The small AUV Maya: Initial Field Results

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Introduction

Autonomous Underwater Vehicle [AUVS] are essentially propelled robot platforms with on-board computers, power packs and vehicle payloads that enable automatic control, navigation and guidance of the vehicle. They are used to acquire data from onboard sensors to sense physical, biological and chemical properties in the ocean, in lakes, in estuaries, rivers, and dams. AUVS are novel to the extent that they can be programmed to dive and to maintain control at any given depth layer in a water body, to navigate by changing course at a chosen depth, to follow seabed terrain, and when a mission is accomplished to return 'home'. There are more than 58 on going developments of AUVS of different classes and sizes around the world (see www.ausi.org/auvs/auvs.html) ; the best known being REMUS, GAVIA, and AUTOSUB [1]. A number of oceanographic problems need data acquisition without disturbing the environment. Shipboard profiling and towed instruments packages and samplers in such cases disturb the layer and can introduce errors in measurements. There are situations and places where divers are at risk and in these cases AUVS and ROVS (Remotely Operated Vehicles) equipped with appropriate sensors, power packs, and propulsion capability are able to address these problems to a large extent.

A significant step in developing a prototype small AUV called Maya was achieved at the National Institute of Oceanography, Goa, India in May 2006. The project received initial seed funding from NIO in 2003 and a subsequent full grant (2004-2006) from the Ministry of Communications and Information Technology (MIT), New Delhi. In addition, cooperative work was also carried out under the scope of the Indo-Portuguese Cooperation Programme in S&T with the group headed by Prof. Antonio Pascoal, Institute of Systems and Robotics/ Instituto Sup.Técnico Lisbon, Portugal. This programme was funded through an exchange visit program by the Dept. of Science & Technology, New Delhi, and GRICES, Portugal.

This article describes salient features of the Maya AUV i.e its mechanical design, control systems, navigation, on board sensors, and safety aspects. Field results of Maya use in a confined freshwater ecosystem, and in open ocean water are also presented to demonstrate its use in an oceanographic setting.

Mechanical design of the Maya AUV

The specifications are listed in Table 1 and a photograph of it in air is shown in Fig .1. The Maya AUV [2] follows a classical submarine design consisting of a low drag slender ellipsoid removable nose cone on which scientific sensors can be mounted, a main hull bored from a single bar of aluminum alloy that has been pressure tested to depths of 200m, and a tapered Myring profile rear cone with a single DC motor at the extreme end for propulsion. It has two stern planes and two rudders to control diving and heading maneuvers respectively. The nose section can accommodate different sensors for specific missions at sea. The AUV can receive commands from the shore over a high-speed UHF radio link or download data over the same link. Underwater navigation uses a Doppler Velocity Log (DVL) to measure speed and a navigation filter that estimates it's position below sea surface. Surface navigation is based on GPS (Global Positioning System.

Table 1 : **Main specifications of the Maya AUV**

Vehicle Specifications	
Total Length	1. 742 m
Diameter	0.234 m
Weight in air	~54.7 Kgf
Nose and Rear Cones	FRPG/Acetal (Removable)
Depth range	200 m
Propulsion	DC brushless motor (Tecnadyne)
Nominal speed	1.5 m/s
Endurance	~ 7.2 hrs
Power source	Lithium Polymer cells
Total average power	130W
Electronics	Distributed networked nodes
RF Communications	2.4 GHz, 115kbaud (Freewave)
Vehicle Payloads	Doppler Velocity Log – Sontek, Attitude & Heading Reference System – Crossbow Pressure sensor – Honeywell, Scanning Sonar – Tritech, GPS - Motorola

Fig1 : The Maya AUV and project team members

Mission Specific Removable Nose cones of Maya

Design considerations have made it necessary to fabricate a series of removable nose cones having mission specific sensors. For example physical properties of the ocean are best studied with a Conductivity-Temperature-Depth (CTD) sensor customized to fit within the available volume offered by the nose. All nose cones are free flooding and can be fitted on to the front pressure endplate of the main hull. Other missions on biogeochemistry require a combination of Dissolved Oxygen (DO), Chlorophyll, and turbidity sensors fitted on an identical nose cone. Examples of these nose cones are shown below in Fig. 2.

