
Advanced Certificate in Subsea Robotics and AI

Subsea Robotics And Ai Applications

ROV – Remotely Operated Vehicle. A tethered platform that is controlled from the surface by a human operator. ROVs are the workhorses of offshore inspection, maintenance and repair. Typical payloads include high-resolution cameras, sonar imagers, manipulator arms and sampling devices. Example: a 12-meter inspection ROV equipped with a dual-frequency side-scan sonar can map a subsea pipeline while a 7-meter work class ROV can lift a valve using a hydraulic gripper. Challenges for ROVs include limited tether length, signal attenuation in deep water, and the need for reliable real-time video streaming.

AUV – Autonomous Underwater Vehicle. Unlike an ROV, an AUV operates without a physical tether and executes a pre-programmed mission autonomously. Modern AUVs integrate sophisticated navigation, sensor suites and AI-driven decision making. Example: an ocean-floor mapping AUV that follows a lawn-mower pattern, collects multibeam bathymetry and adjusts its trajectory based on detected obstacles. Key challenges are energy density, long-duration autonomy, and robust perception in turbid water.

UUV – Unmanned Underwater Vehicle. A generic term that encompasses both ROVs and AUVs, and increasingly includes hybrid platforms that can switch between tethered and untethered operation. Hybrid UUVs can launch from a surface vessel, conduct an autonomous survey, and then reconnect to a tether for data off-load and battery recharge.

Manipulator – A robotic arm mounted on a subsea vehicle, used for grasping, cutting, welding or tool deployment. Manipulators often have six to seven degrees of freedom, force feedback sensors and sealed joints to withstand high pressure. Example: a 4-meter work-class ROV with a 6-axis manipulator can replace a subsea valve using a torque-controlled gripper. Design challenges include hydraulic versus electric actuation, backlash minimisation, and maintaining precision under variable buoyancy.

Thruster – A propulsion unit that generates thrust by accelerating water. Thrusters can be fixed-pitch, variable-pitch, or ducted, and are controlled to achieve desired vehicle motion. In a multi-thruster AUV, vectoring of thrust enables precise station-keeping and agile maneuvering. Example: a 3-thruster configuration (two horizontal, one vertical) provides six-degree-of-freedom control for a small inspection vehicle. Problems arise from cavitation, wear in high-speed rotors, and the need for efficient power conversion.

Buoyancy Control – The ability to adjust a vehicle's overall density to achieve neutral buoyancy or to change depth rapidly. Methods include variable ballast tanks, compressible foam, and synthetic oil-filled bladders. AUVs often use a combination of static buoyancy and active ballast to compensate for payload changes. Challenge: precise modelling of compressibility effects at depths beyond 3000 m.

Acoustic Communication – The primary means of data exchange with submerged assets, using sound waves in the 10 Hz to 100 kHz range. Acoustic modems provide low-bandwidth links (typically 1–10 kbps) over several kilometres. Example: a surface ship sends a mission update to an AUV via an acoustic modem; the AUV acknowledges receipt and continues its survey. Limitations include multipath interference, variable sound speed profiles, and high latency (several seconds).

Sonar – Sound Navigation and Ranging, the cornerstone sensing technology for subsea robotics. Sonar types include single-beam, multibeam, sidescan, imaging and forward-looking. Multibeam sonar produces dense depth maps, while sidescan sonar excels at detecting objects on the seabed. Example: a forward-looking imaging sonar on an AUV can detect a buried pipeline and trigger a local avoidance manoeuvre. Issues: beam pattern distortion, acoustic shadowing, and the need for sophisticated post-processing.

LIDAR – Light Detection and Ranging, increasingly used in shallow water and in air-filled subsea habitats. Water strongly attenuates laser light, limiting range to a few metres in clear water, but LIDAR remains valuable for close-range inspection of structures such as subsea manifolds. Integration with AI enables automatic crack detection on metal surfaces. Challenge: compensating for scattering and refraction at the water-air interface.

SLAM – Simultaneous Localization and Mapping. A computational framework that builds a map of the environment while estimating the vehicle's pose within that map. In underwater contexts, SLAM relies heavily on sonar and inertial data because GPS is unavailable. Example: an AUV performing SLAM with a 2-D imaging sonar creates a 3-D point cloud of a wreck site while maintaining its trajectory estimate. Difficulties include drift accumulation, loop-closure detection in feature-poor terrains, and real-time processing constraints.

