Development of Autonomous Surface Vehicles (ASVs) for mapping marine environments and water quality

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by

Prabhu Rajagopal[1]

[1]Department of Mechanical Engineering, IIT Madras, Chennai, TN, email: prajagopal@iitm.ac.in

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I. Introduction and motivation

India has a large coastline and thus strong and improving maritime infrastructure, including 12 major and over 180 minor ports [1]. India also has over 3200 dams and reservoirs and over 200 large and medium lakes [2]. In such water bodies, it is vital to obtain and update information regarding water and silt levels, for understanding the draft (in coastal regions) and volume storage capacity (in reservoirs). Many water bodies and coastal regions are also used as heat sinks, where industrial plants take in water for cooling and release back effluents. It is critical to study the impact of the temperature and biocides in effluents discharged, on local flora and fauna. This includes measurement of parameters such as pH levels, oxygen saturation, temperature, conductivity, chlorophyll, and turbidity.

Conventionally, tasks including bathymetry and environmental surveyto obtain such information,are carried out manually using boats or vessels. However this approach is labour-intensive and obtaining stable, reliable and repeatable data is difficult. When the water bodies of interest may contain hazardous compounds or subject to challenging environmental conditions, data collection can put the human operators or divers at risk. Sometimes the regions of interest are also vast, requiring extensive communication and endurance or they may just be inaccessible, making it impossible for human personnel to collect the data. Finally, rapid mobilization and service availability is a problem especially during emergencies.

Autonomous underwater vehicles (AUVs) and gliders are unmanned vehicles that can be designed to reach and perform predefined inspection, survey and monitoring tasks along pre-defined paths or at specific locations. AUVs allow for reliable, safe and efficient data collection, and can be tailored to suit various applications such as reaching hazardous or inaccessible locations to perform specific operations. Although some AUVs are now available from both research and commercial sources [3-5], often the products are expensive and do not have much scope for customization. The available solutions do not have much maneuverability and are also not very portable for rapid deployment.

II. Objectives

This project seeks to build a submersibleAutonomous SurfaceVehicle (ASV) for measurement of depth and environmental parameters in water bodies subjected to low current action, with the following goals:

- Ability to map the surface area of a given water body along specified path
- Capability for diving to small depths (up to 10 m) from the surface
- GPS-based remote communication with on-shore location
- Automatic data gathering campaign along programmed path/trajectory
- Bio-inspiration in design for depth navigation and turning
- Focus on portable, modular design for versatility and customization of sensor payloads
- Indigenous parts and components as far as possible

III. Submersible ASV for Depth Mapping and Environmental Survey of water bodies

Launched from on-shore location, the ASV will autonomously navigate as per pre-specified path, taking measurements along predefined grid points with the ability to obtain and store data on-board. The design will be highly modular, to allow for integration of multiple sensing and navigation payloads. Further, novel design features will allow performance optimizing agility and manoeuvrability. Bio-inspired features [6] will be considered for depth diving and vehicle turning during surface mapping. The design will be neutrally buoyant with stabilization algorithms to ensure station keeping with minimal power utilization. The ASV will have on-board electronics for vehicle control, pulsing and receiving data from various sensor payloads, on-line data processing, communication and transmission. Features for safe retrieval (on-board power failure) will also be incorporated.

Figure 1 below presents a snapshot of a 3D model of a dual-hull initial conceptual design for the proposed ASV.The leading hull acts as a command and control module and the follower hull(s) will carry sensor components. The two hulls are connected by a hinge joint mechanism which facilitates in-plane rotation about vertical axis. The ASVcan be either manually controlled through wireless signals from outside or can work in automated mode.