(a) (b) (c)

Fig. 2 : (a) Dissolved Oxygen (DO) and Chlorophyll cum turbidity sensor (b) Conductivity-Temperature –Depth (CTD) sensor (b) (c) Hyper-spectral Radiometers and Chlorophyll sensor combination fitted on the nose cones.

Scientific sensor payloads used on Maya AUV

The choice of scientific sensors was primarily constrained by size, weight, low power consumption and the need to lower cost. Most sensors used here are placed within or external to the nose volume. Table 2 below lists the sensor payloads that have been used on the Maya AUV

TABLE 2: Scientific sensor payloads used on Maya AUV

Sensor used on Maya	Manufacturer	Range & Accuracy	Size & Weight
Dissolved Oxygen	Aanderraa, Norway	0-500uM (<8uM or 5%)	36 x 86mm. 120 gms
Chlorophyll	WetLabs, USA	0.02–60µg/l	63 x 133mm, 80 gms
Turbidity		0–25 NTU	
Conductivity, Temperature, Depth	RBR, Canada	0 to70 mS/cm, (± 0.003 mS/cm)	400mm x 64mm, 389 gms
		-5 °C to 35 °C, (± 0.002 °C)	
		0 to 740 dBars, (<0.001% FS)	
Hyper spectral Radiometers	TRIOS, Germany	Irr: 280-500nm, (6 to 10 %)	47 x 260mm, 838 gms
		Rad: 320-950nm (6%)	47 x 297mm, 913 gms

Control Aspects of Maya AUV

The depth and heading control systems of Maya were designed using the LQ (Linear-Quadratic) optimization technique that was based on a mathematical model of the AUV obtained by resorting to analytical and semi-empirical methods [3].

The controllers have met the requirement of performance and stability in both the vertical and horizontal planes [4]. At a practical level, the use of delta implementation removes the bias form the stern planes obviating the need of a special sensor for precision measurement of control plane angles. Extensive tests of the autopilots were carried out at Amthane Reservoir in Goa so as to arrive at the best set of gains and bandwidths. These tests proved useful when Maya was deployed in real conditions at sea with little or no changes in the control settings.

Simple Line of Sight (LOS) way point guidance scheme was used in guidance of the craft, and Navigation is done using a GPS when vehicle is on surface and dead reckoning under water using a Doppler Velocity Log. The switching from GPS to DVL and vice versa is done smoothly using a complimentary filter.

Safety Aspects on Maya AUV

Building in safety features on the AUV is of prime importance and we have considered and implemented the following:

- Power safety which monitors the bus voltage on a network node, and redirects the AUV towards home coordinates if the power level falls below a minimum threshold level.
- Software safety ensures that the DC thruster is shutdown if the vehicle crosses programmed depth, or exceeds a set pitch angle.

Field tests of the Maya AUV

The Maya AUV was field tested in two different environmental settings. The first important test (May 2006) was carried out in a freshwater ecosystem at the Idduki Dam in Kerala, India.

(A) Idduki Dam Data

In this mission, the AUV was commanded to execute a series of staircase dives to increasing depths starting with a short staircase to 2m, and ending with a staircase dive to 21m. The reason for staircase dives was to fully test the depth control of the AUV, and to permit the slower response sensors to fully settle down when cruising at constant depth. Staircase dives demonstrate the ability of the Maya AUV to operate in confined spaces. An acute oxygen deficiency was discovered by Maya as shown in the plot of Dissolved Oxygen (DO) with depth at ~ 20m in Fig 4. This was validated by measuring DO from water samples collected at site. It was confirmed later by chemists at NIO who visited Idduki shortly after our tests.

