

Unmanned underwater vehicles: Design considerations and outcome of scientific expeditions

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In India, scientific investigations of ocean basins have been in progress for more than five decades using indirect and direct measurement devices. These studies were aimed at resource identification, ecological, palaeo-oceanographic and palaeo-climatic research. To cater to the need of the ocean community, Remotely Operated Vehicles (ROV) rated for 6000 m (ROSUB 6000) and 500 m (PROVe-500) operational depths have been developed at the National Institute of Ocean Technology, MoES, Chennai. This article reports the design considerations for unmanned remotely operated underwater vehicles and the outcome of scientific expeditions conducted for deep sea mineral exploration, ocean biodiversity and polar science.

Keywords: Biodiversity, ocean resources, remotely operated vehicle.

Introduction

VISUALLY observing the sea floor in the Bay of Bengal, the Arabian Sea, the Andaman Sea and the Indian Ocean was a dream of Indian scientists for many decades. Consistent scientific research, capacity building in technology frontier and exploration activities have been undertaken by international research institutes such as Japan Marine Science and Technology (JAMSTEC), Japan; Institut Francais de REcherche pour i'exploitation de la MER (IFREMER), France; Woods Hole Oceanographic Institute (WHOI), USA and Monterey Bay Aquarium Research Institute (MBARI), USA; Shirshov Institute of Oceanology (SIO), Russia; Scripps Institute of Oceanography, USA, etc., using Remotely Operated Vehicles (ROV)¹⁻⁵.

The design of unmanned underwater vehicles considers the requirements towards operating depth, mission objectives, payloads, communication, navigation, power source, propulsion, mission planning capability and buoyancy mechanisms. By considering the scientific requirements, National Institute of Ocean Technology

(NIOT), MoES has developed a deepwater work class remotely operated vehicle (ROSUB 6000) rated for 6000 m water depth capability in collaboration with Experimental Design Bureau of Oceanological Engineering (EDBOE), Russia and an indigenous shallow-water-cum-polar ROV (PROVe-500) for scientific exploration in shallow waters (<500 m) and low temperature polar regions⁶.

ROSUB 6000 consists of ROV, Tether Management System (TMS), control hardware and software, high-voltage and high-frequency power distribution system, 7000 m length electro-optic mechanical umbilical cable with winch and knuckle boom type Launching and Recovery System (LARS)^{7,8}. Launching view of ROSUB 6000 from the knuckle boom crane is shown in Figure 1.

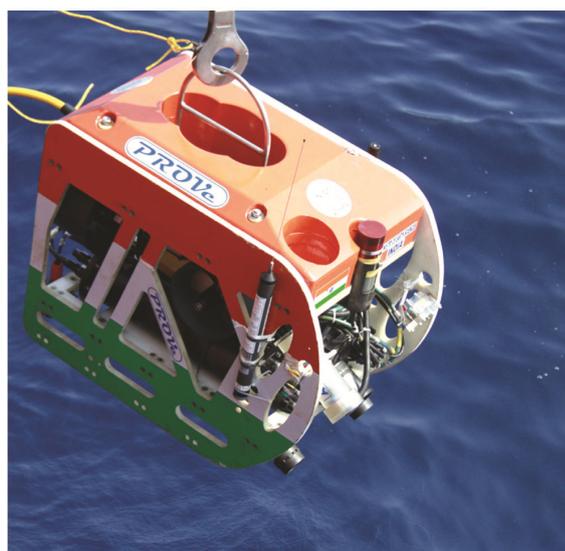


Figure 1. Launching view of ROSUB 6000.

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Table 1. Specification of ROSUB 6000 and PROVe-500

Description	ROSUB 6000 – 6000 m depth rated ROV	PROVe-500 – 500 m depth rated ROV
Diving depth	6000 m	500 m
Dimensions	L 2.5 m, W 1.8 m and H 2.0 m	L 0.96 m, W 0.6 m and H 0.63 m
Weight	3850 kg	183 kg
Movements	Six degrees of freedom	Six degrees of freedom
Speed of movement	2 knots (forward)	2 knots (forward)
Frame	Aluminum alloy	Polypropylene
Payload	150 kg	10 kg
Propulsion	Seven electrical thrusters (10 kW each)	Four electric thrusters
Power	6.6 kV, 460 Hz, 3 Phase, 45 kW	300 V DC, 5 kW
Umbilical	7000 m, 37 mm dia	500 m, 26.5 mm dia
Data telemetry	Single mode fibre optic data and video transmission system	
Hardware and software	National instruments real time controller with d LabVIEW software	
Manipulators	7 function and 5 function (hydraulic)	5 functions (electric)
Cameras	7 nos (color zoom, monochrome, high density and mini)	4 nos (color zoom, monochrome, high density and mini camera)
Luminaries	10 lamps	5 lamps
Navigation	Inertial navigation system, doppler velocity log, depth sensor, acoustic positioning	Doppler velocity log, magnetic compass, depth sensor, obstacle avoidance sonar
Scientific sensors	Multi-beam sonar, conductivity, temperature, depth, dissolved oxygen, CH ₄ , black box detector, push corer	Conductivity, temperature, depth, dissolved oxygen, spectral irradiance, turbidity, pH