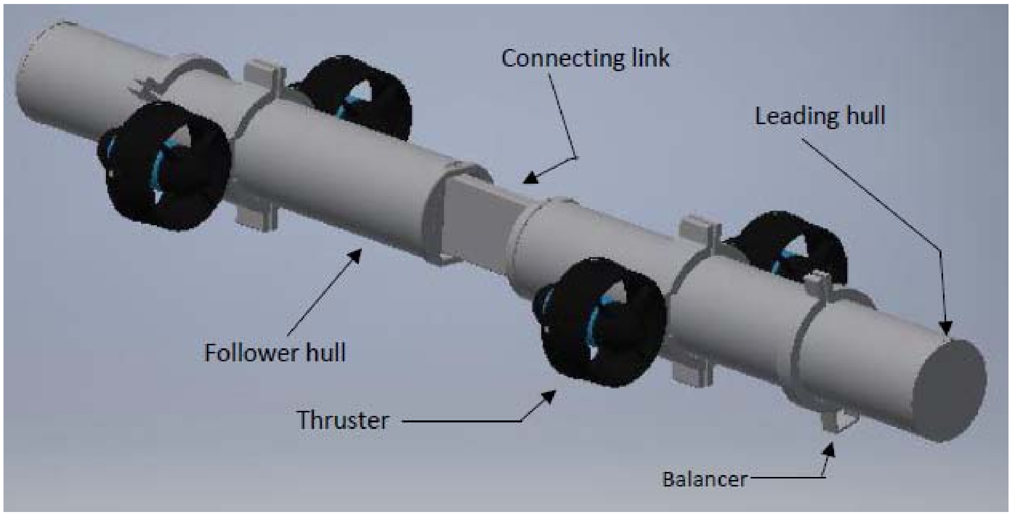

Figure 1: Snapshot of the CAD model of initial conceptual design of the ASV

The project will be completed in 3 phases of 1 year duration each: (a) during Phase 1, a prototype vehicle will be built and tested in stagnant water conditions (b) Phase 2 will involve extensive testing at the experimental facilities with the Center for Ocean Technologies simulating actual tidal, wave and current conditions and (c) finally in Phase 3, the vehicle will undergo a limited set of field trials in lake and low-current ocean environments. Upon project completion, this technology is expected to be in the Technology Readiness Level (TRL) 5-7 range and will require further detailed trials before scaling and deployment.The investigative team will file for initial IP on novel aspects of the developed technology. With the objective of indigenization, the team will seek to involve suitable partners with core competency in areas such as power management, sensing and fabrication, particularly among Start-ups associated with IIT Madras (e.g. Pi Beam Labs Pvt Ltd, Planys Technologieswww.planystech.com). These partnerships will also be valuable in taking the solution to field-deployable TRLs after project completion.

IV. PROPOSED TECHNICAL DETAILS OF ASV

The ASVwill have the following specifications:

- Weight of base system without payloads < 30kg
- Battery pack designed for operations spanning 6 hours at 3-4 knots speed; ensuring coverage of 2km x 2km area/ day

- Modular battery packs to ensure quick replacement of depleted batteries on field with fully charged batteries
- Small turning radius robust navigation using GPS, Wifi link and Doppler velocity logs
- Integration of various on-board sensors:internal temperature, humidity and battery level sensors, three axis digital compass, depth sensor, echo-sounder (height from bottom), object sounder(in nose), water quality - pH/ORP, Temperature, conductivity, dissolved oxygen, turbidity, and chlorophyll..
- Emergency pinger system in case of mid-mission retrieval
- Additional sensors can be integrated as per requirement: Cameras, Side Scan Sonar, algae, TSS, TDS, Nitrates, phosphate, ammonium

V. Budget

The total budget requested is INR 360 Lakhs, with break-up as given below:

S. No.	Particulars	Budget (Lakhs)
1	Materials and Fabrication including electronics, propulsive units and sensors for ASV *(3 numbers)*	105.0
2	Sensor payloads: *5 channel Sensor*(Conductivity, Temperature, Depth, pH & chlorophyll), DO, Turbidity, ORP, Side-scan SONAR, Camera, Pinger+Altimeter (For Bathymetry), DVL (For velocity and current mapping)*	70.0
6	Manpower *(1 SRF@ 40k pm, 2 JRF @25kpm, 1 Technical Staff @15k pm all for 3 years)*	25.0
7	Consultants *(Power management, sensor integration)*	30.0
8	Field Trials	30.0
9	Travel and equipment transport	20.0
10	Contingencies	20.0
11	Computer charges	Under NTCPWC
12	Overheads charges by IIT Madras (20% as per norms)	60.00
TOTAL in Lakhs INR (rounded)		**360**