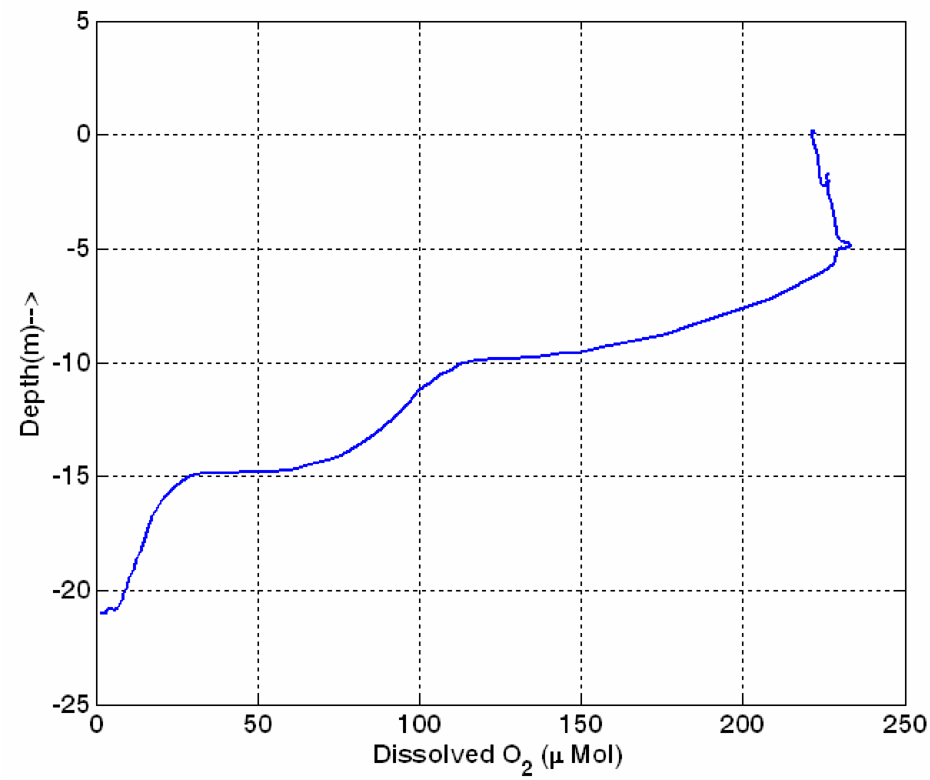

Fig.3: Depth Profile of Dissolved Oxygen taken from a 21m staircase at Idduki Dam, Kerala.

(B) Tests at a Coastal Station in the Arabian Sea

A second set of field tests were carried out on the 22 Nov 2006 at a coastal location (Lat 15° 31.8′N, Long. 73° 13.6′E) off Goa in the Arabian Sea. The maximum depth at this location was 80m. The deployment and retrieval was made from the coastal research vessel Sagar Sukti of the National Institute of Oceanography, Goa. For this test, a CTD nose cone (Fig2 b) was fitted onto front endplate of the hull , and as before the AUV was commanded to dive to different depths in staircase maneuvers. The descent staircase dive to 40m is shown in Fig 4, and the corresponding temperature- depth profile in Fig 5. An inversion layer at 30m was detected by the fast response time (~ 95ms) of the CTD sensor .

