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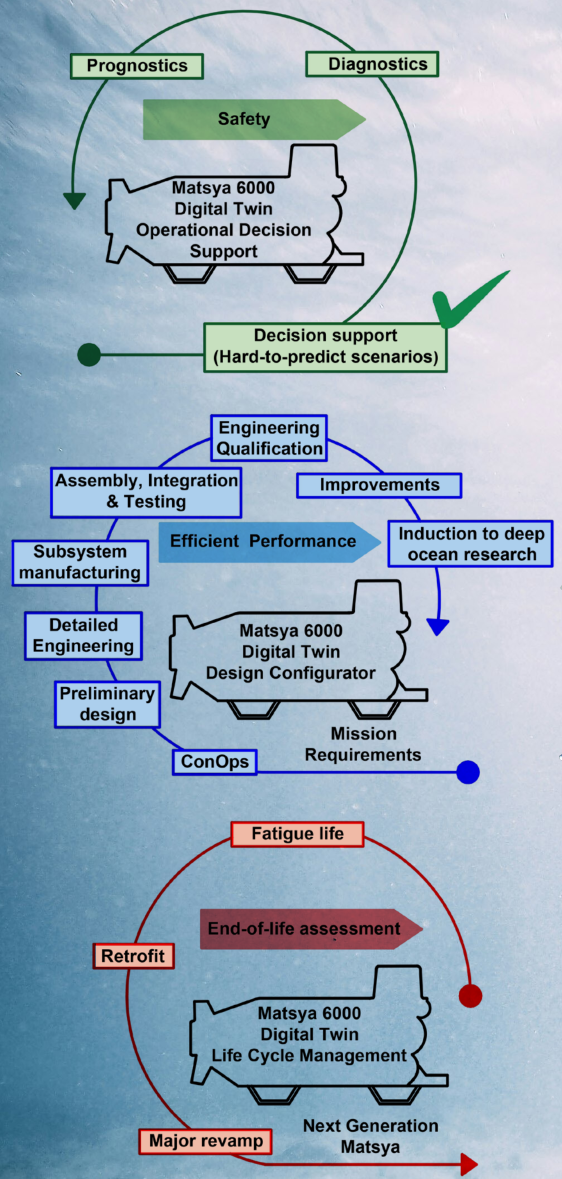

Digital Twins & Deep Ocean Machines

The Institute of Marine Engineers (India)

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2025
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Happy New Year

EDITORIAL

The safety of the people is the highest law.
- Cicero

Two events, one an incident and another an accident are brought into our current discourses. The incident was a confluence, the accident a collision. We need to learn a few lessons from both.

The Confluence first. The World Maritime Technology Conference (WMTC) at Chennai saw discussions on some ongoing technological research to our southern shores. More than half of over a hundred papers were presented. While most of the conferences (guess there is an overdose of them on similar or same themes) and WMTC was no exception; but there was a difference. Technologies were discussed rather than the 'copy-paste', repetitive cacophony of regulations and news items from maritime columns.

From capturing the essence and the novelty of the forum, the Institute (IMEI), especially the Chennai Branch must gain traction in organising engaging forums bringing the students, researchers and marine engineers together. A conscious attempt must be made to look at marine engineering/ocean technologies with an inquisitive fashion rather than from the point of view of examinations. As Einstein observed the questioning must continue. The immediate initiative for IMEI is to capture, build the repository and share the proceedings of the WMTC.

Now to the accident in the Mumbai's inner waters. We may steer clear of the debris of speculations, blame games and pedantic parallels to William Heinrich's safety pyramids and triangles for the moment. One blatant truth which emerges again (the same truth emerges every time), that we have gotten used to lifestyle and situations where risks are apparent and safety is lax. The business as usual now and after is an accepted norm in the galloping world. It does not matter who was responsible. In the heat of things and in line with the maritime mantra of 'course is the cure', one suggested solution was to train all passengers in 'survival at sea'! In safety matters, good enforcement (accountability/penalties) and responsible compliance itself will reduce risks instead of an overkill of hackneyed recourses. After all, human safety is paramount.

In this issue...

We start with the hangover of the AI & ML.

The first article discusses the considerations for design of a digital twin (DT) for a deep ocean vehicle which involves AI & ML applications. All physical and behavioural realistic features are juxtaposed while the DT is envisaged. The battery-powered Human Occupied Vehicle (HOV), Matsya6000, will carry 3 persons. It can reach depths of up to 6000m having an operating period of up to 12h, and an emergency capacity for extra 96h. After introducing the Matsya6000, the risk management profile for the vehicle is briefly discussed. The Authors then explain the DT architecture and pitches for DT as a necessity for the HOV design as well as operational management. Navigation, emergency and safety of the HOV are all covered under the DT umbrella and the educative parts take the readers to the depths and the situations.

We take pride in featuring this article which is a design walk-through of a DT for an indigenous HOV for deep ocean studies. The efforts are under the Deep Ocean Mission project array pursued by India.

The next one is another deep down machine application involving AI & ML. However, here the discussion is on a homing device totally inspired by sea creatures (bio-inspired). The Autonomous Underwater Vehicle (AUV) also needs a DT architecture. AUVs and HOVs are crucial for deep ocean research. The limitations are being overcome and capabilities are being breached with speeding computing capacities, AI & ML supporting data digestion and design development. Intelligence, Surveillance & Reconnaissance (ISR), increased spatiotemporal survey, exploratory dives etc., will be helped by these advanced deep-ocean machines. The takeaway is the description and demonstration of the patented, machine-learnt AI-enabled Electro-Magnetic Homing Guidance System (EMHGS).

MER had carried exciting, informative articles on bio-inspired engineering designs. Here Dr. Veda extends the education in two parts. We hope you enjoy this Part A.

In the third article, we bring Augmented Reality (AR) into the realm of shipboard training. After extolling the merits of AR, the Student-Authors explain the process of learning with a design of a gate valve. This is an easily digestible read and sailing marine engineers might be experiencing such support systems (we hope).

From MER Archives (January 1985), we bring your attention to a Transaction on RO Plants. In the forthcoming issues, we intend hosting one Thematic Issue on Polar Dialogues and an array of articles culled from the WMTC Collection.

Welcoming the New Year 2025, here is the January 2025 issue for your reading pleasure!

Dr Rajoo Balaji
Honorary Editor
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MARINE ENGINEERS REVIEW INDIA

JOURNAL OF THE INSTITUTE OF MARINE ENGINEERS (INDIA)

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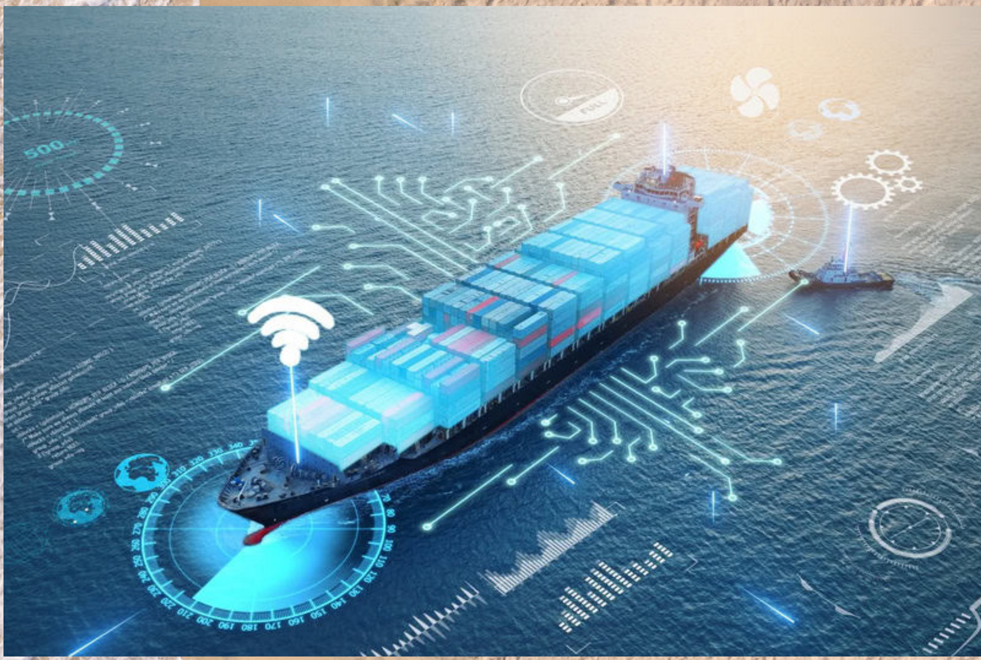

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Digital Twin for India's Indigenous Deep-Ocean Human Scientific Submersible Matsya6000

Digital Twinning Teams
(Efforts by: Deep Sea Technologies Group of National Institute of Ocean Technology & SRM University, Chennai)

Abstract

Ensuring human safety is the key requirement for deep-ocean human-occupied scientific submersibles operating in remote extreme environments. Even-though adequate redundancies are built-in and standards for human-rating are followed to reduce the failure of safety systems in Matsya6000 to as-low-as-reasonably-achievable (ALARA), mechanisms should be in place to mitigate residual risks. While IEC61508 HSE standards confirm the on-demand reliability of the life-critical systems of Matsya6000 are in Safety Integrity Level 3, in-order to manage the residual risk, situation-aware Digital Twins (DT) for emergency power supply, human cabin life-support, microclimate, positioning and propulsion systems, capable of providing proactive decision support by generating situation-aware emergency operating protocols for the mission during identified eight hard-to-predict scenarios are developed and being validated. Development of twins for serving as design configurator, operational support, AI-enabled health monitoring/ prognostics and life-cycle management are in the anvil.

Introduction

Human Occupied Vehicles (HOVs) have the advantages of taking scientists to the deep-ocean for carrying out high-resolution bathymetry, geological surveys, search activities, salvage operations, biological sampling, habitat analysis and carry out in-situ experiments. Scientists can continuously obtain real-time and in-situ data, design experiments and perform fine operations based on actual dynamics in real-time compared to remotely-operated (ROVs) and autonomous under-water vehicles (AUVs). Subsequent to the bathyscaphe Trieste in which Jacques Piccard and Don Walsh descended up to 10.9 km reaching the Challenger Deep, the deepest point of the Mariana Trench in 1960, the 1st generation scientific HOV Alvin was developed in 1964. The 2nd generation scientific HOVs (Nautile, Shinkai, MIR, RUS, Consul and Jaiolong) developed during 1970-2010 featured lighter pressure-resistant hull for the crew, improved power supply for propulsion, and establishment of reliable subsystems that greatly expanded their operating range and efficiency. The 3rd generation hadal-depth HOVs developed during 2012-2023 (Deep Sea Challenger, Triton, & Fendouzhe) pushed the technological boundaries to unprecedented levels.

This article presents the design and development of a **"Situation-aware" decision-support Digital Twin (DT)** for the **4th generation** scientific HOV Matsya6000 which is being indigenously designed and developed by India's Ministry of Earth Sciences-National Institute of Ocean Technology (NIOT), under the Deep Ocean Mission/DOM (to boost Make-In-India initiative and self-reliance). The DOM includes six verticals (involving multiple ministries) for the development of deep-ocean technologies, ocean climate change advisory, exploration and conservation of deep-ocean biodiversity, deep-ocean survey and exploration, energy and fresh water from ocean, and marine biology, with a total funding of Rs 4077 Crores for the period till 2026. The Vertical-1, in addition to Matsya6000, includes technology developments for deep-ocean mineral mining, remotely operable vehicles, deep-ocean AUVs, autonomous homing and docking, and swarm robots. For realisation of the Matsya6000 subsystems, NIOT is supported by top Indian research organisations, leading Indian Industries, international subsea companies and academia. With Matsya6000 planned to be inducted into operation in 2026, it shall enhance deep-ocean research, as well as help to leverage blue economic potential of India. This situation-aware decision-support DT developed by NIOT along with SRM University through a collaborative project shall aid in ensuring best mission performance, human safety and life-cycle management for Matsya6000.

Matsya6000 and its Concept of Operations

The battery-powered HOV Matsya6000 shall carry 3 persons up to 6000m water depth for an operating period of 12h, and supports 96h of emergency. Major subsystems of Matsya6000 include Titanium-alloy exo-structure, Titanium-alloy human cabin (with three acrylic view ports) for accommodating three crew with vehicle control and human support and safety systems, syntactic foam for fixed buoyancy, main ballast system for enabling diving, variable ballast system for fine changes in buoyancy, drop-weights for energy-efficient descend/ascend and emergency, redundant power and control architecture, electric thrusters for propulsion, redundant navigation and positioning systems, voice communication and data telemetry, high-definition cameras, manipulators for sampling operations and mission-specific sensor suite. While main ballast system enables diving and sufficient free-board during launch and retrieval, energy-efficient and reliable descend and ascend operation is enabled by an identified combination of dispensable drop weights and variable ballast system **(Figure.1).**

System engineering approach based on IEC15288 standards is followed for the development of Matsya6000. The detailed system engineering included definition of Concept of Operations (ConOps), optimised general arrangement, hydrostatic stability, hydrodynamic drag determination for propulsion power and energy estimation for the mission, and redundancy definition through Failure Mode Effect and Criticality Analysis (FMECA). The DNV's Underwater Technology rules for deep-ocean human submersible are followed for ensuring human-rated design.

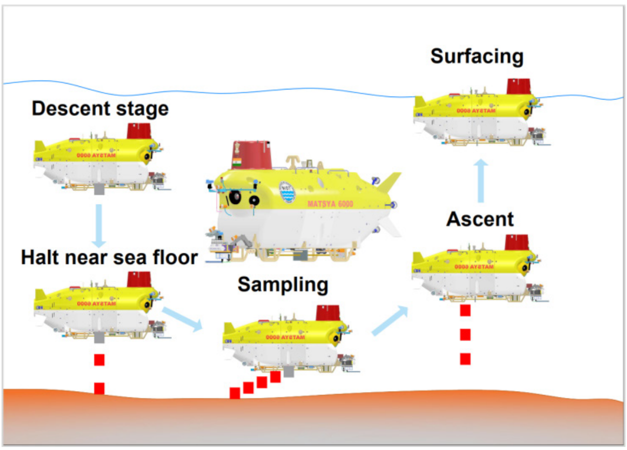

Figure.1. Matsya6000 and its brief concept of operations

The demonstration of Matsya6000 in shallow waters (≤500m) is scheduled in 2025, followed by deep-waters in 2026

The integration of the subsystems on the exo-structure of Matsya6000 is completed and basic functionality tests (wet tests) in the harbour are in progress. The demonstration of Matsya6000 in shallow waters (≤500m) is scheduled in 2025, followed by deep-waters in 2026. Ten distinct features (for increased human safety and reliable performance) including on-board pressure-compensated Lithium-Polymer batteries, redundant power, control, communication and positioning system architecture, human-rated ballast drop-weight system, rapid locate and emergency rescue system, real-time crew health monitoring, subsurface parking capability and the situation-aware digital-twin (DT) identifies Matsya6000 as the 4th generation deep-ocean human scientific submersible (cover picture).

Risk management strategy adopted for Matsya6000

The strategy adopted for risk mitigation and residual risk management for Matsya6000 is shown in **Figure.2,3.**

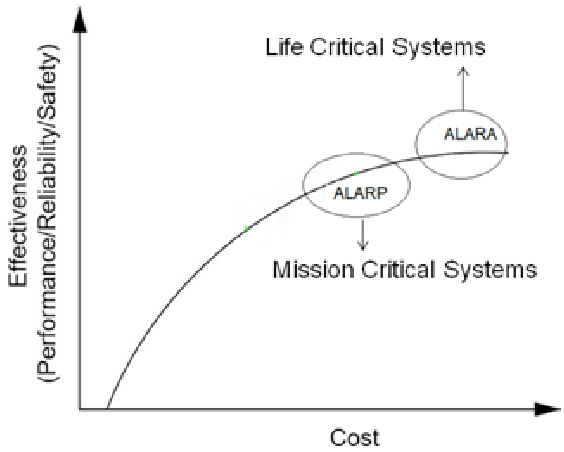

Figure.2. Concept of ALARP and ALARA

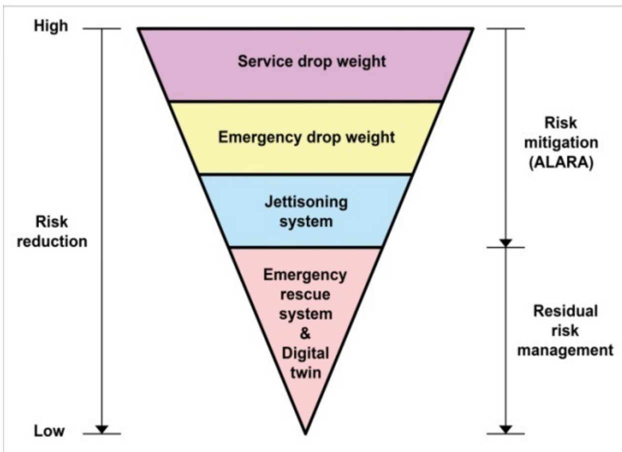

Figure.3. Matsya6000 risk management strategy

While the redundancy requirements for the mission-critical systems are defined based on the principles of As Low As Reasonably Practicable (ALARP), for the life-critical systems, on-demand reliability based on IEC 61508 / Safety Integrity Level (SIL standards)/ALARA philosophy is adopted for the first time **(Figure.2),** where-in the Probability of Failure on-demand (PFD) is computed using proven TOTAL SATODEV-GRIF Probabilistic Reliability Analysis software (with DNV-OREDA's multi-decadal field-failure data as inputs).