VI. Work Plan

The project will be carried out in 3 Phases, with a detailed list of tasks as shown in the table below.Phase 1 will consist of custom-design and fabrication of ASV with addition of requisite payloads and trials in stagnant water. Phase 2 will then consist of performing trials of simulated field conditions. Phase 3 will consist of a limited set of practical field trials to refine the ASV's capabilities to match project needs

Overall project duration proposed is 36months, with the following key milestones:

Task	Task ID	Milestones (Months)	Cumulative (Months)	Phase
Release of Initial Fund, commencement of project	T0	0	00	Phase I (12 months)
Recruitment and induction to ASV systems	T1	T0 + 2	02	
Conceptual Design of ASV	T2	T1 + 2	04	
CAD, incorporation of electronics & sensors	T3	T2 + 2	06	
Fabrication, assembly and diagnostic trials	T4	T3 + 2	08	
Trials of ASV under stagnant water conditions	T5	T4 + 2	10	
Test of ASV under simulated field conditions	T6	T5 + 12	24	Phase II (12months)
Field trials – 1	T7	T6 + 4	28	(6 months)
Field Trials – 2	T8	T7 + 4	32	
Refinements based on learnings from field trial	T9	T8 + 2	34	
Reporting	T10	T9 + 2	36	

VII. Deliverables

At the end of the project period, a field tested ASV prototype at TRL 5-7 for mapping marine environments and water quality will be available, together with IPs on innovative concepts and publications in prestigious Conference Proceedings and high-impact journals. The solution will require further set of practical trials to take it to field deployment. Suitable partners among IITM Startups and local industries will be identified for technology transfer and commercialization.

VIII. REFERENCES ([1-6] for proposal main body and [7-19] for appendices)

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Appendix – I: Profile

Prabhu Rajagopal is Associate Professor in the Department of Mechanical Engineering and an Associate of the Centre for Nondestructive Evaluation (NDE) at IIT Madras. After graduating from IIT Madras in 2003 with a Dual Degree Masters in Mechanical Engineering with specialization in Intelligent Manufacturing, he obtained his PhD in Ultrasonic NDE from Imperial College London, UK in 2007. As a post-doctoral researcher, he developed advanced computational tools for inspection of welds on a Rolls Royce funded project, also at Imperial (2008-2010). He is currently Principal or Co-Investigator in BRNS, DST, TDB, CEFIPRA, MHRD-MNPG and MHRD-MOD funded sponsored projects with a total value of over 12 Crores (about half of that as PI), and has contributed over 100 technical articles in peer reviewed journals and conference proceedings and 9 Indian patent filings. He serves on the editorial board of ISNT Journal of NDE and is the Principal IITM Member on National Standardization Committee of the Bureau of Indian Standards. He engages actively with industry, with links to companies/national laboratories including BHEL Trichy, GE Bangalore, RIL Mumbai, TCS, IGCAR Kalpakkam, BARC Mumbai, NPOL Kochi, Airbus France and Fraunhofer IZFp Germany. His areas of interest include strategies for inspection of structures under challenging conditions, and high resolution ultrasonic imaging using structured and topographic metamaterials. His research is strongly collaborative and international, with joint projects/publications with groups from universities such as Swinburne UT, Australia (with whom he has a joint PhD student), NTU Singapore, ZUT Poland, U. Warwick UK, U. Bordeaux France, Michigan State USA and ETS Montreal, Canada. He is a co-founding Director of the underwater and submersible robotics Startup Planys Technologies Pvt. Ltd which licenses his IP filing on automated submerged pipeline inspections.

Appendix -2: Dr. Prabhu Rajahgopal’s work on Robotic Vehicles for Remote Inspection

Riding the recent wave of affordable and open-source electronics such as the Raspberry-Pi, Dr. Rajagopal is developing robotic vehicles for remote inspectionof various inaccessible land (see [7] and Figure 1 below) and immersed structures such as pipelines and tank floor (see [8], Annexure-F and Figure 2 below).