**Figure 2.** Launching view of PROVe-500.

PROVe-500 consists of ROV, control console, power distribution system and 700 m length electro-optic mechanical cable⁹. Launching view of PROVe-500 is shown in Figure 2. Detail specifications of both the systems are given in Table 1. These two ROVs were used to investigate poly-metallic manganese nodules, gas hydrates, poly-metallic sulphides, cobalt crust, coral biodiversity, etc. These instruments provided direct observations of the sea floor and high resolution measurements. Such *in-situ* approaches are needed for investigating seafloor processes to understand the deep-sea resources, temporal and spatial variations in ocean basins, as well as of diversity of life and its functions.

Design considerations

The design of the unmanned underwater vehicles should consider the underwater environment characterized by high hydrostatic pressure, low ambient temperature, hydrodynamics, corrosive water, darkness, limitation in the communication, etc.

The hydrostatic pressure increases linearly at the rate of 1 bar for every 10 metres of water depth. The pressure rated enclosures, feed through and seals are designed to withstand the external hydrostatic pressure (i.e. 600 bar at 6000 m water depth) to mount the sub-components for control and operations of the unmanned vehicles. The thermal management systems inside the enclosure should consider the external sea water temperature (i.e. 1.5°C at 6000 m water depth), external water velocity, enclosure material, thickness and thermal conductivity and the allowable internal temperature for reliable operation of the electronics systems. Vehicle shape and stability characteristics (traverse stability and meta-centric height) play a critical role for its operation under dynamic environment to obtain the intended stability against overturning. Design of the propulsion system by considering the drag force and added mass is important for operating the vehicle in all the six degrees of freedom (attitude control) for carrying out effective seabed mapping and physical intervention.

Power system design demands proper trade off in the transmission voltage, operating frequency, size of the umbilical and handling systems. Longer umbilical requires higher voltages and frequencies up to 460 Hz for reducing the transmission losses and the weight of power converters in the underwater vehicle. Deep water unmanned vehicle with long umbilical demands fibre-optic

communication to overcome the signal loss in conventional analog systems, and also to transmit high definition visuals. The optical power budget should consider attenuation in the umbilical optical cores, fibre optic rotary joints and match the sensitivity of the remote optical receiver in the vehicle¹⁰.

Global Positioning System (GPS) signals are attenuated in the sea water. To obtain precise underwater position up to 0.02% of the distance travelled and to navigate effectively in dead reckoning mode, the underwater vehicles are to be equipped with low bias Inertial Navigation System aided by Doppler Velocity Log, acoustic positioning system and depth sensor for computing the position aided with tuned Kalman filter¹¹.

Scientific expeditions

Gas hydrates in the Krishna Godavari basin, Bay of Bengal

First deep-water mineral exploration research cruise of ROSUB 6000 having multibeam sonar, methane sensor and cameras was performed to decipher surface expressions of gas hydrate to identify methane seeps in the Krishna Godavari (KG) basin of the Bay of Bengal. The investigations were carried out at 15.87°N and 81.83°E at ~1000 m water depth. High resolution sea floor morphology was brought out using multi-beam sonar. Cameras brought out live images of deep sea organisms such as deep sea fishes, shrimp, corals, holothurians and polychaetes⁷, similar to the observations at Black ridge methane seeps¹². The observed spiral whip coral colony and straight short coral look similar to *Cirrihipathe spiralis* sp. and *Stylopathes* sp. from Angola margins¹³. These communities belong to Antipatherians genera which are suspension feeding fauna similar to those deep waters of NE Atlantic¹⁴. Similar types of coral communities were observed in chemosynthetic habitats¹⁵ and deep sea reef communities in methane seep environment as a matter of preferential settlement¹⁶. The faunal assemblages resemble the habitats of methane seep region, since the studied site has 120 m thick gas-hydrate occurrence at 40 m below sea floor at 1035 m water depth¹⁷. The observed spiral whip corals along with other deep sea organisms were reported for the first time from the KG basin in the Bay of Bengal.