Presently, due to immense advantages, DT is being widely used in space, aviation, defence, robotics, power, product development, maintenance, automotive, manufacturing, medical, logistics and as a decision support system (DSS) in critical manned- and unmanned missions

The approach followed for risk mitigation by means of designing a human-rated descend-ascend drop weight configuration is described as stages A-G in **Figure.4. Upon the finalisation of the submersible general arrangement in the exo-structure, the initial stage (A) involves determination of hydrostatic stability in the surface floating, submerged and subsea damaged scenarios.** In stage B, submerged weight and hydrodynamic shape of Matsya determines the descent/ascent velocity and the minimum service drop weights (SDW) requirements. The flooding of dry compartments in an off-nominal scenario determines the minimum emergency drop weights (EDW) needs. In Stage C, based on the operational requirements, constant descent/ascent velocity requirements under changing ocean salinity and equal weight distribution in submersible port and star board sides, the minimum denomination of the SDW and EDW were determined.

To determine the acceptable number of drop weight actuation failures and to ensure its availability on-demand, reliability analysis is carried in Stage D to determine the failure rate of the drop-weights (SDW, EDW and Jettison systems) during every stage of the mission, from deployment in the ocean surface till retrieval. Based on the failure rates computed in Stage E, on-demand reliability (ODR) analysis is carried out iteratively to identify a SIL3-compliant configuration **(Figure.4),** the level of safety integrity computed based on IEC 61508 HSE requirements. The output of this stage served as an input to the degradation-based MAP in Stage G, to define the mission abort criteria. Thus, ballast drop-weight/ jettisoning system configuration is confirmed to meet human-rated SIL3 during all stages of the subsea mission.

From **Figure.5,** it can be seen that by implementing increased safety features up to D, the rate of risk reduction (RRR) achieved is 266 times, compared to the basic configuration which had only SDW for descent and ascent operations. By incorporating safety feature E (Jettison of the Trim System), the RRR increases only marginally (to 292 times), which implies that the risk reduction is based on the principles of ALARA, while Stage D corresponded to ALARP. The residual risk arising out of Matsya6000 stranding to the deep-ocean floor is managed by having an Emergency Rescue System and a situation-aware decision-support Digital Twin to support hard-to-predict scenarios (when physical and psychological stresses

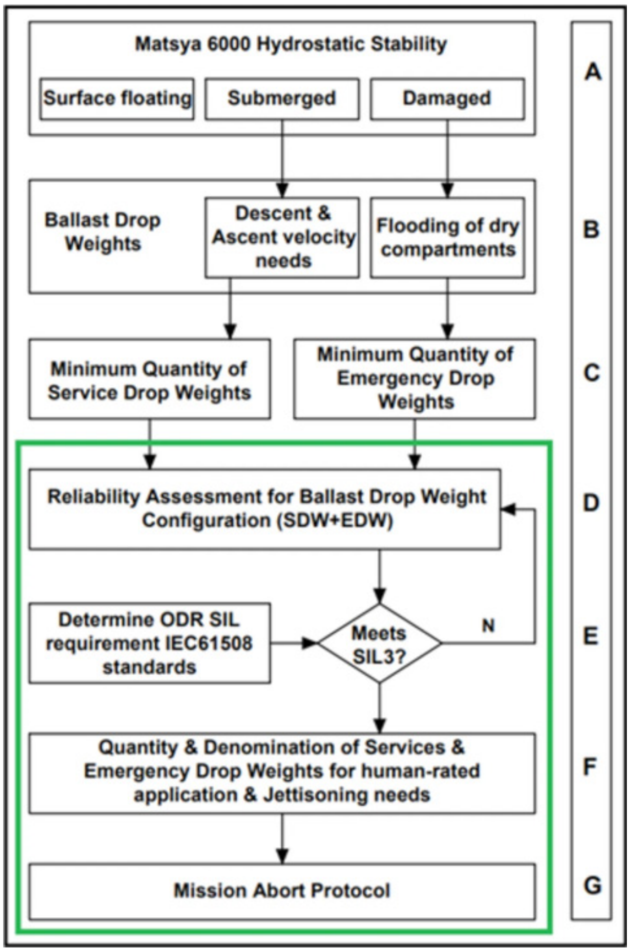

Figure.4. Methodology for defining the Mission Abort Protocol

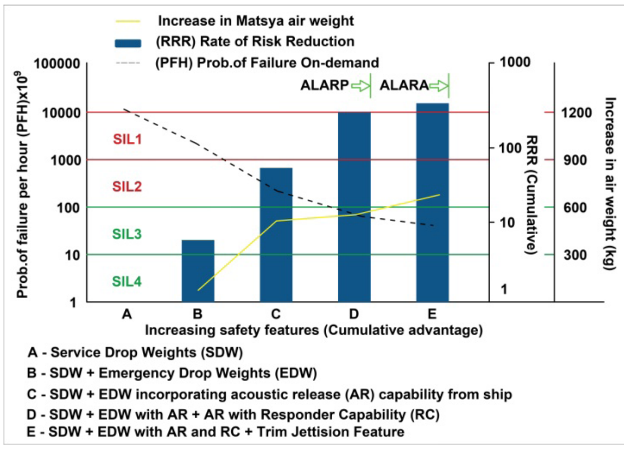

Figure.5. Risk reduction based on principle of ALARA

dominate during the emergency period of 96h), until Matsya is retrieved back to the deployment vessel.

Global progress in Digital Twins

Subsequent to the innovation and implementation of a physical twin in 1970 during NASA's Apollo-13 space mission, advancements in numerical modelling and real-time interfacing capabilities led to the development of the Digital Twin (DT). **A DT is a dynamic digital representation of an object or a system (describing its characteristics and properties as a set of equations) that spans its lifecycle, is updated from real-time data streams (from IOT-based sensors), and uses simulation, machine learning, analyse possible outcomes and reasoning to help decision-making (Figure.6).** Presently, due to immense advantages, DT is being widely used in space, aviation, defence, robotics, power, product development, maintenance, automotive, manufacturing, medical, logistics and as a decision support system (DSS) in critical manned- and unmanned missions. In the industrial sector, DT is used for battery vehicle design (Volvo), racing (Formula1), Cross-rail project (in London), offshore oil &gas platforms (BP), custom-made prosthetics for individuals (OSSUR), Autonomous Cars (Ford), Autonomous Ship (Kongsberg), Cancer drugs (Pfizer) and Virtual model for Singapore city and airport traffic management. In these domains, DT are used as concept configurator, understand how products/systems work, improving the product design, monitor and manage systems in real-time.

Based on the real-time inputs from the physical systems, the DT generates "mission-desired" scenarios by simulating the physical system parameters to understand unsafe conditions "ahead-of-time" for advancing decisions

Extensive use of DT is being reported from space and aviation industry. The AI-based DT are used by General Electric, Rolls-Royce and Pratt & Whitney to maintain simulations of individual engines at engineering centres on the ground-based real-time data from their counterparts in the air, enabling accurate determination of the life of structural components, improve engine performance, operational safety and flexibility. In the defence sector, Lockheed Martin and US Navy use DT for simulating the effects of adverse weather conditions on the performance of fighter Jets, and recently, US Naval Air Systems Command has developed DT for its airborne electronic attack systems for error-free targeting.

In the space segment, DT are being developed by NASA-JPL to emulate complicated manoeuvres such as understanding rocket propulsion system performance optimisation for reducing propellant (Tsiolkovsky approach), orbit-entry, homing and docking, position conversion, astronaut entry/exit of space stations, interaction of space debris with space station, integrating DT with immersive technologies for enabling space learning and habitat scenarios for space tourism within low Earth orbit. The DT of Earth (DTE) is a next-generation Earth Information System (EIS), aimed in leveraging a step-change in spatial resolution in Earth observations of a subset of key geophysical variables. These partial models provide a virtual representation of Earth processes and subcomponents of the Earth system. The development

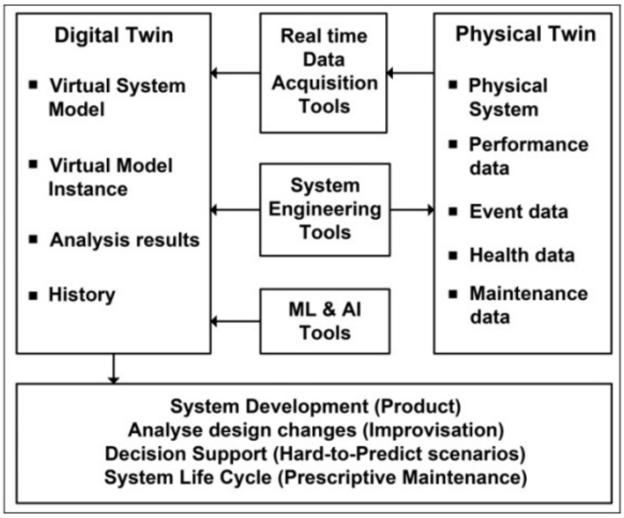

Figure.6. Generic architecture of AI/ML-enabled Digital Twin

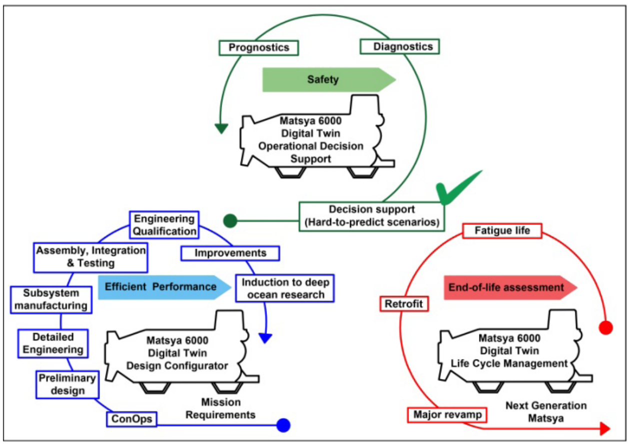

Figure.7. Digital twins envisaged for Matsya6000

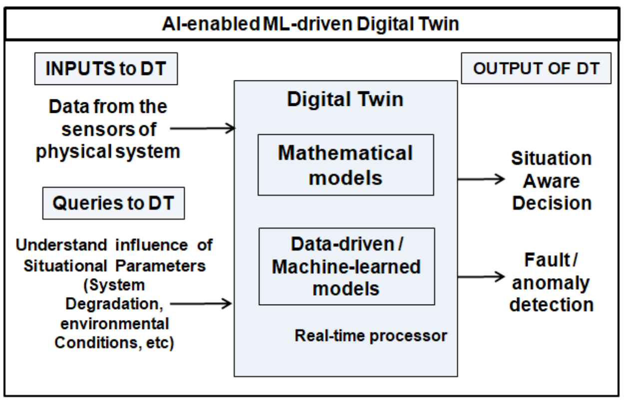

Figure.8. DT in situation-aware decision-making

of the UN decade DT of the Oceans (DITTO) led by the GEOMAR Helmholtz Centre for Ocean Research, Kiel and Kiel University–Germany is expected to establish and advance a digital framework on which all marine data, modelling and simulation along with AI algorithms and specialised tools will enable shared capacity to access, manipulate, analyse, and visualise marine information.

The time until which Matsya can hover in depths before it runs out of energy needs to be determined in advance

Based on the level of application, DTs are classified as Component Twin, Asset Twin and System Twin. Component twins provide detailed information about a component's performance and behaviour both in real-time and over time. Asset twins, comprising of multiple component twins, provide information on an asset's operational status, performance data, and environmental conditions in real-time (buildings, machines and vehicles) help to increase safety and operational efficiency. System twins help to monitor and analyse a system's performance, optimise and identify areas of improvement. The three types of DT envisaged for Matsya6000 during design, operations and life cycle assessment is shown in **Figure.7.** The typical architecture of an AI-enabled situation-aware predictive DT used for operation decision support is also shown in **Figure.8**

Importance of DT for Matsya6000

In the marine sector, with the advanced sensor technology and vessel digitalisation, for the upcoming autonomous ships, DT is finding immense use in predicting ship response to safety-critical events in real-time and uncover previously unknown issues before they become critical by comparing predicted and actual ship responses. A ship DT represents a comprehensive mathematical model /virtual replica of the physical ship (including the ship-specific vessel dynamics, power, propulsion, navigation, positioning, ballast, dynamic positioning and other automation systems) enabled with deep reinforced machine learning (DRL) algorithms with real-time inputs from proprioceptive sensors. Further, AI/ML-enabled DT are capable of mitigating damage or degradation by activating self-healing mechanisms or by recommending changes in vessel or subsystem operational profile to decrease loadings, thereby increasing both the life span and reduce the probability of failure (PoF), thus ensuring the safety of the ship in high and rough seas, as well as for effective implementation of Collision Regulations (COLREG) algorithms. In addition to these, a DT shall integrate

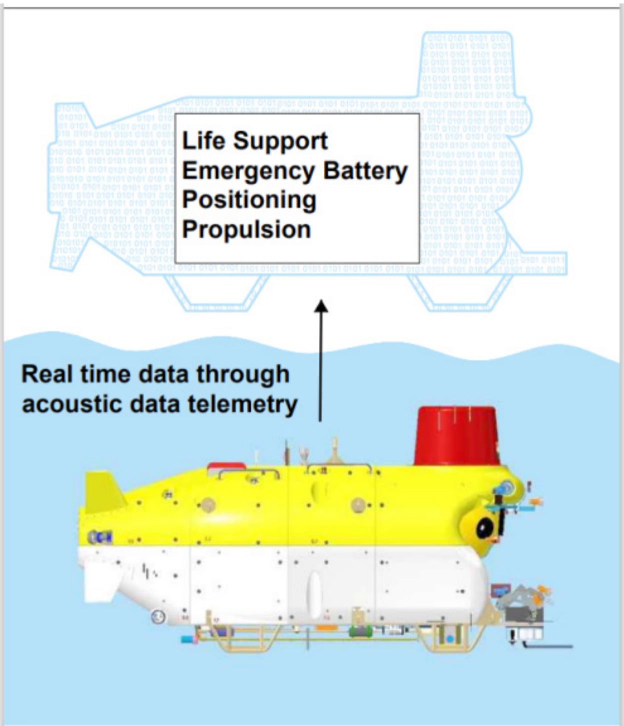

Figure.9. Data exchange between Matsya and DT in ship

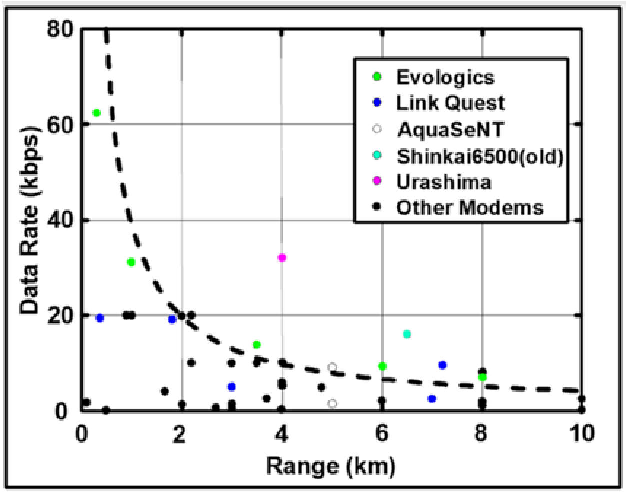

Figure.10. Performance of commercial acoustic modems

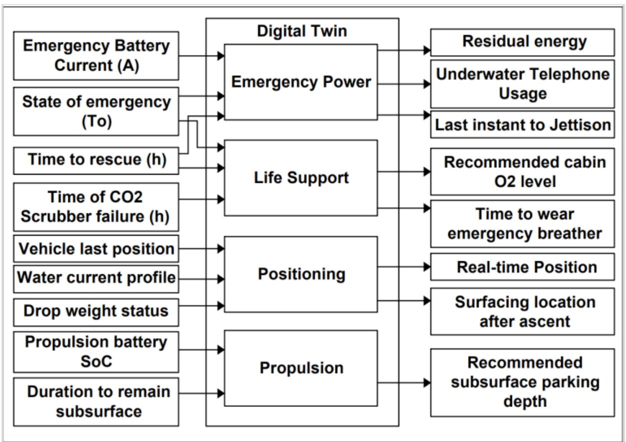

Figure.11. Key inputs and 8 HTPS deliverables of the DSS-DT

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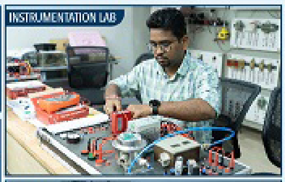
14.	Machinery Maintenance - Skill Enhancement - Module 4	06 - 08, 20 - 22, 27 - 29	10 - 12, 27 - 01



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sensor data from the vessel on-board Integrated Vehicle Health Management (IVHM) system, maintenance history and all available historical and fleet data obtained using data mining and text mining. By combining all of this information, a DT can continuously forecast the health of the vessel or subsystem, remaining useful life and PoF over time. Considering the capabilities and strategic importance, DNV has accorded in-principle approval for the innovative Hyundai Intelligent DT Ship.