AI – Artificial Intelligence, the umbrella term for algorithms that enable machines to perceive, reason and act. In subsea robotics AI is applied to perception (e.g., object detection), decision making (e.g., mission replanning), and control (e.g., adaptive thruster allocation). AI techniques often require large datasets; however, labelled underwater data are scarce, prompting the use of synthetic data generation and transfer learning.

Machine Learning – A subset of AI that builds statistical models from data. Supervised learning can classify sonar images into "pipeline", "rock" or "debris". Unsupervised learning can cluster sensor readings to detect anomalies. Example: a convolutional neural network trained on thousands of sidescan patches identifies potential corrosion spots on a subsea pipeline. Challenges: overfitting to limited datasets, and ensuring models remain robust to changing acoustic conditions.

Deep Learning – Multi-layer neural networks that automatically learn hierarchical features. Deep learning has revolutionised computer vision, and its adoption underwater is growing. An AUV equipped with a deep-learning model can recognise marine fauna in real time, enabling biodiversity surveys without human

supervision. The main obstacle is the high computational load, which must be balanced against limited onboard power.

Computer Vision – The discipline that enables machines to interpret images and video. Underwater computer vision must contend with low contrast, colour distortion and backscatter. Techniques such as histogram equalisation, de-hazing and domain adaptation improve performance. Example: a vision system on a manipulator uses edge detection to locate a bolt head before applying a torque wrench. Real-world deployment demands robust calibration and fault detection.

Sensor Fusion – The process of combining data from multiple sensors to produce a more accurate estimate of the vehicle state. Typical fusion pipelines integrate inertial measurement units (IMU), depth sensors, Doppler velocity logs (DVL), acoustic positioning and sonar. Kalman filters, particle filters and factor graphs are common fusion algorithms. Example: an AUV fuses DVL velocity with IMU acceleration to correct drift during long-duration surveys. Challenges include time-synchronisation, handling out-of-order data packets, and coping with sensor failures.

Digital Twin – A high-fidelity virtual replica of a physical subsea system that runs in parallel with the real asset. Digital twins can predict structural health, simulate mission scenarios and test AI algorithms before deployment. Example: a digital twin of a subsea valve incorporates finite-element stress analysis and AI-based wear prediction, allowing operators to schedule maintenance proactively. Maintaining twin accuracy requires continuous data ingestion and model updating.

Autonomy Levels – A taxonomy that describes the degree of decision-making capability of a vehicle. Level 0 is manual control; Level 1 adds assistance (e.g., depth hold); Level 2 introduces partial autonomy (e.g., waypoint navigation); Level 3 provides full mission execution with dynamic replanning; Level 4 enables collaborative behaviour with other vehicles. Understanding autonomy levels helps define certification requirements and risk assessments.

Mission Planning – The process of defining tasks, waypoints, survey patterns and resource allocations for a subsea operation. Planning tools generate trajectories that respect vehicle dynamics, battery constraints and environmental regulations. Example: a mission planner creates a “lawn-mower” pattern for an AUV to cover a 2 km² area, while inserting “recharge” waypoints at a surface buoy. Planning must be adaptable; unexpected obstacles or weather changes often require on-the-fly adjustments.

Path Planning – The algorithmic determination of a collision-free route between two points. Common approaches include A* search, D* Lite, Rapidly-exploring Random Trees (RRT) and their variants. In underwater settings the cost function typically incorporates energy consumption, safety margins and acoustic shadow zones. Example: an AUV uses an RRT* planner to navigate through a dense kelp forest, preferring paths with stronger acoustic returns to aid localisation. Path planning is computationally intensive; efficient heuristics are essential for onboard execution.

Obstacle Avoidance – Real-time detection and evasion of hazards. Sensors such as forward-looking sonar,

imaging sonar and short-range laser scanners provide the raw data. AI-based classifiers can distinguish between static structures and moving marine life, allowing the vehicle to decide whether to stop, slow down or execute a detour. Example: an inspection ROV detects a fishing net using a high-frequency sonar and automatically halts to avoid entanglement. The main difficulty is achieving low latency while maintaining high detection reliability.

Fault Tolerance – The capacity of a system to continue operation despite component failures. Redundant hardware (e.g., dual thrusters, multiple processors) and software strategies (e.g., graceful degradation, watchdog timers) contribute to fault tolerance. Example: a dual-processor architecture runs the primary navigation stack on one CPU and a backup on the second; if the primary crashes, the backup takes over without mission interruption. Designing fault-tolerant systems involves trade-offs between weight, cost and complexity.