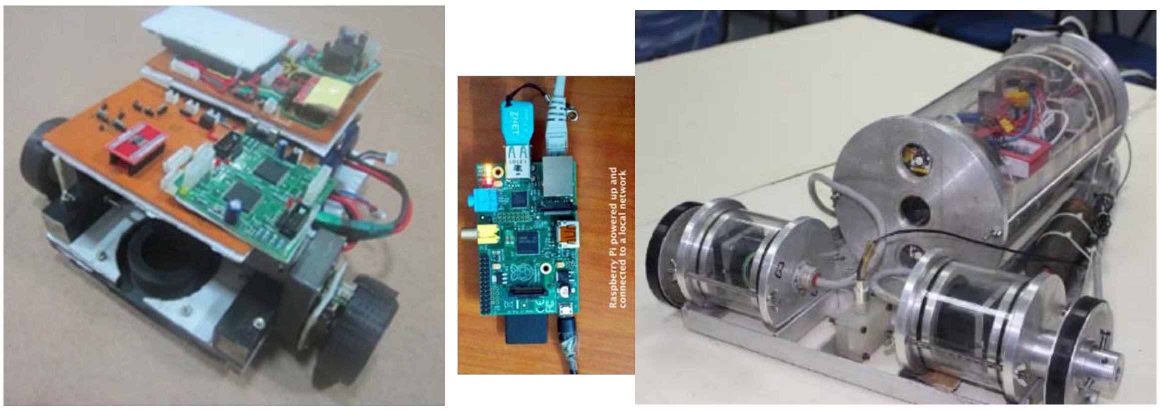

Figure 1: Affordable robotic crawler with portable ultrasonic C-Scan capacities, controlled by a Raspberry-pi (photograph inset)

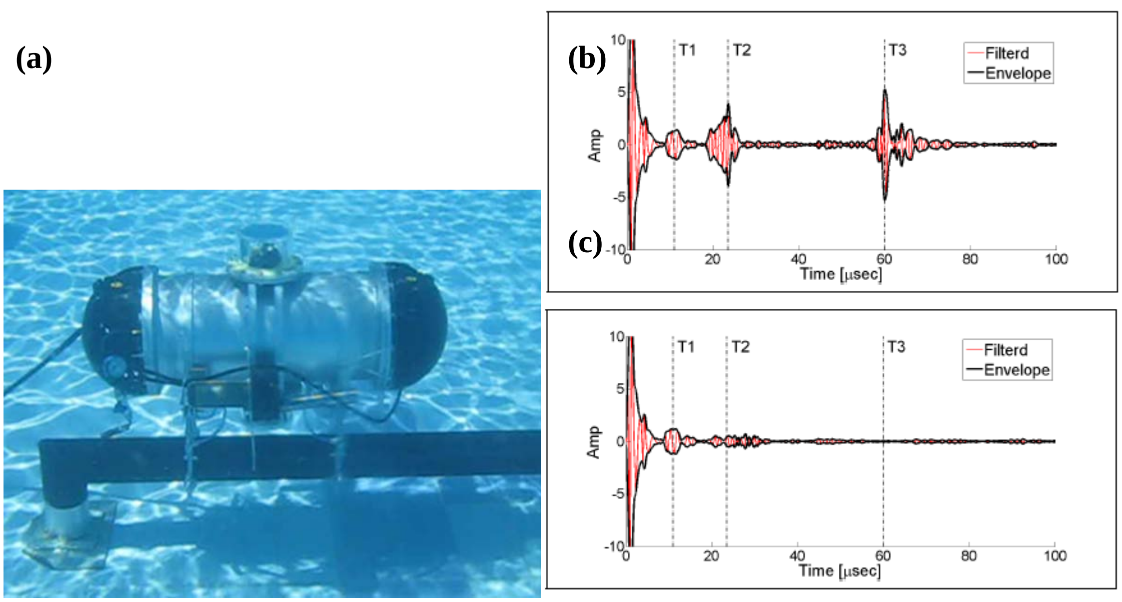

Figure 2: Remotely operated robotic vehicle for inspection of submerged pipelines: (a) photograph of test in Swimming Pool; (b) and (c) show circumferential guided wave inspection of pipe cross-section –presence of defect suppresses direct arrival signal in (c)

Dr. Rajagopal's general Design approach combines features of aesthetics, ergonomics and form-function optimization within the framework of minimalism. He was awarded the prestigious Bhagyalakshmi & Krishna Iyengar Prize for guiding the best final year projects on submersible inspection ROV twice (2016 and 2014) and the J.C. Bose Best patent award in 2015.