Under nominal conditions, the O_2 concentration inside the human cabin shall be maintained at 21% by the crew by opening the oxygen cylinders one after one, as they are exhausted

In the case of defence submarines (that operate up to 400m water depths) passive CO_2 removal curtains and O_2 candles supports seven days of survivability for the full submarine crew. During system failures, the surfacing time is less, as the operating depth is low. Upon accidents/emergencies/bottoming, during the time between localisation and rescue of crew from the distressed submarine, internal conditions is secured by providing Emergency Life Support Stores (ELSS) either in the wet re-supply mode, using pressure-tight pods posted into the escape tower by Intervention Remotely Operated Vehicle (IROV)/divers or in dry mode by a Submarine Rescue Vehicle (SRV). Thus, ELSS is used to extend crew life, while rescue assets are being mobilised. Further, the International Submarine Escape and Rescue Liaison Office (ISMERLO) coordinate international submarine search and rescue operations. Thus, for conventional submarines, technology is matured in rescuing humans during distress by "Transferring under Pressure" (TUP) and carrying out safe decompression. In the case of deep-ocean human submersibles, custom-designed emergency rescue systems are developed by few advanced nations having deep-ocean submersibles, and NIOT is also developing a novel system for Matsya6000. However, managing emergency situations arising out of subsystem failures/degradations are challenging, which are compounded due to psychological stress factors (as Matsya is untethered, hostile deep-ocean environment, fear of fault aggravation and longer time required to surface from deep oceans).

Development of DT for Matsya6000

Situation-aware model-based predictive decision-support DT modules for emergency power supply, human cabin life-support and microclimate, positioning and propulsion subsystems are developed to generate situation-aware protocols that are optimal for the survival of the crew during emergency situations.

Based on the real-time inputs from the physical systems, the DT generates "mission-desired" scenarios by simulating the physical system parameters to understand unsafe conditions "ahead-of-time" for advancing decisions. The data from these physical subsystems shall be transmitted to the DT modules operated on-board Matsya6000, as well as to the Mission Control Centre (MCC) on-board deployment vessel through acoustic data telemetry **(Figure.9).** As the data rates of commercially available acoustic modems **(Figure.10)** at longer ranges are limited to few kbps, only essential data will be exchanged between Matsya and the deployment ship.

The DT modules serve as a decision support system (DSS) for the deep-ocean mission during eight different hard-to-predict scenarios (HTPS), including rationing of energy to emergency life-critical systems, optimising O_2 consumption and CO_2 scrubber usage during 96h (and slightly beyond). Upon failure of the acoustic baseline positioning systems, based on the last known position and ocean current profile, trajectory of Matsya during ascend and likely surfacing position can be predicted, enabling precise positioning of rescue assets for quick recovery of distressed crew, specifically during an emergency ascend, such as during cabin smoke/fire where emergency breathers cannot last long.

Figure.12. DT being installed in the Mission Control Center

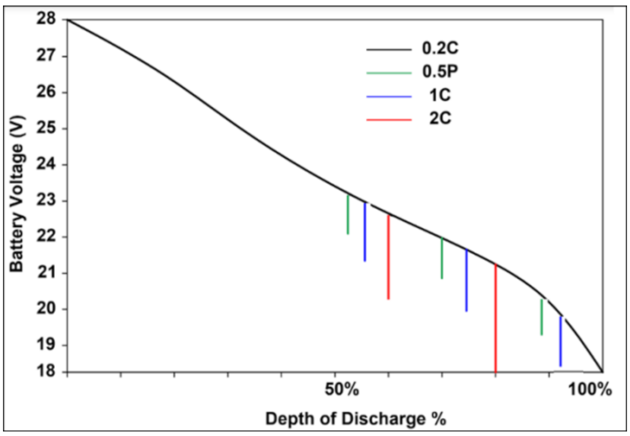

Figure.13. Sensitivivess of battery voltage at different SoC

By protocol, the launching of Matsya will be done only in fair weather conditions. During rough weather conditions or ship-based retrieval system failures, Matsya needs to hover below the sea surface, as well as maintain its position below the deployment ship, until it is retrieved on-board. The time until which Matsya can hover in depths before it runs out of energy needs to be determined in advance. The eight HTPS that require decision-support (involving four major subsystems) are mapped in **Figure.11.** The four independent DT modules are developed using MATLAB and deployed in FPGA Kintext-7 based OPAL4510_RT HIL (Hardware-In-Loop) simulator with high performance rapid control prototyping system with processing speed of 3.5GHz, 16GB RAM and 256GB SSD, 32 digital I/O channels, 16 analogue I/O channels, 65ns propagation delay, and RS422 communication interface. The Human Machine Interface (HMI) is developed using LabView software. The DT is deployed in the Mission Control Centre (MCC) which is designed for installation on-board deployment ship **(Figure.12).**

"The O_2 consumption rate for the crew is calculated based on the level of physical activity and the respiratory quotient"

Emergency Power System

The Emergency Power System (EPS) of Matsya6000 is designed to cater the energy needs of life-critical systems during 96h of emergency. Based on the Emergency Operating Protocol (EOP), CO_2 scrubbers, Underwater Acoustic Telephone (UAT), shape-memory alloy (SMA) based actuators & cabin lighting shall consume 62%, 8%, 6% and 4% of energy. About 20% of energy is for surface communication and contingency. During the emergency period predicting the real-time before which the emergency systems should be operated (so that they operate reliably above the minimum critical voltage) should be made known to the Matsya pilot so that the availability for the emergency systems is ensured till 96h. In addition to this, the real-time at which the battery SoC goes below 20% is to be informed to the pilot, in advance for advancing decisions. As shown in **Figure.13,** during emergency, jettisoning of the trim system at 40% residual SoC results in a battery voltage drop from 23 to 20V, while at 20% residual SoC, the same operation results in voltage drop to <18V, which is insufficient to jettison.

The EPS-DT (with load-current input in real-time from the emergency batteries of Matsya) takes into consideration the characteristics of the lead-acid battery chemistry, emergency devices and the dynamic ambient temperature conditions inside the human cabin (when Matsya is operating at different ocean depths), energy

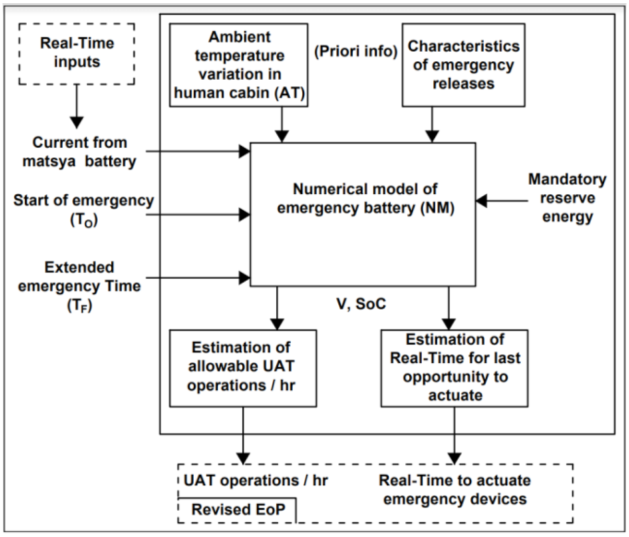

Figure.14. DT of the Emergency Power System (EPS-DT)

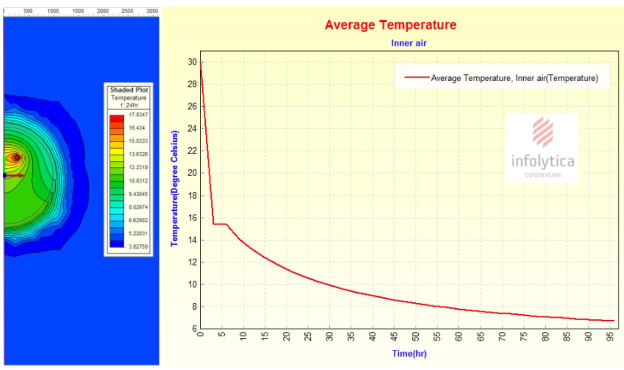

Figure.15. Ambient temperature variation inside the human cabin

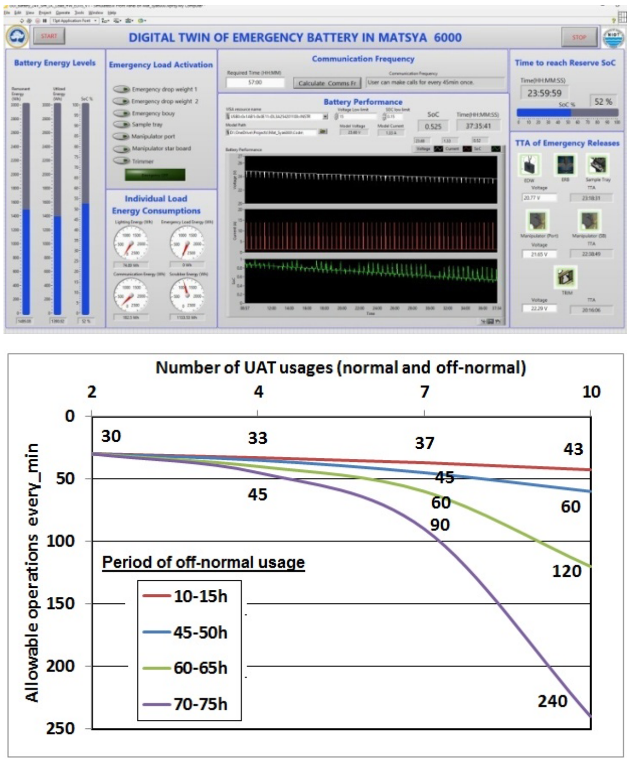

Figure.16. HMI of EPS-DT and permissible usage of UAT during off-nominal scenarios

utilised, energy requirements for the remaining /extended mission period, surface communication and contingency energy as constraints, redefines the EOP ensuring the power supply/energy availability during the entire period of emergency, thus ensuring human safety **(Figure.14).**

Matsya is designed to be launched and retrieved in fair weather conditions

At the core of the EPS-DT are the precise mathematical model of the lead-acid battery (third-order electrical equivalent circuit incorporating thermal effect) and priori data of the ambient temperature profile inside the human cabin at various ocean depths (modelled using Siemens Magnet-Thermnet FEA software and simulated based on the environmental conditions during a practical mission, **(Figure.15).** Based on the "only" real-time load-current input information, the EPS-DT simulates the discharge characteristics (ahead-of-time, up to 96h and beyond), including discharge times at various current rates, and battery voltage versus State of Charge (SoC). The performance of the EPS-DT is validated based on real-time experiments with the actual physical battery and found to have a prediction accuracy of ~97%.

During the 12h mission, the UAT shall be used every 30min, to communicate between Matsya and deployment ship. Upon failure of the voice communication, it is necessary that the mission has to be terminated and Matsya has to return to the sea surface. During the emergency period of 96h, there are possibilities that the UAT is used more frequently (>2 times/h) to understand the status of recovery operations. Increased usage of the UAT results in increased energy consumption (than the envisaged budget of 8%) which will affect the energy availability for other devices to serve the remaining emergency period. Hence the utility of the UAT has to be restricted. This is a hard-to-predict-scenario (HTPS) for the crew/ mission team during the emergency period, when psychological stresses dominate.

From the EPS-DT HMI and results (outcome of multiple simulations summarised in **Figure.16,** it can be seen that EPS shall support increased number of off-normal usages of the UAT during the initial emergency period. An off-normal usage of 10 times/h during the 10-15h results in allowable operations of every 43min, while at the end of the emergency period (70-75h) the EPS can support only once every 240min (2h). The HMI periodically updates every 5min (update rate can be modified by the user) simulates the time-series SoC and Voltage of the battery, and predicts the real-time to reach 20% of SoC, real-time (last opportunity) before which the "voltage-sensitive" SMA-based emergency releases needs to be operated, and the allowable operations for the UAT/hr, enabling the mission and Matsya6000 crew to "foresee" scenarios and redefine the EOP.

Navigation and Positioning

The navigation and positioning system (NPS) of Matsya6000 includes a Global Positioning System (GPS), high-precision Fibre Optic Gyro (FOG)-based Inertial Navigation Systems (INS) aided by a Doppler Velocity Log (DVL), depth sensor and redundant ultra-short base-line (USBL) Acoustic Positioning Systems (APoS). The navigation system initialised with the position input from the GPS receiver (when at the ocean surface) works in dead-reckoning (DR) mode during underwater operations.

In the DR mode, based on last known computed position, the navigational algorithm estimates the current position based on the inputs from navigation sensor suite. The position is updated from the inputs from the both

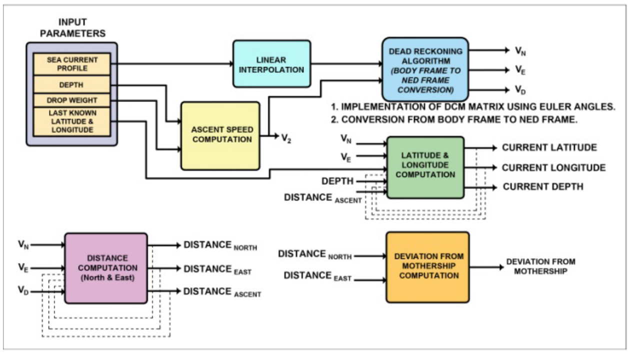

Figure.17. Principle of the NPS-DT module

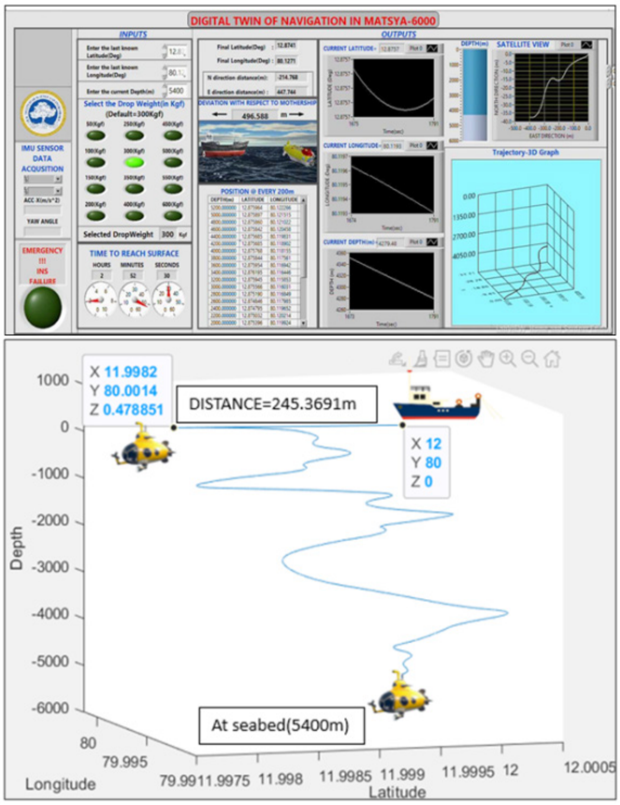

Figure.18. HMI of NPS-DT with key decision support information

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APoS continuously in real-time. During the failure of the NPS, Matsya initiates an ascent to the ocean surface from the deep-oceans. It is important to predict the trajectory during the ascent and the likely surfacing position of Matsya, in real-time, enabling precise positioning of the deployment ship for early retrieval. In order to predict this HTPS, the NPS-DT module **(Figure.17)** is designed to support the deep-ocean mission during the outage of the NPS. The NPS-DT takes in-situ ocean vertical water current profile (casted before the deployment), vehicle buoyancy computed in real-time (based on drop weight status) and the last position update of the APoS.