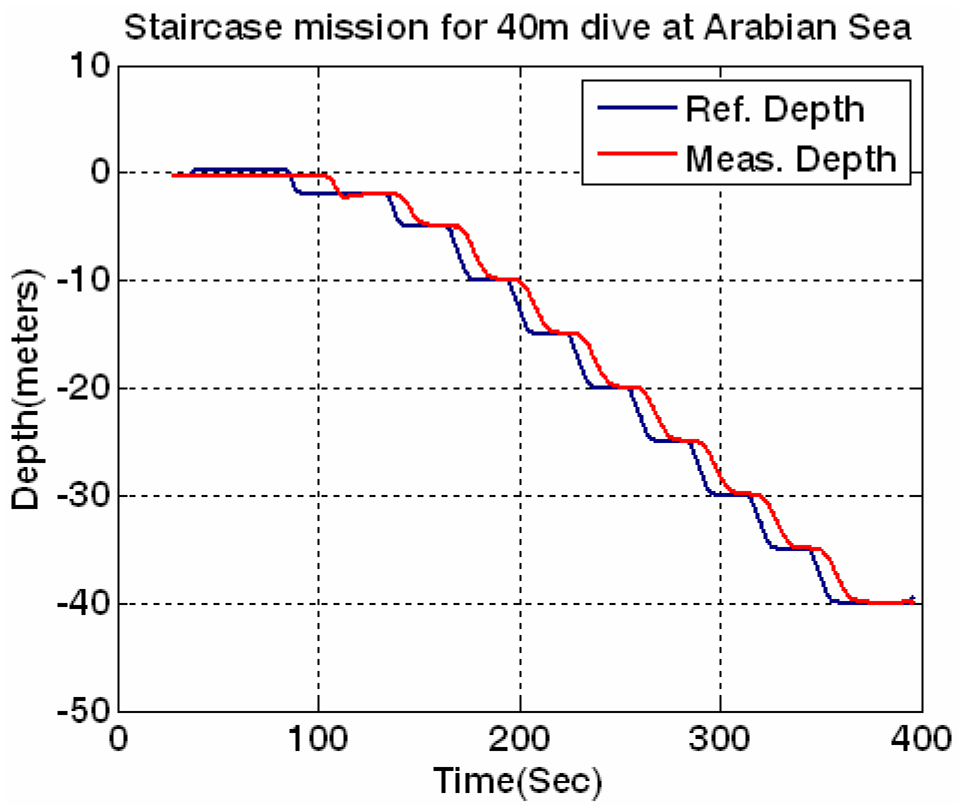

Fig 4 : Staircase descent of the Maya AUV to 40m in the Arabian Sea

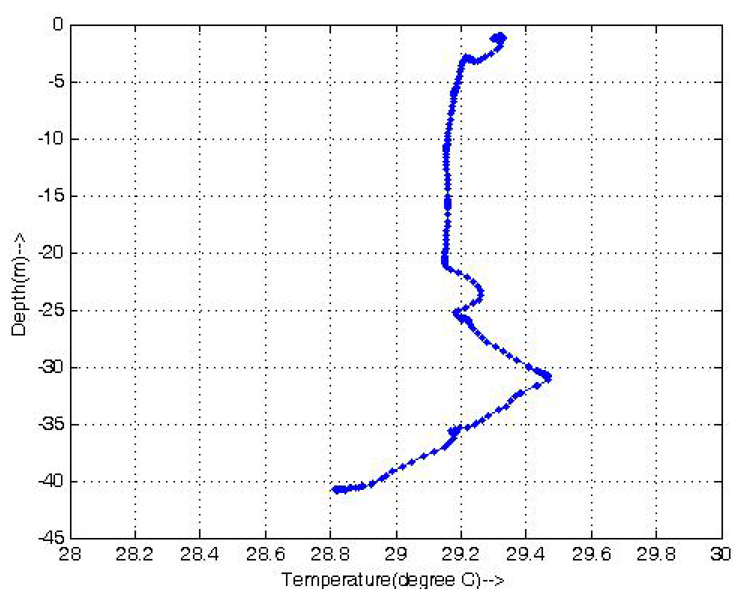

Fig 5: Profile of Temperature (CTD) sensor extracted from staircase dive to 40m showing an inversion layer 30m.

Conclusions

A small Autonomous Underwater Vehicle [AUV] has been designed and developed for the first time in India at the Marine Instrumentation Division of the National Institute of Oceanography in Goa. The small AUV Maya was field tested in two very different environmental settings namely the Idukki Reservoir in Kerala, and a coastal station in the Arabian Sea. Our experience in this project has confirmed the potential of small AUVS to work in confined spaces and in the open ocean, and as we have experienced, to discover unexpected processes in the ocean.

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Fig 6: Retrieval method of the Maya AUV using an inflatable craft.

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