Dr. Rajagopal is also developing a cutting-edge Design interpretation of the 21st century cultural trend of Magical Realism led by such iconic figures as Marquez and Rushdie and also the precursor movement of Surrealism. In his Design interpretation of Magical Realism, Dr. Rajagopal believes in incorporating features by form or functionality that would be considered magical or otherwise impossible to achieve in a certain price bracket. This means going beyond merely satisfying the end-user, to incorporating features that delight and surprise them. Often such elements are possible purely by clever Design thinking and no additional cost.

The Duli bio-inspired underwater robot (see Figure 3 below and also [9,10]) can be thought to be the first vehicle made as per Dr. Rajagopal's interpretation of Magical Realism.The combination of bio-inspired tail-fin type propeller for linear motion at high speed and rotary propellers for high manoeuvrability provide unmatched possibility of motion and control. Such features are not achievable otherwise, except by expensive precision controllers.

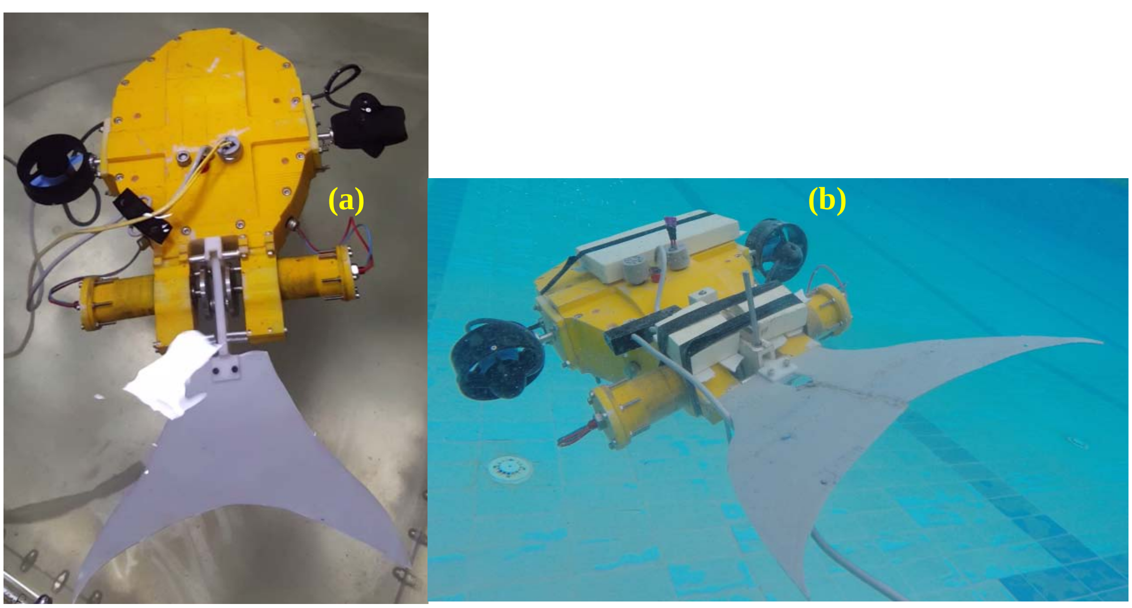

Figure 3: Duli, a bio-inspired hybrid robotic vehicle for visual underwater inspection: Snapshots of (a) Laboratory and (b) Swimming Pool trials [9,10]

Another example of design incorporating Dr. Rajagopal's interpretation of Magical Realism is the concept Swarm Robot presented in Figure 4 (see also [11]).This design consists of a cylindrically shaped 'mother' robot doubling up as the hull housing all electronics and two detachable bio-inspired 'child' robots which can carry probes for visual and other diagnostics. The overall assembled Swarm travels like a bio-inspired tortoise. Once detached from the mother robot, the child robots travel by fish-like flapping and geometric reconfiguration. The detachable and reconfigurable features add a magical charm to overall design of the Swarm, which also incorporates concepts of Minimalism, Design for Assembly and Maintainability.The mother robot's hull is transparent ensuring easy troubleshooting and maintenance.