The position estimation using the DR principle is carried out, in which the in-situ water current velocities in the X and Y directions are translated into Matsya velocity in horizontal (XY) plane, with the help of Ansys CFD modelling and simulations. To compute the position of Matsya with respect to the navigation/earth frame (EF), the measured Matsya body frame (BF) velocity in X &Y axis are transformed to EF velocity resolved in the North and East directions. The conversion of BF velocity to EF velocity is done using the Direct Cosine Matrix

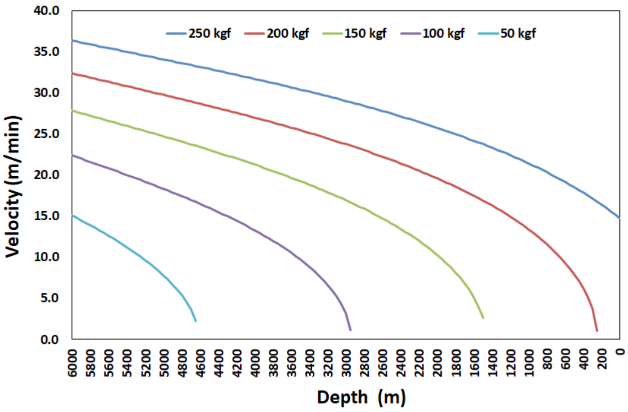

Figure.19. Ascent velocities from 6000 m depth with different buoyancy and depth-reach

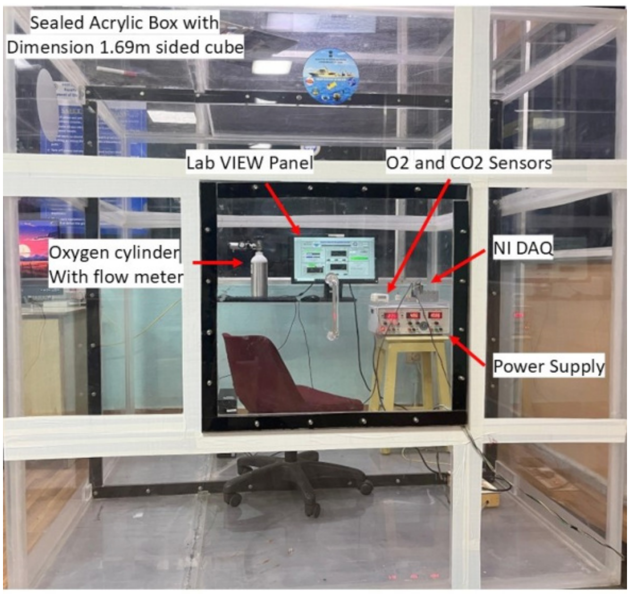

Figure.20. Human cabin (equivalent) made of acrylic material equipped with sensors and DAS

(DCM) transformation, which is used for computing the distance traversed in X and Y directions. Further, based on the deployment ship position, the computed distance is recursively added to prior position to estimate the geo-referenced position.

The trajectory and surfacing position of Matsya when the ascending from 5500m water depth, computed using NPS-DT during an NPS outage scenario is shown in **Figure.18.** The NPS-DT uses the ocean vertical current profile obtained in the Indian Ocean **(Figure.22)** by NIOT during a deep-ocean scientific mineral exploration. The accuracy of the NPS-DT results shall be validated during forthcoming Matsya qualification trials in the ocean, with location-specific water current profile as input.

As seen in **Figure.18,** the HMI has provisions to accept last location (Lat and Lon) and depth data streamed from Matsya in real-timeand the configuration of the drop weights (which can be selected manually by selection buttons). Based on these inputs the NPS-DT simulates the respective scenario "ahead-of-time", and displays the most-likely surfacing position, time-to-surface (TTS), as well as the ascend trajectory (3D) in real-time. The results can be refreshed with time at the desired update rate. The ascend velocity of Matsya from 6000m water depths for various buoyancy conditions in various water depths, computed based on hydrostatic calculations and taking into consideration the water density changes and compressibility of Matsya subsystems **(Figure.19)** and provided as a priori data the NPS-DT.

Life support system

During 1973, a multinational effort lasting 76h resulted in the successful rescue of the 2-crewed deep-ocean

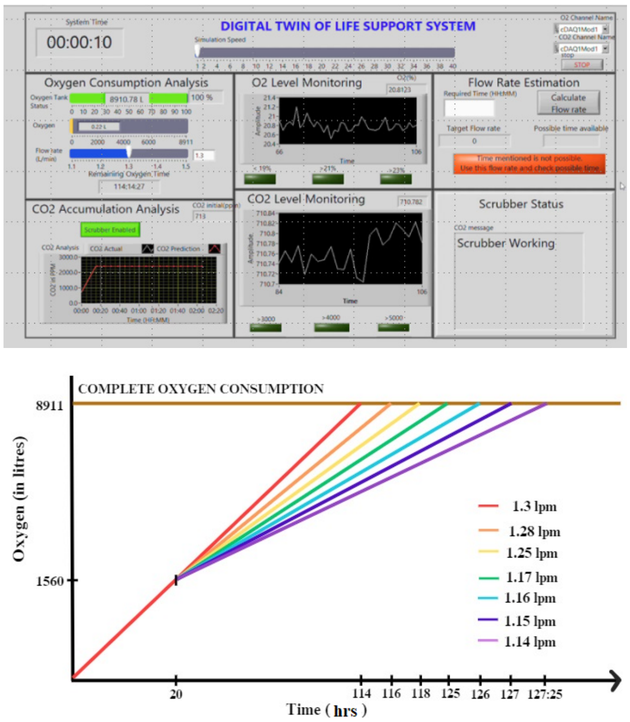

Figure.21. HMI of LSS-DT and the decision for survial beyond 96h

submersible *Pisces III*. The craft was trapped on the seabed and was lying upside down (due to flooding of its compartments) at a depth of 480 m, 240 km off-Ireland in the Celtic Sea. This highlights the importance of proactively managing the onboard O_2 usage during an emergency. At the time of accident, *Pisces III* (which was laying a transatlantic telephone cable) had 64h of O_2 storage left.

The synergised effort that involved Controlled Underwater Recovery Vehicle (*CURV-III*), *Pisces II & V* submersibles and multiple ships explained by Chapman in his book titled *No Time on Our Side* can be appreciated from the fact that only 12 min of O_2 was remaining when *Pisces III* was rescued. The survival as possible as the crew decided to allow the CO_2 in the air to build up beyond the normal 40 min to conserve O_2.

The human cabin of Matsya is equipped with life-support systems including O_2supply system (with 1045L of O_2 stored in 67 cylinders) for catering the requirements of 3 crew for 108h, two CO_2 removal scrubbers, four emergency breathers, smoke & fire detectors and environment monitoring sensors, alarms and data acquisition systems.

Under nominal conditions, the O_2 concentration inside the human cabin shall be maintained at 21% by the crew by opening the oxygen cylinders one after one, as they are exhausted. The cylinders are equipped with needle valves so that the flow rate can be varied so as to maintain the desired O_2 concentration at the desired level. Based on OSHA standards, the O_2 concentration inside the closed human cabin should be in the range 18.5-23%. A concentration of <18.5% is detrimental to the crew health and concentrations >23% creates an environment supporting combustion, possibility by electrically-generated sparks. During the emergency period, when the O_2 requirement has to be met for a period >96h, the flow rate has to be reduced to support the additional period, provided the O_2 concentration is >18.5%. This depends on the O_2 consumed, balance O_2 and the remaining period to support the crew. This HTPS is supported by the LSS-DT, which includes a mathematical model that incorporates O_2 consumption and CO_2 generation, integrated with sensory information from the real-time environment inside the human cabin.

A mathematical model of the human cabin internal environment is analysed using CFD Fluent software based on gas diffusion principles (based on partial pressures) to analyse flow patterns and velocity of gases. The O_2 consumption rate for the crew is calculated based on the level of physical activity and the respiratory quotient. The CO_2 exhalation rate of the crew is determined based on the body parameters, O_2 consumption and the respiration quotient. The model results are validated for a period of 3h using cubical acrylic chamber of interval volume equal to the human cabin, equipped with oxygen supply cylinder along with gas monitoring sensors **(Figure.20).** The validated numerical model is used for developing the

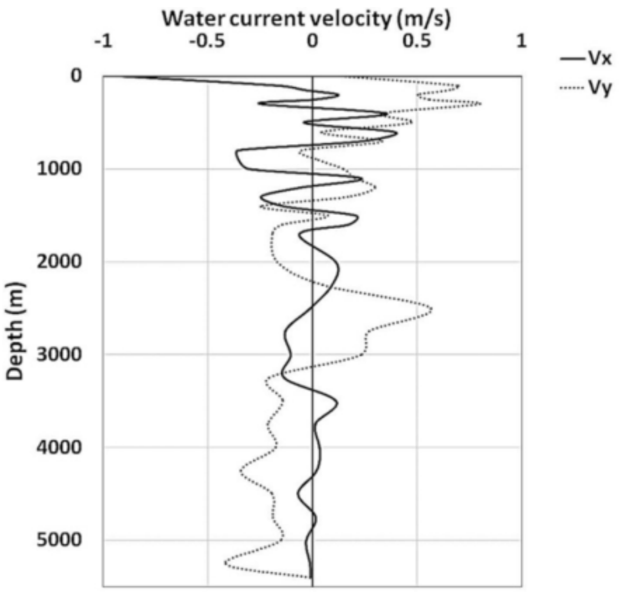

Figure.22. Water current velocity profile in Indian Ocean

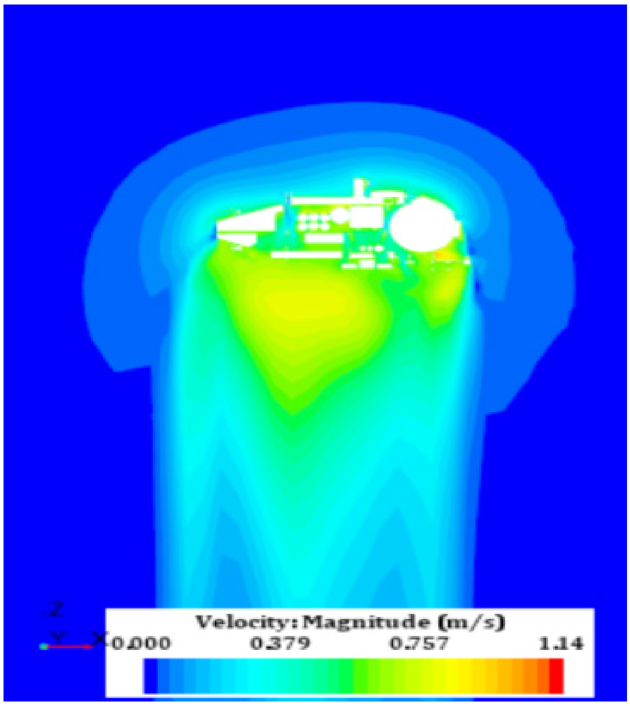

Figure.23. Velocity of fluid around Matsya during ascent

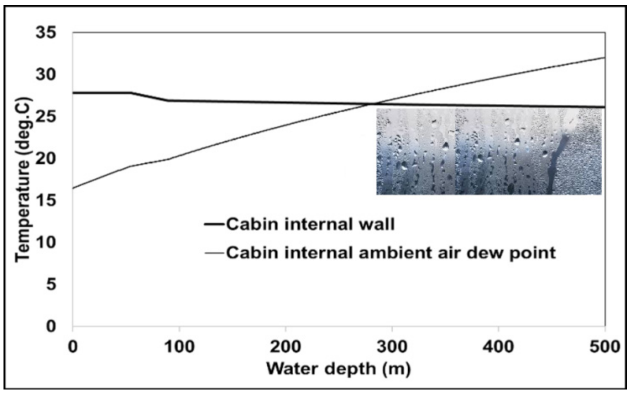

Figure.24. Microclimate DT determining the minimum depth for passive dehumidification

LSS-DT which shall support HTPS in during the mission in real-time, including monitoring of O_2 usage with time, O_2 balance availability, CO_2 generation during scrubber failure, and the flow-rate required for extending the survival of the crew beyond 96h.The LSS-DT thus helps to proactively manage O_2 levels inside the human cabin when there is requirement for the crew to survive beyond 96h of emergency.

The HMI developed for the LSS-DT and output of the DT summarising the O_2 flow rates required for the crew to survive beyond 96h is shown in **Figure.21.** During scrubber failure, the CO_2 levels increase inside the cabin. Under such circumstances, the crew wears the emergency breathing apparatus (EBA) which has a limited support period (usually few hours). The TTS from deep-oceans and the time to retrieve Matsya onboard deployment ship takes ~4h, and could be more if the ascent velocity is less due to system degradations. As indicated in the HMI, the LSS-DT also supports such HTPS for understanding the CO_2 accumulation inside the cabin during scrubber failures, so that EBA can be optimally used during such a crisis.

Propulsion System

The propulsion of Matsya in 6 degrees of freedom (DoF) is enabled using eight brushless direct-current (BLDC) motor- driven thrusters, 4 for forward/reverse, 2 for up/down and 2 for lateral DoFs. The mechanical, electrical and control configurations ensure full redundancy against system failures, physical damage, water ingress and single-point failures. Matsya is designed to be launched and retrieved in fair weather conditions. **While launching is under our control, retrieval during unfavourable weather conditions or during ship retrieval system failures is challenging.** Under such delayed retrieval scenarios, Matsya needs to hover below the ocean surface and maintain its position below the deployment ship (essential to maintain acoustic communication), until it is retrieved on-board deployment ship. The maximum duration (real-time) up to which Matsya can hover below the ocean surface is a HTPS that depends upon four key parameters. They include residual propulsion battery energy (SoC), battery discharge performance at that hovering depth, energy consumption of the thrusters at that depth which is characterised by varying water velocities **(Figure.22)**

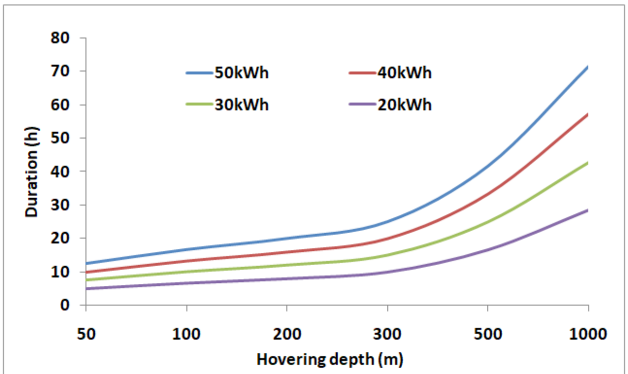

Figure.25. PS-DT outcome for hovering duration at various depths for various residual battery energy

(water current profile logged in the Central Indian Ocean Basin up to 5500m using on board NIOT Technology Demonstration Vessel Sagar Nidhi in April 2019) and the energy required by the human cabin dehumidifiers to maintain comfort level (which depends on the relative humidity inside the human cabin, wall temperature which depends on the depth and the dew-point temperature).

Based on the hydrodynamic CFD analysis performed using Ansys, the thrust in desired DoFs and respective power required to maintain Matsya's 3D position in the presence of varying water currents (X and Y velocities) in different water depths is determined **(Figure.23).** The energy required by the variable ballast system and vertical thrusters for subsurface depth cum position-keeping under various buoyancy conditions and battery discharge performances at different depths (characterised by temperature changes) are determined using analytical and CFD.

Based on these CFD inputs for the power requirements in all DoF at various depths (as priori data), along with the residual SoC of the propulsion batteries (streamed from Matsya in real-time/ and also determined as a part of DT) and the microclimate DT that provides energy demand from the dehumidifiers at various depths based on dew point **(Figure.24),** the Propulsion System (PS-DT) determines the water depth and duration for which Matsya shall hover before the battery runs out of energy. The output of the PS-DT is summarised in **Figure.25.**

Upcoming developments

The ever-increasing scientific demands require strategic deep-ocean HOVs capable of operating in hadal depths with increased performance and endurance, ensuring human safety. Developing comprehensive and integrated digital twins for Matsya helps to address aforesaid multi-facet and multi-disciplinary challenges within the stipulated time and reasonable costs, as system development could be initiated without the need of prototypes. At the same time, the influence of design changes on the existing submersible should be studied rapidly. Hence development of a comprehensive and integrated digital twin is essential for Matsya from design improvisation perspectives. At the same time, while the need for a situation-aware decision-support digital twin for Matsya is hereby justified in terms of increased operational safety and mission performance, taking into consideration the fatigue life of the structural components, ageing of the power sources, performance degradation of the electrical and electronics systems, demands development of a digital twin for Matsya's life cycle management/ prescriptive maintenance.