Poly-metallic manganese nodules at Central Indian Ocean Basin

Sea floor images were obtained using underwater cameras mounted on ROSUB 6000 during the deep ocean mineral exploration depth in the Central Indian Ocean Basin for the poly-metallic manganese nodules at 5300 m water at the location 12.65°S and 75.95°E. The images

show the presence of nodules on the sea floor. Using the push corer, sampling of nodules was carried out and the collected nodules were analysed for metal contents and associated siliceous faunal assemblages. Results from the metal analyses show abundance of Mn (14–29%), Fe (3–15%), Ni (0.5–1.5%) and Co (630–900 ppm) (Table 2). The associated fauna show the presence of radiolarians of *Stylatractus cronos* sp., *Spongaster tetras*, *Dictyocrynetruncatum*, *Euchitonia*, *Furcate*, etc. (Figure 3). The bottom temperature was 1.5°C with dissolved oxygen concentration of 218 µmol (ref. 18).

Hydrothermal sulphides

An expedition for the scientific exploration of hydrothermal sulphides at the Central Indian Ridge system using ROSUB 6000 was conducted and sea floor photography shows the occurrence of fresh pillow basalts, basalt and weathered rocks at a water depth of 2835 m near SONNE field regions¹⁹ (Figure 4).

Dissolved oxygen as a tracer in deep oceans

ROSUB 6000 has scientific payloads to measure the water column parameters such as water temperature, dissolved oxygen, salinity, dissolved methane, etc. During the expeditions, close interval high resolution vertical profile data were collected for conductivity, water temperature, dissolved oxygen continuously, in the Arabian Sea, Central Indian Ocean Basin (CIOB) and Southern Indian Ocean (SIO). Vertical profiles for deep waters are rare and very few data sets are available for north–south mixing in this region²⁰. Results from the profiles revealed second oxygen maxima in the Indian Ocean region due to the influence of Sub Antarctic Mode Water (SAMW) from the Southern Indian Ocean Basin to the Arabian Sea. Observed second oxygen maximum concentration at a depth of 300–700 m at the Indian Ocean ranges from 150 to 220 µM and at the Arabian Sea profiles it ranges from 25 to 40 µM with peak value at a depth at 450 m (ref. 18). Reduction in dissolved oxygen concentration in the Arabian Sea profiles may be due to very low concentrated Oxygen Minimum Zone in the Arabian Sea and

Table 2. Chemical composition of manganese nodule collected from CIOB at 5289 m depth

Element	MN-CIOB 1	MN-CIOB 2
Mn (%)	14.09	29.22
Fe (%)	15.30	3.41
Cu (%)	0.59	0.73
Ni (%)	0.51	1.52
Al (%)	2.30	1.82
Co (ppm)	639.50	894.00
Li (ppm)	69.00	297.50
Ba (ppm)	467.00	679.43

influence of the Red Sea water. These observations have brought out usage of dissolved oxygen data as tracer for intermediate water circulation in the Indian Ocean and also show the influence of SAMW up to 8°N from 13°S along 75°E.

During these deep water investigations falling particulate matter (marine snow) and organisms with luminescence were recorded in the water column at a depth of 2000–3500 m in the CIOB (Figure 5) and are yet to be identified.

Expeditions in the Antarctica

As part of the 34th Indian scientific expedition to Antarctica (ISEA) in the summer 2015, PROVe with connected sensor was tested at the epi-continental Lake Priyadarshini in front of Maitri station. The vehicle was qualified in low temperature environment and collected high resolution video images of algal mats covered over the glacial debris²¹ (Figure 6). Further to lake studies, PROVe was reassembled onboard the ship *Ivan Papanin* to study the ice shelf at the New Indian Barrier and dived up to 62 m water depths in low temperature polar environment (−20°C with wind speed of 20 knots). ROV-based obstacle avoidance measurement clearly showed the ice shelf thickness at the New Indian Barrier to be more than 62 m. Irradiance measurement connected with PROVe showed decrease in intensity with depth from 150 W/m²

to almost zero at 50 m water depth, indicating the limitation of light for productivity at 50 m at the New Indian Barrier site.