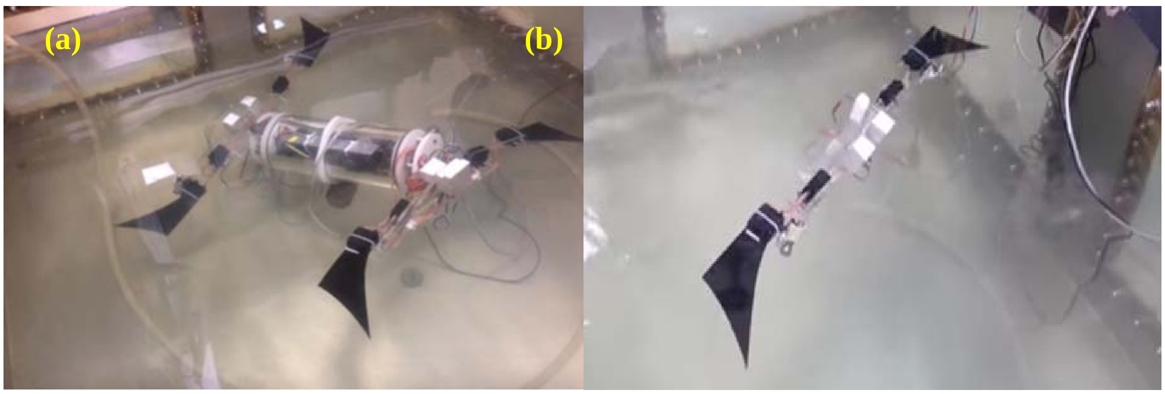

Figure 4: Snapshots from Laboratory tests of bio-inspired Swarm robotic vehicle for visual inspection: (a) Complete System resembling Turtle & (b) Detachable 'child' robot

This wellspring of laboratory-based knowledge and resource base has led to Dr. Rajagopal co-founding an IIT Madras incubated spin-out company, Planys Technologies Private Limited (http://www.planystech.com/, incorporated in June 2015). Figure 5 (a) below presents a photograph of the ROV MIKE [12] developed by Planys, during a field trial at a Fishing Harbour close to Chennai (4 m water). Figure 5 (b) presents a photograph of Ultrasonic inspection of immersed structure performed by Beluga, the latest ROV developed by Planys and to be released shortly for commercial applications. ROV Beluga, also has elements of Magical Realism, with advanced features such as manoeuvrability and sensor flexibility rarely available in the price bracket these products are being marketed at.

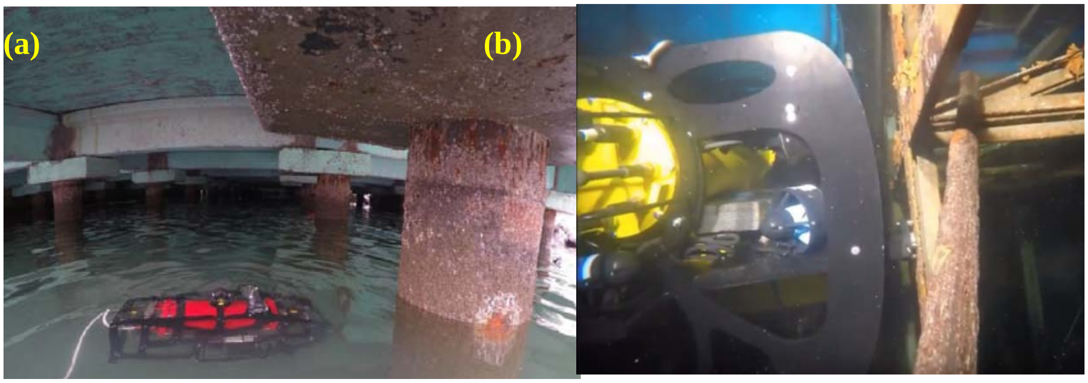

Figure 5: Snapshots showing : (a) Field trial by Planys Technologies, an IITM spin-out co-founded by Dr.Prabhu Rajagopal at Fishing Harbour, Chennai for visual inspection using ROV MIKE [12] and (b) Ultrasonic inspection of immersed structure by ROV Beluga by Planys

Dr. Rajagopal's work on Underwater Robotics has received much interest in national and regional print media, with features in New Indian Express (February and July), Dinakaran, The Hindu- BusinessLine, Times of India, Deccan Chronicle (July and August), Eenadu and Rajashthan Patrika, all in year 2016 alone (see for example, References [13-19]).