Further, operational systems require digital twins for diagnostics/prognostics, and predicting Matsya's response to safety-critical operations (such as manoeuvring in limited areas) in real-time and uncover previously unknown issues before they become critical, by comparing predicted and actual responses of Matsya.

These life-cycle management and operation support twins require extensive field-data to build multi-disciplinary database, enabling ML and imparting AI required to implement rapid fault prognostics and for justifying major revamping of Matsya over a period of time. Considering these purposes, development of an integrated and comprehensive digital twin for Matsya6000 is being undertaken in a rapid pace for serving as a design configurator, operational support, rapid fault diagnostics/prognostics and life-cycle management.

FOR FURTHER READING

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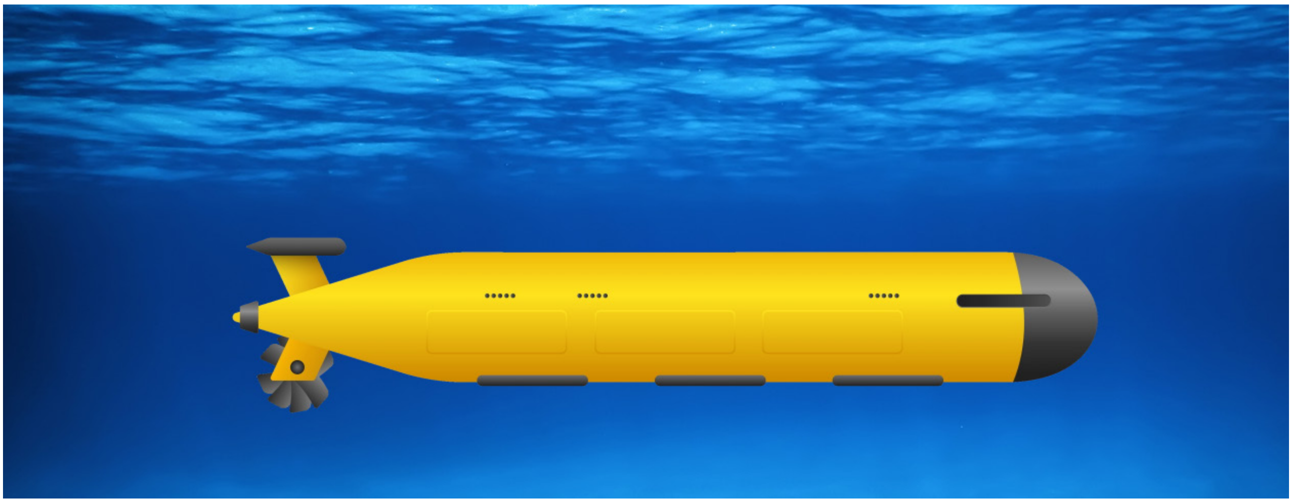
Evolution of next-generation Bio-inspired AI-enabled Homing Guidance System for Autonomous Underwater Vehicles - Part A



V. Bala Naga Jyothi, A. Vadivelan, N. Vedachalam, S. Ramesh

Abstract

This paper describes the decade-long efforts in the development of an AI-enabled Bio-Inspired Homing Guidance System (BIHGS) for enabling long-endurance subsea missions. The inspiration is from the pigeons and passerine sea & land migrants that use a variety of olfactory clues derived from geomagnetic field and visual clues, and how they switch between them navigational strategies to navigate very-long distances. This part describes the electromagnetic finite-element analysis-aided design and demonstration of a machine-learnt AI-enabled Electro-Magnetic Homing Guidance System (EMHGS) in which a MagHomer AUV (based on Differential Magnetometry/DM), by effecting precise attitude correction, was able to home onto a dock from a range of 7m. Part B of the article combines the EMGHS and Vision Guidance (VG) with Kalman filter based multi-sensor fusion, in which the MagHomer AUV uses DM for in-situ attitude correction and range determination, and YOLO-V5 VG algorithm to synergise DM data for precisely guiding the MagHomer into the 1m diameter cylindrical illuminated dock equipped with low-frequency electro-magnetic dipole generator. The deep-learnt AI-based BIHGS, which is immune to stray magnetic fields and turbid water conditions, is found to have a range of 7m and terminal homing precision of ±0.2m, with a success probability of 99.65%. An ocean-deployable, on-board Intelligent & Situation-aware Digital Twin aided BIHGS with ability to negotiate blind zones and re-course to a dynamic dock (during homing failure) is under development.

Introduction

Oceans covering 72% of the Earth's surface houses immense living and non-living resources, plays a key role in regulating the Earth's climate. Considering the strategic importance of the oceans, the United Nations have proclaimed 2021-30 as the decade of ocean science for sustainable development. Policies are initiated across the globe for leveraging the growth of blue economy with appropriate vision, technology, integrated management, monitoring and time-bound regulatory reforms. The world economic forum has highlighted the development of intelligent AUV for exploring oceans resources and studying climate change, as one of the priority areas **(Table.1).**

AUVs have a wide range of applications in the scientific, military, surveying, commercial, deep-sea search and policy sectors. Their ability to operate autonomously makes them well-suited for exploration activities in the challenging environments, from the world's deepest hydrothermal vents to locations beneath the Polar ice sheets. AUV are designed considering the mission objective, environmental conditions for the operative depth, payloads, communications, navigation, power source, buoyancy mechanisms and mission planning capability.

Table.1. Global priority areas and technologies

Priority areas
Technology, Climate change, Ocean Resources, Biodiversity, Cyber Security, Industry & Corporate Governance, Geopolitical & Geo-economic Cooperation
Emerging technologies
Artificial Intelligence (AI), Internet of Things (IOT), Advanced Materials, Smart Grids, **Autonomous Vehicles**, Drones, Big Data Analysis, Precision Medicine, Genomics.

The first generation AUVs include the Unmanned Arctic Submersible (UARS) that was deployed in the Beaufort Sea in 1972 for carrying out under-ice elevation mapping and deep-water AUV L'Epaulard was deployed in 1980 for marine geosciences research at a depth of 5300m in the Pacific Ocean. The second generation AUVs developed during 1990-2010 include Odyssey, CR-01&02, Dorodo, Explorer, Deep-C, Sentry, Jacquar, D'Allan, Remus, Aster-X, Autosub and Abyss. The third generation AUVs developed during 2010-2020 include ABE, Urashima, Seal, Bluefin, Hugin and Gavia. The significant AUV developments in deep-water, Polar and Intervention domains include AUTOSUB6000 (1a), Autonomous Benthic Explorer ABE (1b), Theseus (1c&d), Neried (1e) & GIRONA (1f) **(Figure.1).**

AUVs have a wide range of applications in the scientific, military, surveying, commercial, deep-sea search and policy sectors

The developments hitherto have resulted in AUV with performances **(Table.2)** including higher vehicle endurance, precise navigation, reliable acoustic telemetry, high resolution bathymetry/imagery, collision avoidance, path/trajectory planning capability and excellent system reliability. With the Synthetic Aperture Sonar (SAS) covering a range of 200m on each side of the AUV cruising at 2 m/s, it is possible to have on-board high resolution of up to few centimeters, as well as co-registered images, covering ~2 km^2/h.

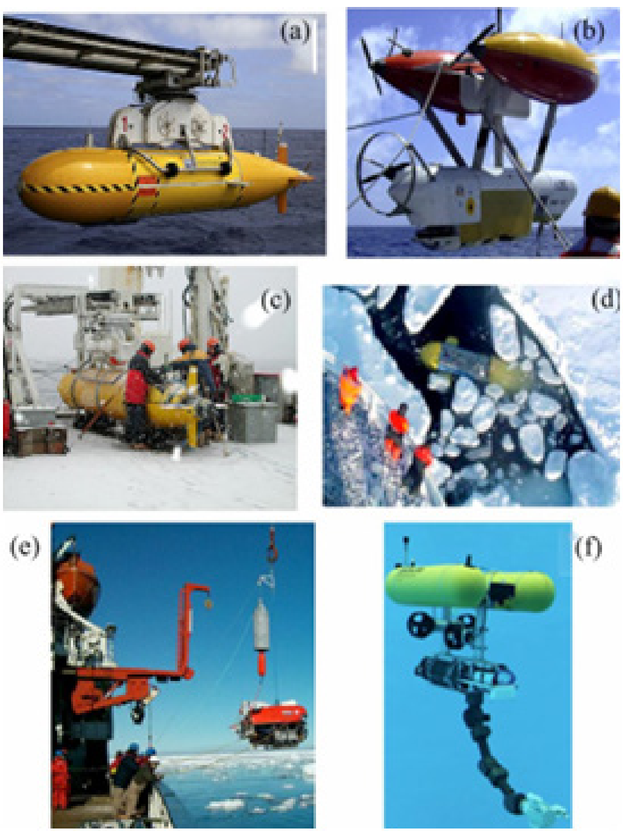


Figure.1. Significant AUV developments

The demands for the strategic fourth generation AUVs involved in scientific, Intelligence, Surveillance & Reconnaissance (ISR), increased spatiotemporal survey and exploration missions are mapped in **Figure.2.**

Need for underwater H&D stations

The key challenge to AUV operations is the finite mission duration due to the limitation in the on-board energy and data storage. In case of deep-water AUVs, a significant portion of the energy is expended during descend and ascend phases. In AUVs used for coastal surveillance and oceanographic applications, the effective operation mission time is limited by the on-board battery capacity. In order to overcome these limitations and to increase the subsea mission duration, underwater Homing and Docking (H&D) stations connected to the mother ship or shore facility, with provisions to recharge the batteries, upload the acquired mission data and download the mission profile are under development. The underwater homing guidance system has to provide a reliable guidance for the AUV

Table.2. Technological maturity of present AUV

Feature	Technological maturity
Navigation	0.01% of distance travelled with a CEP50, heading accuracy of 0.01° sec Lat
Positioning	USBL accuracy with 0.2% of slant range with CEP50
Acoustic telemetry	Data rates of 62kbps in shallow waters at 10W; 9 kbps at 6km range at 55W
Propulsion	~7kms/kWh for a 6m long, 1m diameter, 2T AUV at 3 knots speed;

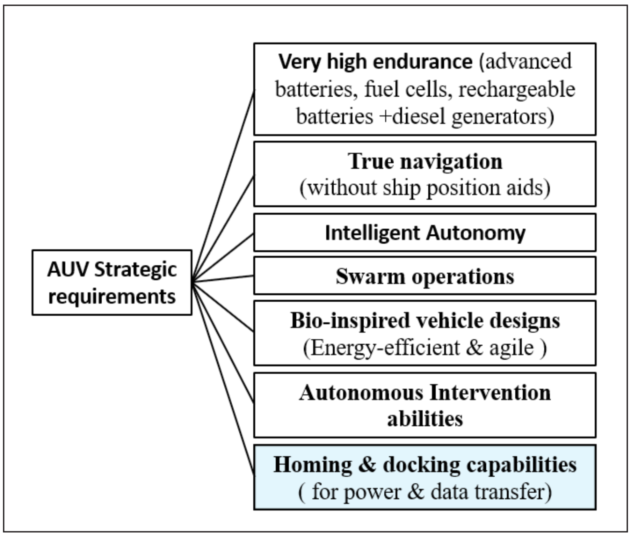


Figure.2. Demands for strategic fourth generation AUV

to return to, and manoeuvre into the dock, taking into consideration the AUV dynamic response capabilities and the residual energy in the batteries.

For an approaching AUV **(Figure.3),** long-range homing guidance, usually in the range of few kilometres (till few 10s for m) is done using the proven acoustic base line systems with acoustic transceiver and transponder located in the docking station and in the AUV, respectively. The AUV computes its range and bearing with respect to the dock for the required course and attitude correction. When the AUV approaches closer to the dock, vehicle attitude/pose correction becomes increasingly important to ensure reliable docking, and this requires precise AUV spatial measurements with high update rates with adequate temporal resolution.

Homing and Docking (H&D) stations connected to the mother ship or shore facility, with provisions to recharge the batteries, upload the acquired mission data and download the mission profile are under development

Determining the orientation/attitude of the AUV using acoustic systems with high update rates involve extensive signal conditioning and it is challenging with the limited residual on-board energy. Moreover, acoustic systems will have increased complexity if it must operate near the surface, bottom, or near acoustically reflective boundaries. When the AUV is closer to the dock, in the order of few meters, reliable short-range homing guidance are required. Over the past two decades, technologies for H&D are being studied in various AUVs including REMUS, Odyssey, Dorodo and ISE-Explorer, based on a combination of acoustics, inertial and vision techniques **(Figure.4).**

With the mandate of leveraging the blue economy of India, NIOT's Deep Sea Technologies Division, over the past

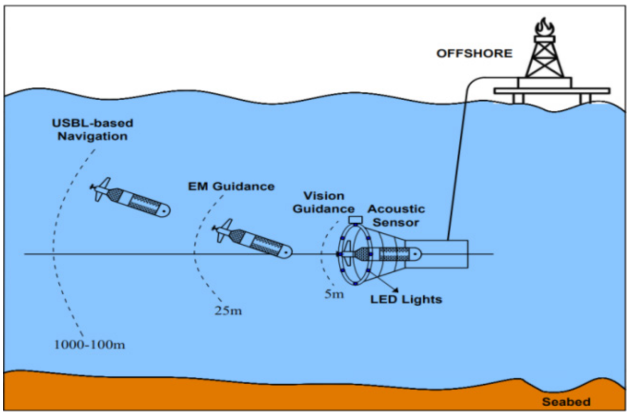


Figure.3. Stages involved in AUV homing to the dock

Figure.4. Homing demonstration by ISE, REMUS & Dorado

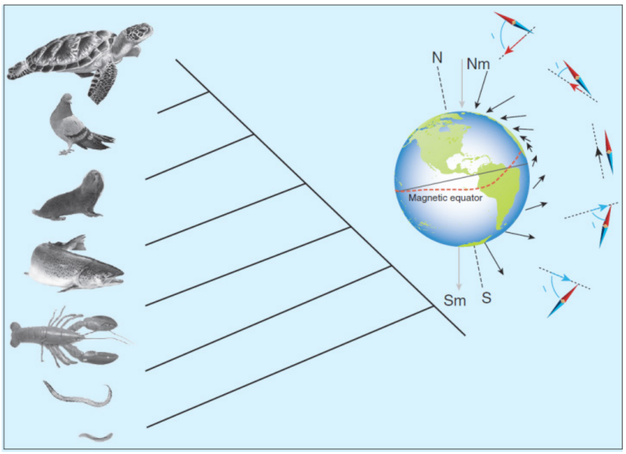


Figure.5. Animals utilising GMF for navigation

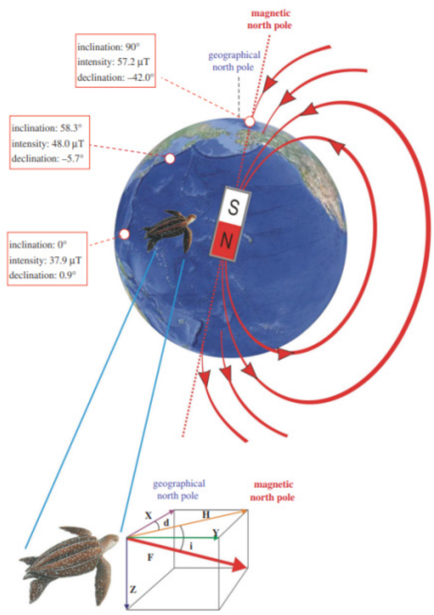


Figure.6. Representation of GMF & vector describing the field at any given location on the Earth's surface

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Delegates for Annual Meet		Rate in INR
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two decades, have demonstrated a range of technologies including deep-water remotely-operated robotic vehicles, autonomous subsea floor coring systems for exploration of deep-ocean mineral resources and hydrocarbons. The technologies developed are transferred to Indian Industries (including L&T and BEL). Under the Deep Ocean Mission of Government of India, NIOT-DST division is indigenously developing India's first deep-ocean human scientific submersible Matsya6000 (4th generation in global scenario) for enabling human missions, bio-inspired technologies like homing & docking, swarm robotic systems, and situation-aware intelligent autonomy enabled by Digital Twins, for enabling long-endurance mineral-mapping and oceanographic missions using AUVs.

