_d(0^+) \text{ where } L_w = t/n^2 * Lu(0^-)$$

$E_d(0^+)$ and $Lu(0^-)$ are the irradiance and radiance, just above and below the water surface respectively. A value of 0.546 [5] was used for the proportionality factor t/n^2 .

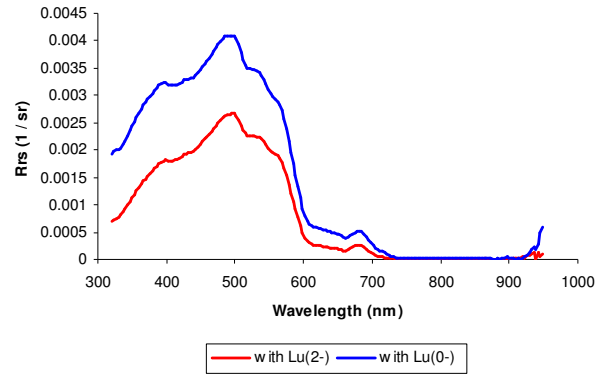


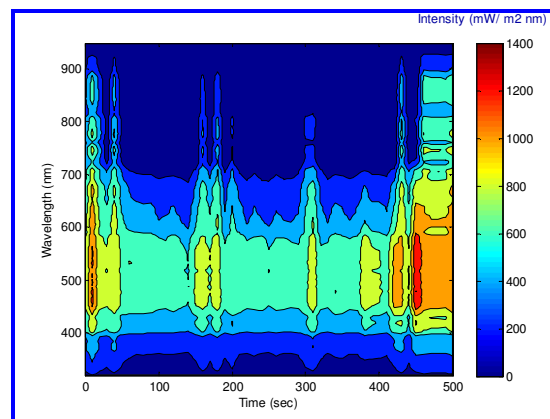
Fig.7 Remote Sensing Reflectance

Fig. 7 shows the computation of Rrs for two cases

- 1) Lu(0⁻) measurements when cruising on surface (blue)
- 2) Lu(0⁻) measurements when cruising at 2m (red)

From the above graphs we can conclude that for more accurate results one needs to operate Maya at very shallow depth preferably less than 1m. This confirms that Maya is a stable platform for optical measurements.

Fig. 8 shows the contour plots of Ed, Lu and Rrs during the yoyo mission.



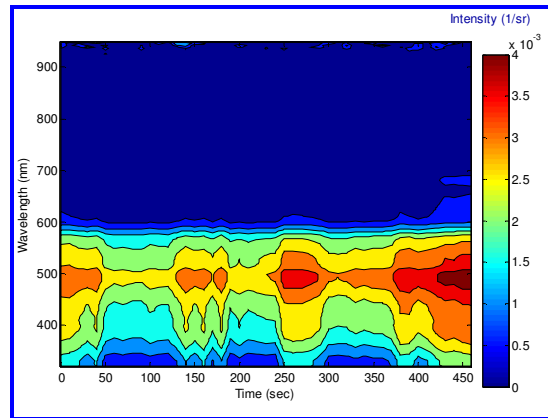
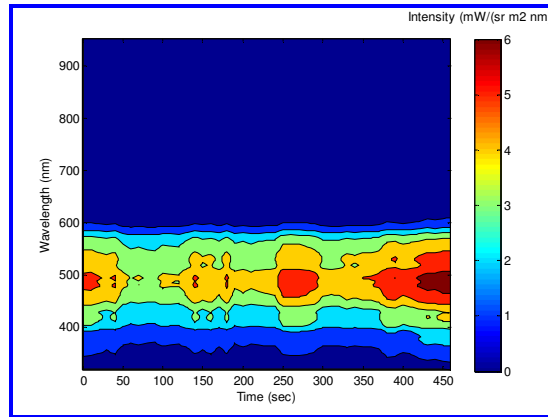
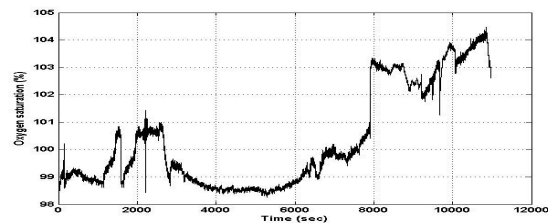
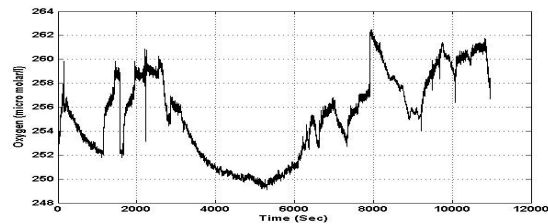


Fig. 8 Contour plots of Ed, Lu and Rrs

DAM MONITORING

Maya, equipped with, Chlorophyll-a, turbidity and dissolved oxygen sensors was deployed at Supa dam in Karnataka to study the surface properties. Data was collected during a 3.5 km (corresponding to the time segment between 3000-6500 seconds) straight run on the surface. Fig.9 shows the sensor outputs.



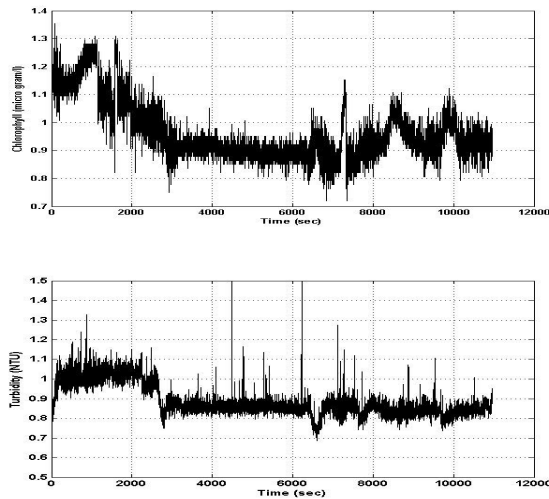


Fig. 9 Sensor outputs during a surface mission at Supa

ESTUARY EXPERIMENT

With the objective of using Maya in the estuary, hardware in loop simulation was performed in the laboratory using Maya model and actual code. The simulation was carried out for surface operation in a path following configuration and in the presence of tidal currents as shown in Fig 10. During tidal influx the currents tend to hug the shore and Maya, without a path following controller would tend to move towards the coast. The straight line indicates the simulated movement on the surface from start to end with the path following controller switched on. These simulations allow the user to visualize and optimize the performance before actual field deployment.



Fig. 10 Simulation of Maya following a straight path in the presence of tidal current

CONCLUSION

The hyperspectral radiometers and fluorometer were successfully integrated and tested on Maya. The quality of data indicates that this vehicle is stable and suitable for optical measurements. As a novel method for remote sensing applications and satellite validation studies, Maya could be operated just below the sea surface. In future it could be used to study

subsurface trichodesmium blooms. It can also be used as an effective probe to address science problems in dams and estuaries.

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