Coral reef observation around the Andaman Islands

Coral reef biodiversity and driving parameters at five different South Andaman Islands were studied using PROVe. The vehicle was manoeuvred in coral reef habitats using underwater navigational aids. Faunal assemblages along with underwater spatio-temporal spectral irradiance characteristics and surface radiance, water temperature, salinity were recorded. Even though the recorded water temperatures during March–April 2016 are in the threshold for coral bleaching ~31°C, no coral bleaching was observed in the recorded visuals (Figure 7). However coral bleaching was reported few weeks later to the survey period in some of the islands due to further increase in sea surface temperature to 33°C. Irradiance intensity variation at different depths with reference to different wavelengths was measured and the calculated value of photons up to a depth of 8–10 m is greater than 200 m⁻² s⁻¹ which indicates clear/low turbidity coral island water to support the rich biodiversity as reported earlier²², which is also supported with underwater visuals of coral assemblages.

Seaweeds in the Arabian Sea

PROVe was deployed off the Mangalore coast in the Arabian Sea and recorded the occurrence of a sublittoral seaweed at 37 m water depth (Figure 8). The underwater photographs indicated the mono species dominance of a seaweed namely *Codium*^{23,24}. The cosmopolitan seaweed *Codium* comprises approximately 125 species^{25,26}. The algal thallus appears to have central holdfast with several erect, repeatedly dichotomously branched cylindrical fronds and grow upright. The species resembled *Codium tomentosum* which is a perennial species of the infralittoral zones. The present study documented its occurrence at 37 m water depth near the Sesostris Bank,

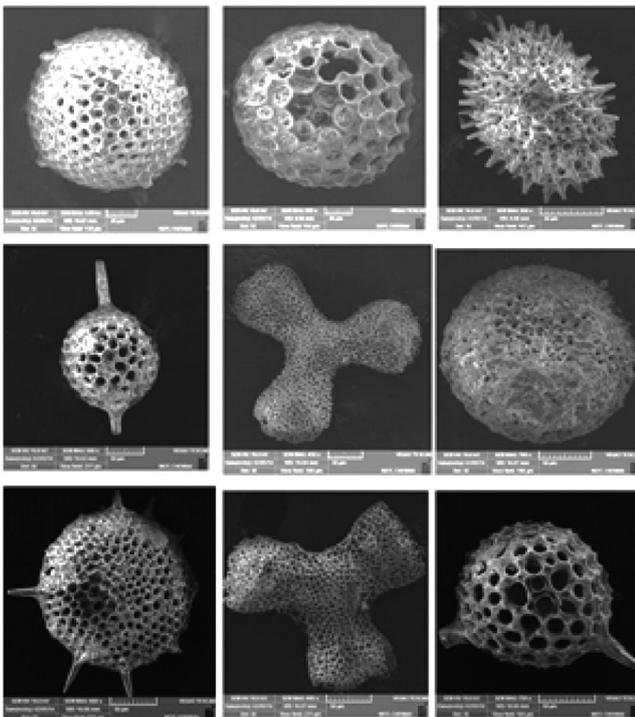


Figure 3. Scanning electron photomicrographs (×400 magnification) of radiolarians collected from the core sample at the depth of 5289 m using push corer.

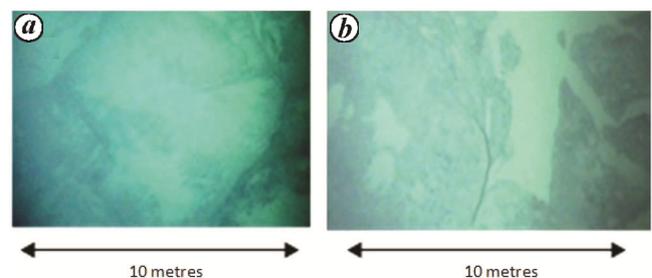


Figure 4. Underwater photograph from ROSUB 6000 showing (a) pillow basalt and (b) weathered talus at a depth of 2813 m at the Central Indian Ridge in Indian Ocean.