The idea that terrestrial magneto-reception (MR) could be used as a compass by animals dates back more than a century

Bio-inspiration

The 3-stage development of the BIHGS is based on the inspiration from the migrating sea animals and birds that use magnetic and visual (others include olfactory and inertial) clues to trace back their way home, when displaced several kilometres, and how their brain processes the visual information for path guidance. The navigational accuracy of the sea animals and trans-ocean birds and their unerring ability to travel between any two points by the shortest possible route, or the ability to home to a target area from anywhere provides evidence to support the usage of geo-magnetic field (GMF) as the key parameter for navigation and positioning of long-range AUV. The idea that terrestrial magneto-reception (MR) could be used as a compass by animals dates back more than a century. MR is the capacity to perceive the GMF is pervasive across animal kingdoms including magneto-tactic bacteria to nematodes, crustaceans (spiny lobster), fishes (salmon), birds(pigeon), mammals (whales, mole-rat) and reptiles (sea turtle) **(Figure.5).**

Unravelling the mystery of the organisation of the magnetic maps, and the exploitation of the magnetic positional information (intensity, declination and inclination) by animals to guide their movements (map/geo position sense) offers new insight into GMF-based navigation **(Figure.6, Table.3).** During the flight/swim, they have the capability to detect magnetic anomalies and compile the information in the mental map for use as magnetic signposts enabling route planning. For many species (birds and fish taxa), migratory routes are not learned, but are innate, which requires them to possess internal orientation mechanisms enabling autonomous navigation to specific targets. However, the complexity of local magnetic contours suggests that any navigational strategies that exploit magnetic topography over these smaller spatial scales are likely to be site-specific, difficult to generalise, and learned rather than inherited,

Table.3 Significant advances in compass/map sense in sea animals

Year	Significant advances
1970	First evidence for magnetic sensitivity in bony fishes
1976	Experimental evidence for magnetic orientation in cartilaginous fishes
1982	Magnetic compass sense identified in sockeye salmon
1997	Report of potential magneto-receptor in nose of trout
2014	Magnetic map sense identified in Chinook salmon
2016	Reef fish larvae have a magnetic compass sense
2020	Evidence for a magnetic map in bonnet head sharks

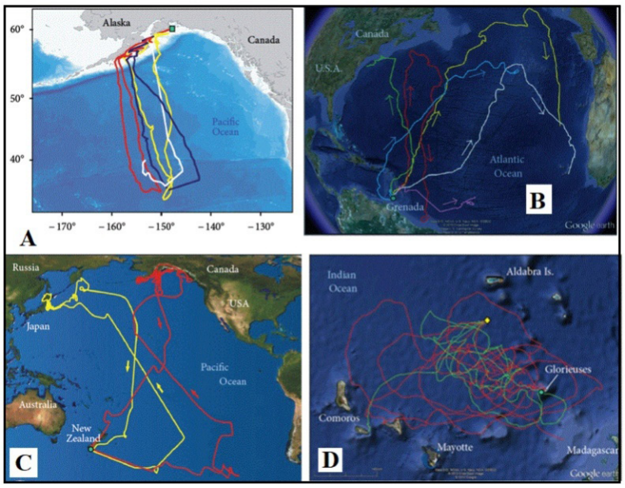

Figure.7. Spectacular trans-ocean fish journeys

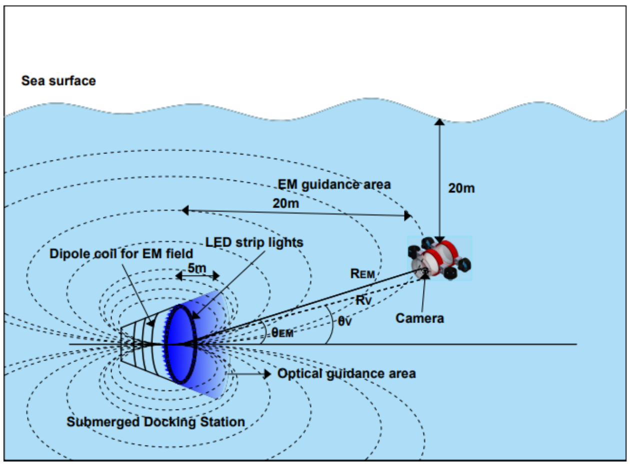

Figure.8. BIHGS implemented for AUV homing

which opens up new avenues in AUV navigation with a prior GMF map and on-the-go machine-learning capabilities for in-situ navigation and positioning guidance.

Homing pigeons have long served as model animals to study large-scale spatial cognition that establishes idiosyncratic routes back to their home from distances >1000km based on olfactory clues that they recapitulate when flying solo. They easily determine map location at least at an order of magnitude better than the 2 km, which are estimated from the returns of visually impaired pigeons**.** When released, they fly in circles to imprint the regional GMF and to get themselves oriented. The magnetic wires around the heads predictably distorted their departure bearings. Experiments conducted on adult pigeons, trained to carry miniature GPS loggers revealed that over a track of ~10km (distance to home), the mean perpendicular distances between the penultimate and final training tracks were about 100m. From their course correction capability, it is found that their MR sensitivity could be in the order of few nT.

Migratory movements of trans-ocean birds and animals tend to be extremely accurate towards geographic locations such as oceanic islands or offshore reproductive areas. The advancements in the geo-tagging and tracking systems have helped to track spectacular trans-ocean fish migrations **(Figure.7). Figure.7a** shows the multi-year tracking of the salmon shark (green square indicating tagging site) shuttling between Alaskan coastal waters and a specific offshore foraging area. Each track represents the migratory journey undertaken in a different year. The spectacular migrations of six satellite-tracked leatherback turtles nesting at Grenada Island (green dot) spanning over the entire Northern Atlantic Ocean is shown in **Figure.7b.** Most turtles wandered over large oceanic areas, but some (green and red track) migrated directly towards specific sites along the North American continental shelf. **Figure.7c & d** shows the inter-hemispheric migratory journeys of two sooty shearwaters moving from their New Zealand breeding colony (green dot) first to oceanic areas in the Southern Pacific Ocean and then to wintering foraging grounds in the North Pacific.

The You-Only-Look-Once (YOLO) is a powerful object detection deep-learning (DL) algorithm used in different fields that is bio-inspired for processing visual information.

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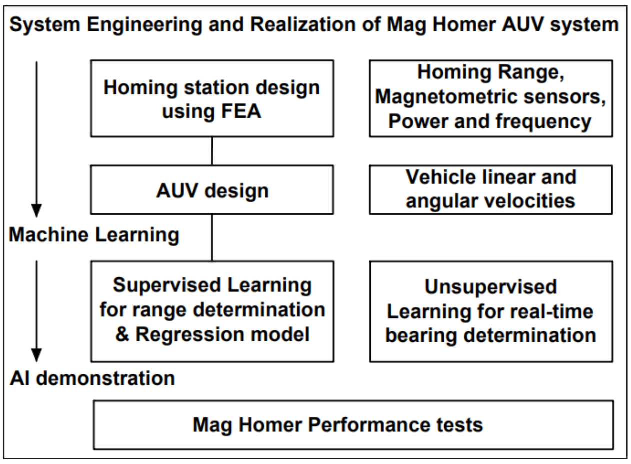

Figure.9. Development of DM-based MagHomer

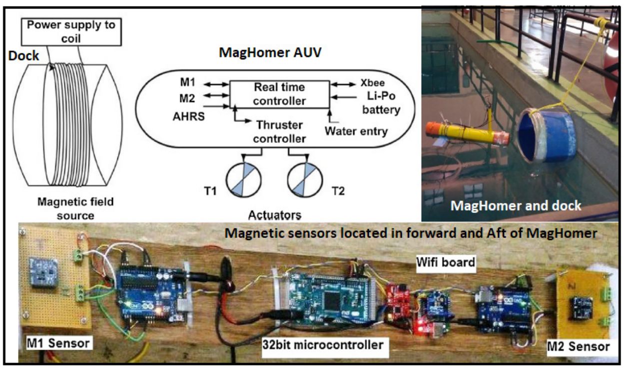

Figure.10. Hardware assembly of DM system

Table.4 Specifications of MagHomer and dock systems

Subsystem	Detailed technical specification
Dock systems	
Dock dimension(mm)	600mm diameter
Dipole coil	40 turns, 10 sq.mm thickness, L= 1.74mH, R = 0.52 ohms.
Power supply	0-32V,20A
Solid state relay	4-200V,25A
Micro PLC	11V,20Hz
MagHomer AUV systems	
Vehicle dimensions	820mm(L)x140mm(D)
Vehicle weight	6.16Kg
Battery	Lithium Polymer 3S1P,11.1V,10AH
Microcontroller	AT9173x8E 32bit controller, SAM3x8EARM Cortex-M3 CPU,84MHzclock,SRAM96KB, Flash memory 512KB,4 UART's
Attitude sensor	PNI AHRS module
Magnetic sensors	+/-800µTesla, Sensitivity 13nT
Wi-fi module	2.4GHz,250Kbps,120mrange
Thruster	2.4Kgf Forward,1.8Kgf Reverse 12V,300-4200rpm,130watts
Degrees of freedom	Two

YOLO is faster and more accurate than many other algorithms such as CNN (Convolution Neural Network)-based image recognition, Single shot multi box detector (SSD), Retina-Net and other DL algorithms. The YOLO algorithm, based on regression, instead of selecting the interesting part of an image, it predicts classes and bounding boxes for the whole image in a single run**,** making it capable of detecting multiple trained objects in a single image based on classification and segmentation. This technique works efficiently with less datasets and challenging environments, and hence selected for this underwater vehicle application.

> **"This is how pigeons imprint the magnetic field by flying in circles before leaving an unknown location, which needs to be re-visited"**

Thus, the 3-staged development of BIHGS is based on the MR in sea animals and visual object detection capability of humans/animals. **Figure.8** depicts the concept of BIHGS based on artificially created low frequency electromagnetic field and vision, implemented in the docking station and in the AUV. The first and second stages include development of the AUV attitude control based on DM and VG trained using DL techniques. In the third stage, Kalman filter based Multi-Sensor Fusion (MSF) technique is used to synergise the AUV pose/attitude data computed with DM and VG data to achieve precise and consistent terminal homing at the dock.

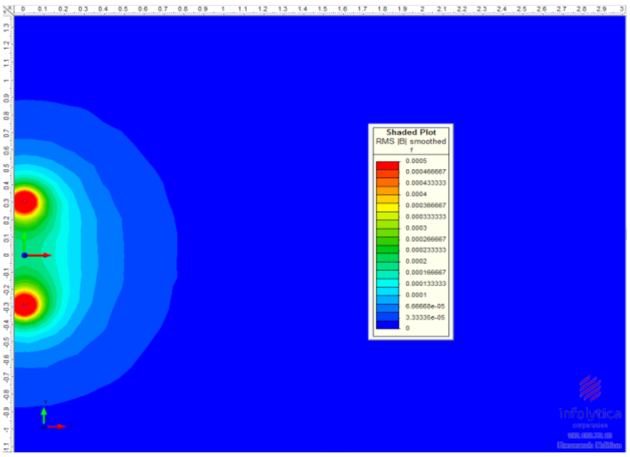

Figure.11. FEA simulation results near-field distribution

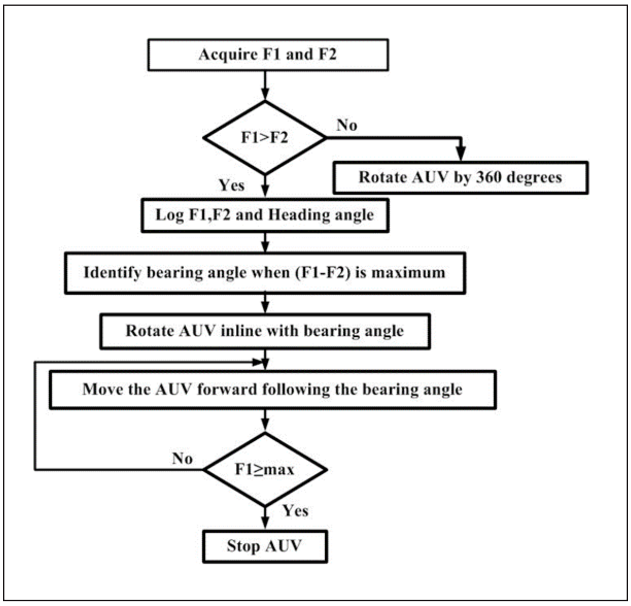

Figure.12. Algorithm for MagHomer identifying heading

Stage 1: Demonstration of DM-based EMHGS

System engineering and realisation of DM-based EMHGS is described in **Figure.9.** The AUV named as MagHomer is used for demonstrating the concept.

An alternating dipole magnetic field of fixed frequency and power is generated using the electric dipole coils located in the dock. The unique frequency is used to enable the AUV detect the produced magnetic signature demarcated from the static GMF, other regional magnetic signatures and stray fields. A DM system is located in the approaching MagHomer AUV, with magnetic field intensity measurement sensors located in the forward and aft ends **(Figure.10, Table.4).** The MagHomer determines its heading towards the dock when the forward-located sensor measures a relatively higher magnetic field strength compared to the aft-located sensor. The difference between the magnetic field strength measured by the forward and aft sensors provides the field gradient, and in turn the bearing angle. The bearing angle is the angle between the axis of the dock and the MagHomer, which provides the orientation of the approaching MagHomer with respect to the dock. Ideally, bearing angle has to be corrected to zero for achieve a successful dock and for ensuring proper mechanical alignments required for underwater wireless power charging and optical data transfer systems. The minimum bearing angle is achieved when the magnetic field gradient is the

Table.5. Hydrodynamic response in heading DOF

Speed in rpm		Angular velocity (º/s)
Thruster 1	Thruster 2	
178	120	2
644	565	4
1200	1150	12
1586	1480	18
1711	1611	20

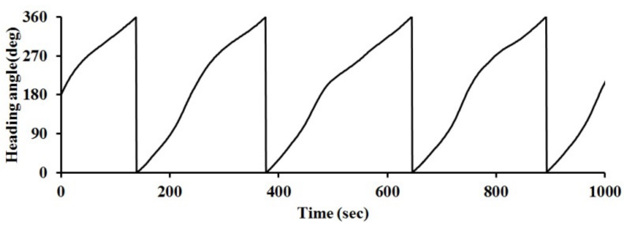

Figure.13. MagHomer heading rate for differential speed of 106 rpm

maximum. In addition to the attitude correction, it enables measurement of MagHomer range, bearing and velocity for a priori spatial magnetic map.

In order to determine the magnetic field to be generated, magnetic field gradient and electrical power input, the dock dipole coil is modelled using Infolytica Corporation's MagNet v7 electromagnetic finite element analysis (FEA) software. The simulation results showing the 2D magnetic field distribution from the dock is shown in **Figure.11.**

Based on the modelling and simulation results, a 20-turn copper wire is wound circumferentially over the 0.6m diameter cylindrical shaped underwater docking station. The excitation frequency of 20 Hz is chosen to have a reduced skin effect induced eddy current power losses in the saline sea water medium. The MagHomer comprises of a DM system and two thrusters in the aft enabling operation in surge and heading degrees of freedom **(Figure.10).** The magnetic field strength measurement sensors located in the forward and aft ends of the MagHomer communicates the measurements to the co-located 32-bit master microcontroller. The microcontroller computes the magnetic field gradient, stores a priori magnetic map and offers attitude control guidance for the MagHomer based on the identified vehicle dynamic performance parameters. Based on the measured magnetic field gradient and the MagHomer model, the microcontroller issues appropriate speed command to the two thrusters for necessary attitude correction enabling heading towards the dock. The methodology by which the MagHomer identifies the heading angle towards the dock is described in flowchart **(Figure.12).**

Identification of MagHomer hydrodynamic response parameters

The process of bearing angle identification and heading towards the dock requires precise vehicle control in the heading and surge DOF. The MagHomer is equipped with two axially located thrusters enabling operation in the heading and surge DOFs. The thruster configuration has a comparatively faster response compared to other AUV configurations. The forward function is realised with both the thrusters operating with equal thrust. Heading function, accompanied with a surge, is achieved by operating the thrusters with appropriate differential speeds. This requires identification of the MagHomer heading response for various thruster differential speeds. The action-response methodology is adopted to identify the hydrodynamic behaviour of the MagHomer. Parameter identification tests are carried out in the NIOT test tank under various differential speeds and the corresponding heading angular velocities logged **(Table.5).** The data logged for a differential speed of 106 rpm resulting in a heading rate of 18º/s **(Figure.13).** The identified results are implemented in the MagHomer control system with a straight-forward proportional controller.

Machine learning process

Range and bearing angle computation is done using in-situ and real-time magnetic field measurements in 3-axis (in X, Y and Z direction). For range determination, supervised/predictive ML algorithm is used, in which the algorithm learns from the training datasets mapping the EM field data to the range (distance between dock and MagHomer) until it achieves the desired level of accuracy. The Exponential Regression and KNN algorithms are used from the open-source Python SKL (Scikit-Learn) packages to model the relationships and to find the best fit, by means of which an accuracy (R2 score) of 99.8% and 98.7% were obtained.

For bearing determination, below indicated Unsupervised/Descriptive ML algorithm-based K-means clustering technique is used by which the ML model learns and extracts the features (create clusters) from the series of magnetic field data from the forward and aft-mounted sensors of the MagHomer.

$$\underset{\substack{\text{objective}\\\text{function}}}{J} = \sum_{j=1}^{\overset{\text{(no of clusters)}}{k}} \sum_{i=1}^{\overset{\text{(no of cases)}}{n}} \underbrace{\Big\| \underset{\text{(case i)}}{x_i^{(j)}} - \underset{\text{(centroid for cluster j)}}{c_j} \Big\|^2}_{\text{Distance function}}$$

The main objective of the model is to group the unsorted data considering their patterns, similarities, and differences with the measured magnetic field values.

Table.6. Performance metrics of Unsupervised ML algorithm

Cluster	Accuracy (%) Recognition rate	Centroids
Cluster 1	95	8.9. 4.8
Cluster 2	95	397, 42

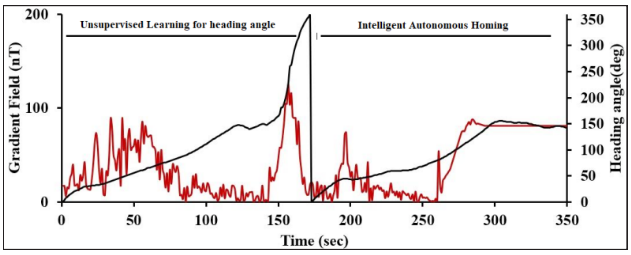

Figure.14. Identification of bearing angle and heading correction

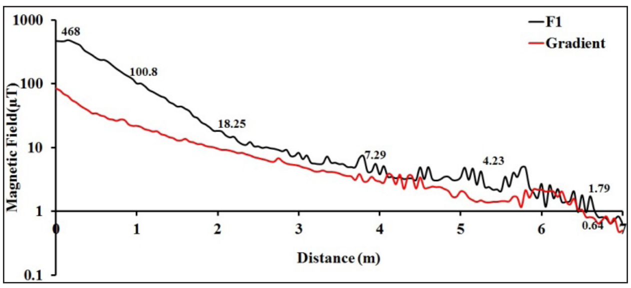

Figure.15. Range based on field strength measurement

During tank testing and homing operation, two sensors F1 and F2 series measured data forms clusters1 and 2, where the cluster 1 consists the data with F1> F2, and cluster 2 consists the data with F2>F1. During MagHomer homing operation, it must move forward when F1>F2, else it has to rotate till F1>F2. The decision for rotating the MagHomer is very important as the vehicle has very short time to move towards docking station (residual energy will be very less and needs battery recharging). Hence, there is a need of unsupervised ML algorithm, where in real-time, F1 and F2 measured values can be compared with values in Cluster 1 or Cluster 2, and compare with the nearest mean and closest centroid computed with Euclidean distance of each cluster, for making a *real-time decision* in relative bearing angle determination **(Table.6).**

Demonstration of intelligent DM-based homing

The demonstration of EMHGS based on DM-based homing is carried out in the tank (15m x 11m x 7m) facility of National Institute of Ocean technology (NIOT). The dock coil is energised with 400AT producing the 20Hz varying magnetic field and the MagHomer is deployed at a distance of 7m from the dock.

In the MagHomer bearing angle identification sequence **(Figure.14, Figure.16** from 0 to 180s), from an initial heading of ~0°, the AUV executed a 360º heading turning a period of 175s with the minimum angular velocity of ~2º/s. This is how pigeons imprint the magnetic field by flying in circles before leaving an unknown location, which needs to be re-visited. During the process, the bearing angle was identified to be ~170º, which corresponded to the maximum differential field gradient. The aft end sensor recorded 140nT of magnetic field intensity when the MagHomer is at a distance of 7m from the dock. In the subsequent bearing angle correction sequence, MagHomer continued its heading at the same angular velocity until it reached 150º in a further period of 125s. Thereafter, MagHomer heading stabilised at 150º for

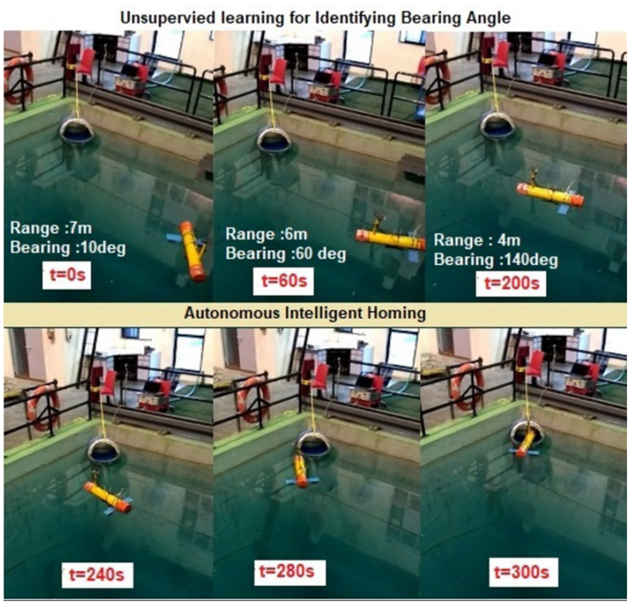

Figure.16. Demonstration of intelligent DM-based homing

heading towards the dock. The magnetic field strength logged by the forward located magnetic field sensor is shown in **Figure.15,** which provided the range of the MagHomer with respect to the dock. Out of 60 runs, 56 homing operations were successful, and hence a success possibility of 93%. However, two runs were unsuccessful due to an imprecise bearing angle.

The demonstrated innovative EMHGS is being protected through patent number 441091 granted on July 2023 by The Patent Office of the Government of India.

In the next part

This next part describes the development and demonstration of the system that combines EMGHS and YOLO-V5 algorithm-based Vision Guidance (VG) with Kalman filter based multi-sensor fusion, in which the deep-learnt MagHomer AUV is found to have an increased terminal homing precision and reduced probability of homing failure. An ocean-deployable, on-board Intelligent & Situation-aware Digital Twin aided BIHGS with ability to negotiate magnetic and optical blind zones and re-course to a dynamic dock (during homing failure) which is under development, will also be described.

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Augmented Reality in Marine Machine Training

Dheeraj Kumar Devaraj, Jayesh Chandrapurakkal Sasi, Sharon Mathew George

ABSTRACT: Due to lack of knowledge and development, seafarer often cause operation faults and equipment damage while on sail which causes cargo delay and financial loss. The high dependence on machine manual for the operation and maintenance has caused confusion and bypass of right procedure. Augmented Reality is one of the best solutions for this case as it is used to substitute paper manuals with digital instructions which are overlaid on the manufacturing operator's field of view. Virtual manuals help manufacturers adapt to rapidly changing product designs, as digital instructions are more easily edited and distributed compared to physical manuals.

KEYWORDS: Maintenance, Operation, Safety, Manual

1. INTRODUCTION

Machine operation and maintenance has seen a drastic change in the following years. However, we see that due to lack of knowledge and development, seafarers often cause operation faults and equipment damage while on sail which causes cargo delay and financial loss. The long tradition of highly dependence on machine manual for the operation and maintenance has caused confusion and bypass of right procedure by seafarers. As autonomous ships are slowly being introduced into the industry, number of manning individuals are reduced in those ships. Companies feel reluctant to spend their resources for training purpose. Also, seafarers find its time consuming and frustrating to train new cadets. So, introduction of new technologies is highly demandable in this scenario.

Augmented Reality (AR) is one of the best solutions for this case as it provides a wide variety of problem solving. Using AR an engineer can get accurate information about a marine equipment and a clear understanding of its operation, components, maintenance through a 3-Dimensional portrayal of the component in an Augmented Space through an AR device (smartphone, AR glasses, tablets). This 3D projection can either be static or an interactive 3D projection. It's a very user friendly, error proof, exciting and valuable innovation that can be bought into the marine field.

AR is used to substitute paper manuals with digital instructions which are overlaid on the manufacturing operator's field of view, reducing mental effort required to operate. AR makes machine maintenance efficient because it gives operators direct access to a machine's maintenance history. Virtual manuals help manufacturers adapt to rapidly changing product designs, as digital instructions are more easily edited and distributed compared to physical manuals. Digital instructions increase operator safety by removing the need for operators to look at a screen or manual away from the working area, which can be hazardous. Instead, the instructions are overlaid on the working area. The use of AR can increase operators' feeling of safety when working near high-load industrial machinery by giving operators additional information on a machine's status and safety functions, as well as hazardous areas of the workspace.

AR can be programmed to project the machinery or component by the manufacturer as per the model used in the ship. The manufacturer can input the details and correct procedures into the AR platform as per the requirement. Each machinery or component can be provided with an AR facility to understand it in a better way. The engineer can use the AR projection to carry out maintenance and operation with ease. AR can be easily used through the engineer's phone or the owner provided AR smart device.

2. MAIN WORK

2.1 APPROACH TO THE ISSUE

According to the Maritime Transportation Research Board of the USA, human error in the maritime domain is "the commission or omission of acts by maritime personnel that cause or contribute to merchant marine casualties or near-casualties" (NAS, 1976). In addition, Lu (20012) remind us that "shipping is one of the riskiest service industries. Although shipping companies attempt to assure work safety, they are not completely successful in eliminating human failures". All crews and shipping companies in the world are aware of the influence of the human element in accidents.

In 1976, a research board in the U.K. concluded that human error was the cause of 80% of accidents (Guglielmo's, 1997). Ever since, most of the published studies on maritime accidents have found that maritime accidents are caused mainly by human errors (Berg et al., 2013a). In marine accidents, society tends to make an assessment quickly in order to find a scapegoat. In many cases, the Master and the crew are the target of criticism before the investigation starts (Sánchez-Beaskoetxea and Coca, 2015). Human factors are involved in many cases, but the crew is not always to blame. In recent decades, many researchers have published papers on the causes of maritime accidents, focusing both on technical failures and on the errors of the people working on board ships (crew, pilots, on-shore personnel, inspectors, etc.).

Several of these studies found that in many accidents human error was the main cause or an important factor. We can highlight some of them as an example: "Of a total of 880 accidents analysed during the investigations between 2011 and 2015, 62% were attributed to erroneous human action" (EMSA 2016), "Over 80% of marine accidents are caused or influenced by human and organization factors" The high dependence on machine manual for the operation and maintenance has caused confusion and bypass of right procedure. From many case studies it can be found that cadets as well as other seafarers find it confusing or difficult to understand a machine manual properly which leads to at times a lot of confusion and wrong working space a case study of this can be seen below.

2.2 AUGMENTED REALITY

Augmented reality (AR) is an emerging Human Computer Interaction (HCI) technology that renders virtual information on a real scene. An AR system is formally defined as an application that fulfils the following three properties, namely,

(a) able to blend real and virtual content in a real environment,
(b) is real time and interactive, and
(c) can register virtual content in 3D environment.

Typical AR application consists of five modules, namely, registration, tracking, rendering, interaction, and content generation. In short, computer-generated information, such as annotations, graphics and 3D models, should be rendered and registered on the real scene with accurate tracking and alignment, followed by user-friendly interaction modes, such as gesture-based input, speech input or with the help of external input devices, such as data gloves, ray casting using mouse, etc. Lastly, relevant content in response to specific request or task should be generated and displayed to the users.

2.3 RELATED AR APPLICATIONS

In the modern world AR is already in use in many industries even in transportation & logistics such as on land and air. Transportation systems and fleets are becoming more complex, and the need for longer service life is increasing, making transportation planning challenging. But experts with the required skills to maintain vehicles are becoming scare due to an aging workforce. When experts retire, their expertise is lost forever. Manifest helps capture this knowledge, before it is too late, to standardise and digitise even the most complex procedures. Knowledge is transferred seamlessly providing the needed competency, consistency and agility to address the growing workforce skills gap and the increasing complexity and diversity of fleets and transportation services.

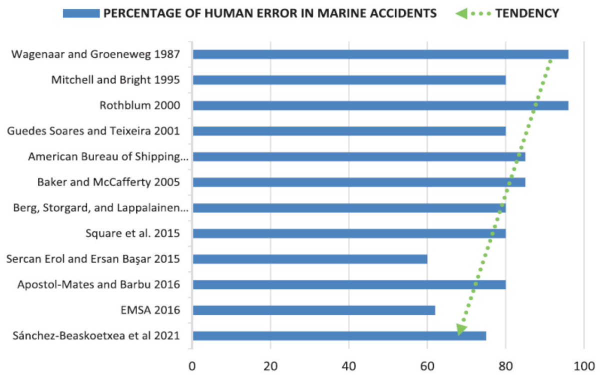


Figure.1. Percentage of Human Error in Marine Accidents
Source: https://www.sciencedirect.com/science/article/pii/S2666822X21000083

Types of human errors among the crew on cargo and passenger ships.

TYPES OF HUMAN ERROR AMONG THE CREW ON CARGO & PASSENGER SHIPS (44 ships)

GROUP	*N°*	*ERROR*	*Q*	*% cases*
A (Physical problems)	1	Physical problems due to marine environment (storms, cold, etc.)	1	50.00%
	2	Fatigue due to lack of sleep / Physical problems	1	50.00%
	3	Fatigue due to excessive workload	0	0.00%
		TOTAL GROUP A:	2	4.55%
B (Damaging substances)	4	Adverse reaction to medication	1	50.00%
	5	Alcohol	0	0.00%
	6	Drugs	1	50.00%
		TOTAL GROUP B:	2	4.55%
C (Communication error)	7	Failure to communicate among crew members (misunderstanding, inappropriately expressed orders, language. ...)	4	19.05%
	8	Failure to communicate with the pilot (language, etc.)	10	47.62%
	9	Communication error among crew members due to personal problems	0	0.00%
	10	Communication error with other ships	6	28.57%
	11	Communication error with ground personnel	1	4.76%
		TOTAL GROUP C:	21	47.73%
D (Distractions)	12	Distraction during the watch caused by performing several tasks at the same time	1	16.67%
	13	Distraction during the watch caused by non-work tasks (telephone, etc.)	2	33.33%
	14	Lack of proper monitoring of navigation	3	50.00%
		TOTAL GROUP D:	6	13.64%
E (Navigation error)	15	Navigation error due to misjudgement	12	30.77%
	16	Navigation error due to poor technical training or inexperience	7	17.95%
	17	Navigation error due to overconfidence	10	25.64%
	18	Navigation error due to misuse of vessel equipment	10	25.64%
		TOTAL GROUP E:	39	88.64%
F (Inadequate planning)	19	Lack of trip planning or maneuver planning	12	70.59%
	20	Failure to follow trip plan or maneuver plan	0	0.00%
	21	Not following the procedures	5	29.41%
		TOTAL GROUP F:	17	36.96%
G (Lack of training)	22	Ignorance of the procedures	2	40.00%
	23	Ignorance of the use of ship equipment	1	20.00%
	24	Ignorance of regulations	2	40.00%
	25	Ignorance of working language	0	0.00%
		TOTAL GROUP G:	5	11.36%
H (Lack of leadership)	26	Error in the exercise of command	3	100.00%
		TOTAL GROUP H:	3	6.52%
(Maintenance)	27	Poor maintenance of the ship known by crew	3	100.00%
	28	Failure to take adequate corrective measures against a known mechanical failure	0	0.00%
		TOTAL GROUP I:	3	6.82%
J (Fear)	29	Fear	0	0.00%
		TOTAL GROUP J:	0	0.00%

Figure.2. Types of Human Errors on Board
Source: https://www.sciencedirect.com/science/article/pii/S2666822X21000083

2.4 AR GUIDANCE

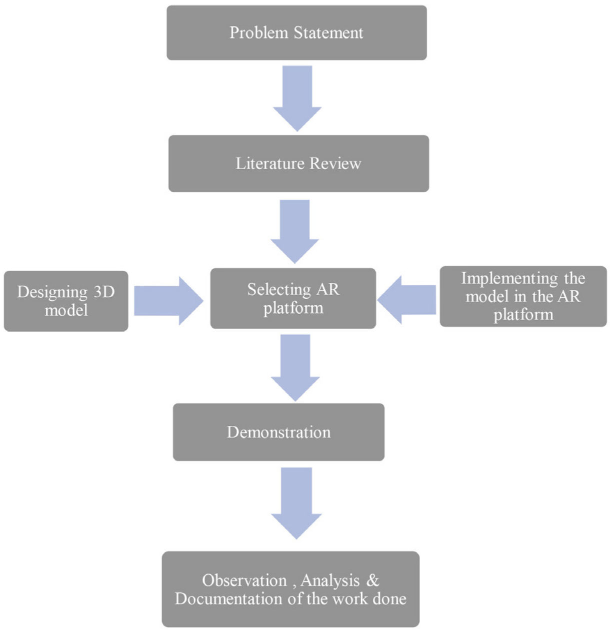
AR applications involve different kinds of augmentation including visual augmentation, audio and haptic feedback, etc. In the proposed framework, visual augmentation is applied. Generally, there are two types of visual information, namely, static information (general and prompts) and dynamic information (guiding scene and instructions). Particularly, static information can be pre-defined beforehand while dynamic information requires constant update during the disassembly process according to the disassembly sequence generated earlier. Given the disassembly sequence and product information, a series of disassembly tasks can be identified, which consists of an action and direction, and linked to the corresponding visual cues, such as arrows or 3D models for AR visualisation and guidance. Augmented work instructions and 3D models are used to virtually train, increasing safety and eliminating the need to schedule equipment downtime, improving maintenance and operations for transportation companies.