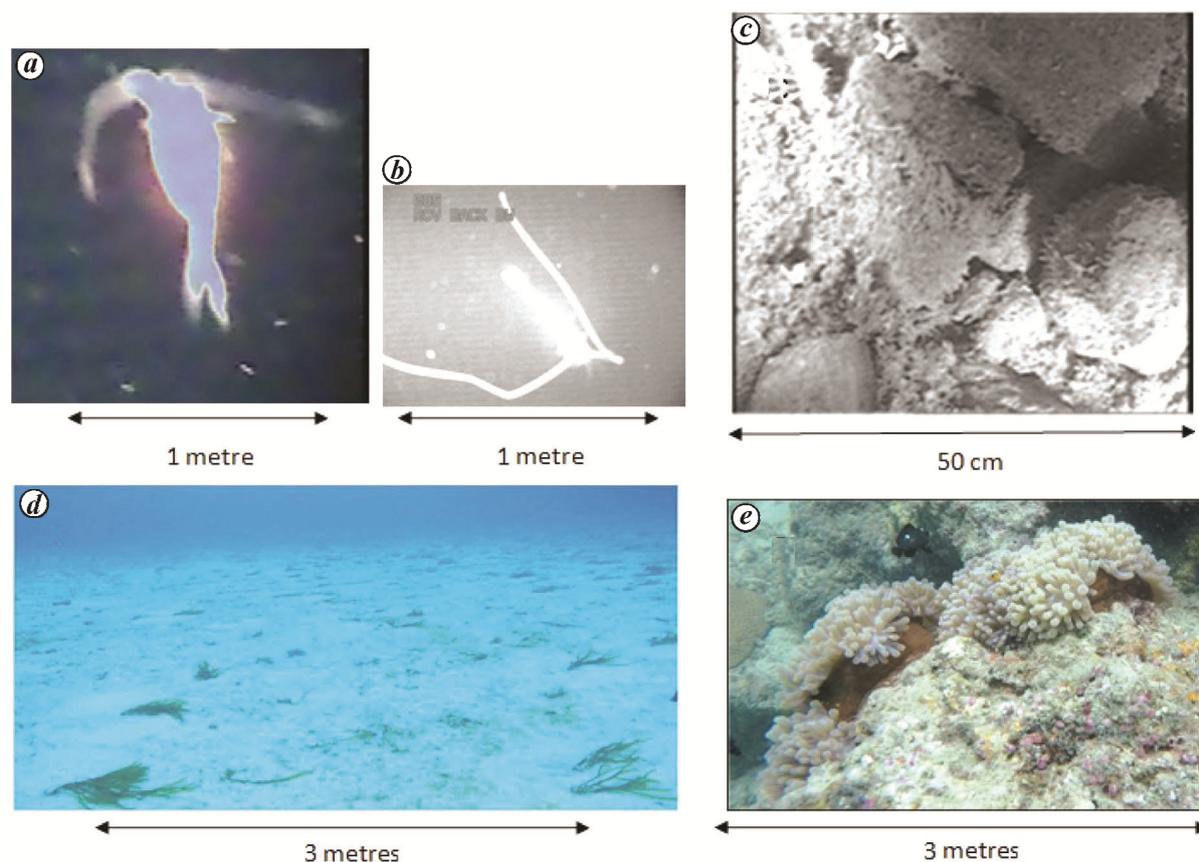


Figure 5. Organisms captured using unmanned underwater vehicle camera from Central Indian Ocean Basin (*a, b*), algal mat at Priyadarshini Lake, Antarctica (*c*), Sesostris bank seaweed field, Arabian Sea (*d*) and coral biodiversity from Jolly Buoy Island, Andaman (*e*).

a sunken atoll of Arabian Sea. Abundance of the seaweed adjacent to the coral reef knoll of the sunken atoll may be due to availability of light at 37 m water depth. The quadrat method was adopted to quantify the population density of the seaweed with PROVe based photographic technology. The population density of seaweed is estimated to be in the order of 3–5 nos/m² based on the 50 m² high resolution video footages. Even though reports are available for the seaweed by sampling, this PROVe based assessment is first in the country to understand the distribution of the seaweed field in the natural environment of the Sesostris Bank.

Conclusion

Design of unmanned underwater vehicles involves multi-disciplinary approach for the demanding scientific needs to operate in challenging deep ocean environment such as high hydrostatic pressure, low temperatures, corrosive sea water, absolute darkness beyond 100 m depth, acoustics as medium of communication, no GPS connectivity, etc. NIOT had developed unmanned underwater vehicle for deep water and shallow water applications as ROSUB 6000 and PROVe respectively. The deep water vehicle,

ROSUB 6000 had brought out high quality sea floor images from the deep ocean mineral resource fields of gas hydrates (~1000 m), polymetallic manganese nodule (~5300 m) and hydrothermal sulphides (~2800 m) apart from sampling and water column measurements using scientific sensors. Shallow-water-cum-polar-vehicle (PROVe) developed indigenously has provided first time photos of the lake bed of the Priyadarshini Lake near Maitri station, the New Indian Barrier ice shelf thickness at Antarctica apart from biodiversity studies carried out at coral reef of the Andaman Islands and sea weeds of the Arabian Sea near Sesostris Bank. These types of deep sea vehicle development and outcome from scientific payloads have shown that they are new additional tools for the Indian scientific community to map the deep sea habitats, resources, coral reef habitats, other biodiversity assessment in open oceans and polar low temperature environment.

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