Machine Manual	AR Interface
Misinterpretation of procedure due to less visualisation	Proper Maintenance and Operation process and machine data is shown to the user leaving no space for misinterpretation
Difficult way of identifying new and complicated machine data	The data can be made easy for understanding for any machine irrelevant of its complicity or newness
Cannot be updated	Can be updated as needed for renewal or upgradation
Requires a senior operative to explain the manual to a cadet	The ease of understanding can help the cadet to understand all the required info without any external help
Complicated machineries are hard to operate or maintain using the manual only	Most part of the data is easy to interpret but in case there is any doubt the user can get more detailed explanation or view through the AR software itself
Understanding the process through words and diagrams are very traditional and not innovative	A virtual elaboration is very innovative and interesting and instigates curiosity and deep learning
Time required is more for the understanding the whole manual	Proper Time Management due to ease of understanding
Each machinery requires a separate manual	All data, visuals, procedures, projections can be accessed from a single AR smart device
To find a about a part of the machine the user has to go through most of the manual	Any section that is required can be easily selected out from the AR depiction

Figure.3. Machine manual vs AR Interface

2.5 IMPROVEMENTS

2.6 METHODOLOGY



Problem Statement:

From the study carried out we found that due to emerging technologies, requirement of less operating personals and reliability on traditional manuals the training process onboard has become rushed and not taken into serious consideration, hence there is a huge number of accidents that follows with it. It has become a situation where new means for training should be sought out. AR is a wonderful solution to it.

Designing a 3D model:

For the trail we chose the design of a Gate Valve. It is a common type of valve found aboard on all types of ships. It is used to connect many machineries aboard. Gate valves are made of several parts: Body, Wedge, Cover, Seats, Stem, Gland Flange, Stuffing Box, Hand wheel, Gear box & Square drive nut.

The design was made in AutoCAD Fusion 360.

Selecting AR Platform:

One of the best applications we found free to use here is UniteAR, which can be used in many smart devices. UniteAR is a cutting-edge no-code AR SaaS platform that enables users to effortlessly build WebAR plugins,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UniteAR's features include:

- Image detection and tracking: Create image-based AR experience by uploading your 2D images to the editor, and upload any types of digital contents like 3D models, Video, 360-degree contents, GIF, Call to action buttons, and Audio.
- Image detection with QR: Allows the user to create AR experiences without regarding the quality of the image, an auto-generated QR code will be placed on the tracker image and then you can follow the process similar to image detection.
- WebAR with image detection: It allows the user to experience augmented reality with just a weblink. You can either load the link directly into your mobile web browser or scan the QR code to load the web link, and then the WebAR based scanner will be opened and scan the images which you have already created with the image-based editor.
- Ground plane tracking WebAR: It enables detection of the surface or ground plane such as floor, table top and similar surfaces to place the digital contents. (Supports only 3D model and Video, does not support multiple contents)

Figure.4. Gate Valve
Source: Great Eastern Institute of Maritime Studies, Lonavala

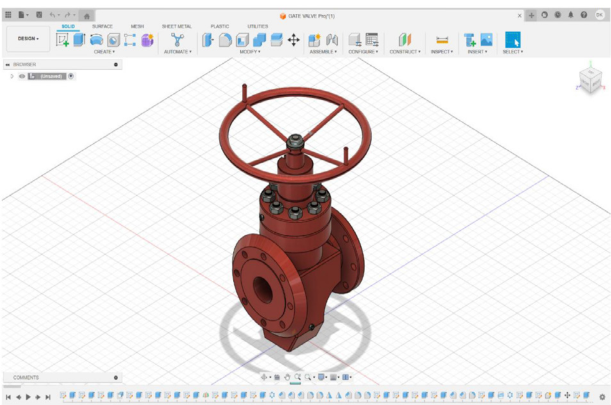

Figure.5. Design of Gate Valve

Implementing the model in the AR platform:

After the model of the Gate valve is designed, it is uploaded into UniteAR Along with its information, maintenance and operation sequence. Then the correct project out sequence is programmed into the AR software. After all the information is set, we give an accurate target image for the app to project out the information.

2.7 DEMONSTRATION

2.8 IMPLEMENTING AR ONBOARD

The machine manufacturer provides an AR software and if required an AR Smart Device to the shipping company which is delivered to the crew. In case the AR Smart Device is not provided by the manufacturer, the operator can install the AR software into their smartphone and use it as an input/output AR device. All the data of maintenance and operation of the machinery is programmed into the AR software by the manufacturer. As of such the crew can easily open the AR software in the AR device and afterwards scan the machinery or its component and get the visual data required through the AR projection inside

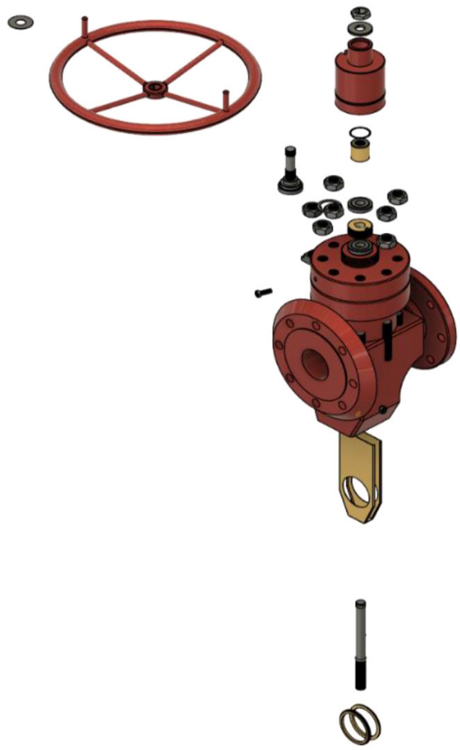

Figure.6. Disassembled view of Gate Valve

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the device with ease. Whether the seafarer needs a part of the machine knowledge or it as a whole, both can be provided as needed in the AR space.

The operator can further zoom into the details if any doubt arises in the AR space and understand what he/she requires. If at all the operator feels any change should be done to the AR visuals they can request to the manufacturer as required and the manufacturer can get it updated or fixed through a program update with ease.

3. CONCLUSION

An AR-guided operation & maintenance framework has been described in this article. The main contribution of proposed framework is automatic content generation that translates a maintenance sequence into AR based instructions for the human operators. An efficient and error-free maintenance process will greatly benefit both the marine industry and the operators considering that it is an efficient tool in an operation cycle. Overall, the proposed framework is useful for this age of marine development in the field of operation & maintenance.

FUTURE SCOPE:

The next stage of marine machine training can be achieved through Mixed Reality (MR). Which is like an advance phase of AR which involves the same working but with a good interactive interface.

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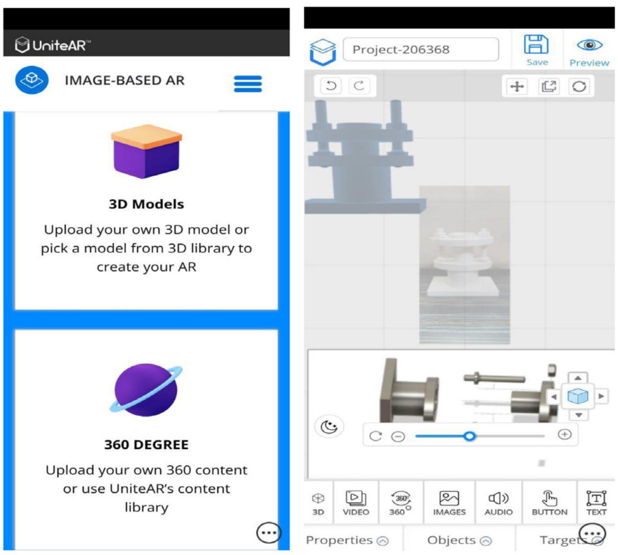

Figure.7. Implementing the model in the Unite AR

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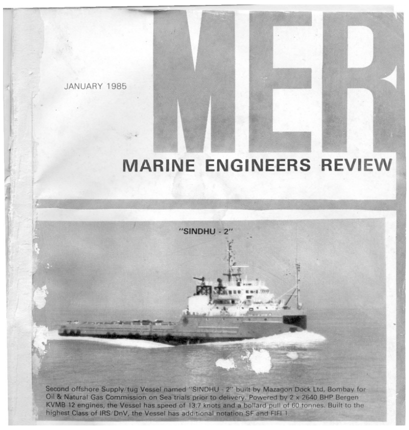
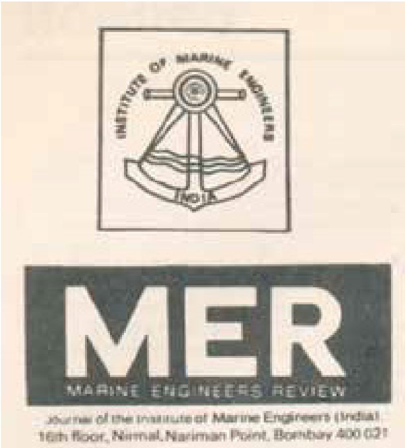
Going Astern into MER Archives…





The Editorial talks on paints and coatings, in particular the anti-fouling (AF) paints. The AF paints did come and while displacing the traditional coatings brought the advantages of having hulls with only nominal hull growth, extending time between dockings, reduction in drydock periods and importantly a reduction in fuel reduction. The debate on harm caused by copper based self-polishing copolymers (SPC) followed and then came the formulations without the organotin compounds. Present day solutions are looking better and kinder to the sea organisms while assuring the merits of efficiencies and fuel savings. The Editorial also mentions the MV Chidambaram fire.

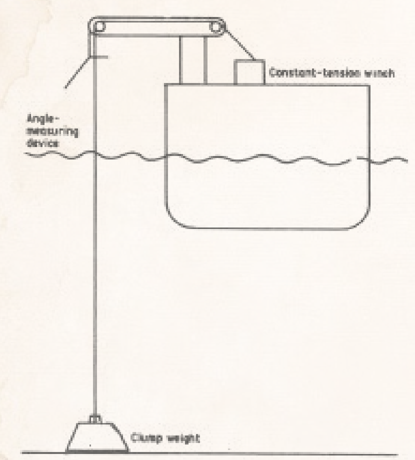
The first two articles discuss Dynamic Positioning (DP) arrangements and operations. The next one talks about bunker purchases which happens to form 40-60% of the operational costs.

(In present times there are statistic which indicate this share has come down yet forming a considerable share of the OpEx). This will be of interest to Superintendents.

These are followed by an interview with the UK Under Secretary of State discussing shipping matters. However, the insights are somewhat UK centric and the relevance to then and now still needs to be stretched out. IMO, Middle East and tanker trade, the European scenario etc., feature in the talks anyway.

There is one article on inventiveness touching upon steel/iron ships, diesel/steam arrangements, ship/boat yards etc. Then there is an informative article on corrosion protection of pipelines (the insides). One table has been inserted for reference though it looks a bit worn out from the archived issue. The next one continues on coatings for oil and chemical tankers (insides). There is one article on submarine cable maintenance vessel.

Fig 1: Typical taut-wire arrangement.



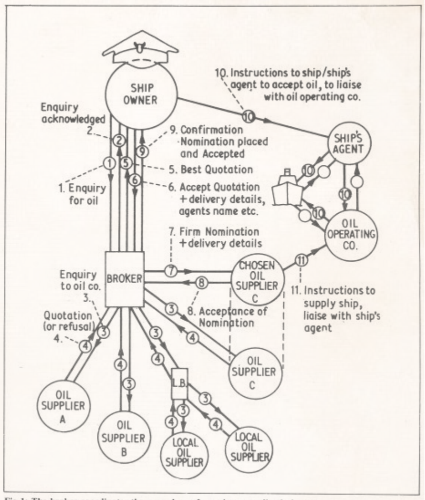


Fig 1: The broker coordinates the procedure of enquiry as outlined above.

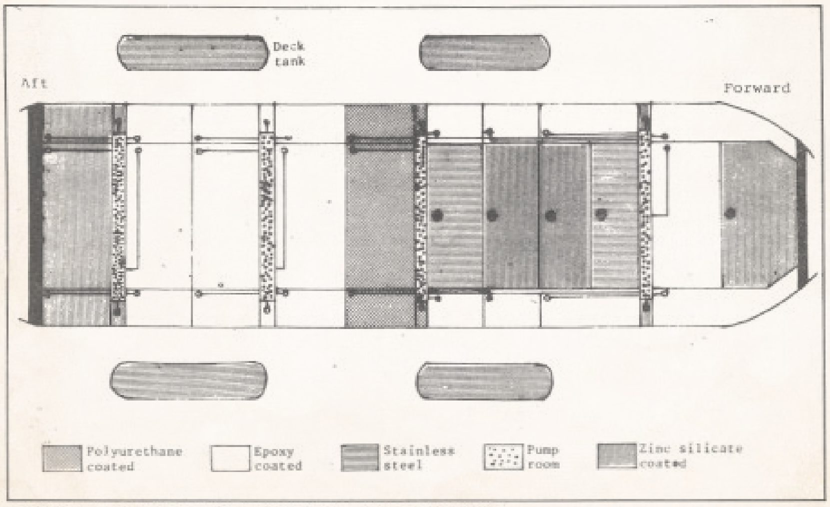


Fig 2: Parcel chemical carrier with different types of coating.

The Transaction featured in the Jan 85 issue (read in February 1983) is the best amongst all the articles. It discusses Reverse Osmosis (RO) as the viable alternative for ships' drinking water requirements. An interesting ad. soliciting enquiries on Sulzer RTA super-long stroke caught our eyes. This should interest readers.

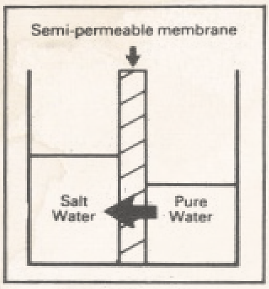


FIG. 1 Osmosis

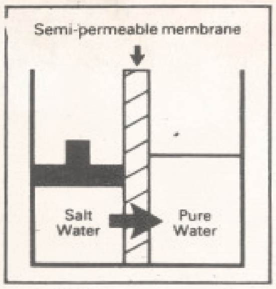


FIG. 2 Reverse osmosis

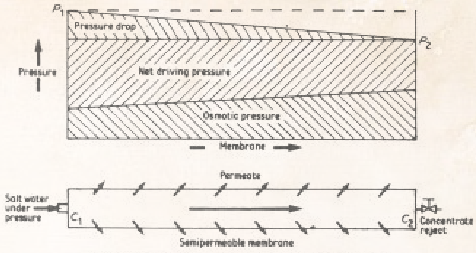


FIG. 3 Pressure changes in a RO system

Table I: Variation of osmotic pressure with salt concentration

SALT CONCENTRATION (mg/l)	OSMOTIC PRESSURE (bar)
1000	0.7
15 000	11.6
35 000	27.8
50 000	40.4

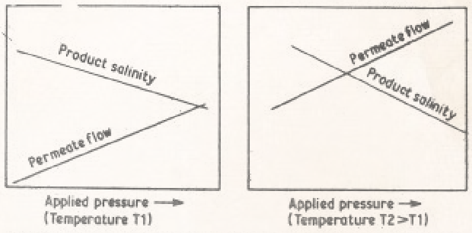


FIG. 4 Effect of change in applied pressure on permeate flow and product salinity at different temperatures

We invite observations, discussion threads from readers, taking cues from these sepia-soaked MER pages. – Hon.Ed.

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