Reliability – A statistical measure of the probability that a system performs its intended function for a specified period under stated conditions. Reliability engineering in subsea robotics uses failure-mode and effects analysis (FMEA), accelerated life testing and Bayesian reliability models. Example: a pressure-rated connector rated for 10000 cycles is selected based on a reliability target of 0.99 over a 2-year service life. Accurate reliability predictions are crucial for certification and insurance.

Redundancy – The inclusion of extra components or pathways to enhance reliability. Redundancy can be active (both units operate simultaneously) or passive (a spare is idle until needed). Example: a thruster cluster with four units provides two-fold redundancy; the vehicle can maintain six-DOF control even if one thruster fails. Redundancy adds mass and power draw, so optimisation is required.

Power Management – The suite of techniques that control energy generation, storage and consumption. Subsea vehicles typically use lithium-ion batteries, fuel cells or hybrid systems. Power budgets are allocated to propulsion, computing, sensors and communication. Example: an AUV reduces thruster thrust during idle periods to extend mission duration by 20%. Power management must also account for temperature effects on battery performance at depth.

Energy Harvesting – The extraction of ambient energy to supplement onboard power. Options include ocean-current turbines, thermoelectric generators that exploit temperature gradients, and wave energy converters. Example: a tethered ROV equipped with a small current turbine can recharge its batteries while hovering near a strong seabed flow. Harvesting systems add mechanical complexity and require careful integration with the vehicle's control architecture.

Tether – A physical link between a subsea vehicle and a surface platform, often containing power conductors, fiber-optic data lines and strength members. Tethers enable high-bandwidth communication, real-time control and unlimited power, but also impose drag and limit operational radius. Example: a 3 km fiber-optic tether allows an ROV to stream 1080p video with low latency for precise manipulation tasks. Tether management systems must prevent entanglement and accommodate vessel motion.

Fiber Optic – Light-based data transmission that provides high bandwidth and immunity to electromagnetic interference. In subsea applications, ruggedized fiber is used for both telemetry and high-resolution sonar data. Example: a fiber-optic cable within an ROV's tether carries 1 Gbps of raw sonar imagery to the surface workstation for live processing. Challenges include connector sealing, bend-radius limits and long-term reliability under pressure.

Latency – The time delay between sending a command and observing the response. In tethered operations latency is primarily due to signal propagation and processing, typically on the order of milliseconds. In acoustic communication latency can be several seconds because sound travels at roughly 1500 m/s. Example: a teleoperation system compensates for a 2-second acoustic latency by predicting vehicle motion and smoothing operator inputs. Managing latency is essential for safe tele-manipulation.

Bandwidth – The data rate that a communication channel can sustain. Acoustic links often have low bandwidth (Data Compression – Techniques that reduce the size of sensor data before transmission. Lossless methods preserve exact information (e.g., PNG for images), while lossy methods sacrifice some detail for higher compression ratios (e.g., JPEG). In underwater contexts, specialized sonar compression algorithms exploit the redundancy in echo returns. Example: a forward-looking imaging sonar stream is compressed using a wavelet-based scheme, achieving a 4:1 reduction with negligible impact on obstacle detection. Compression must be computationally lightweight to avoid draining limited processing resources.

Cyber Security – Measures that protect subsea robotic systems from unauthorized access, data tampering and malicious interference. Threat vectors include compromised acoustic modems, spoofed GPS signals (when surfacing), and infiltration of on-board software. Example: a secure communication protocol encrypts all telemetry using AES-256, and authenticates commands with digital signatures. Maintaining security on low-power devices requires careful algorithm selection and regular firmware updates.

Human-Machine Interface – The suite of tools that allow operators to monitor and control subsea robots. Interfaces range from simple joystick controllers to immersive virtual-reality (VR) stations that display 3-D reconstructions of the underwater scene. Example: a VR cockpit renders a point-cloud from a multibeam sonar, enabling the operator to “walk” around a subsea structure while issuing commands via a haptic device. Designing intuitive HMIs reduces operator fatigue and improves mission success rates.

Teleoperation – The remote control of a vehicle by a human operator, typically over a tether or acoustic link. Teleoperation is essential for tasks requiring fine dexterity, such as valve turning or cable splicing. Example: an ROV pilot uses a dual-joystick controller to position the manipulator arm while receiving live video feedback. Latency, limited bandwidth and operator workload are primary concerns.

Haptic Feedback – Tactile sensations delivered to the operator to convey forces experienced by the robot's end-effector. Haptic devices can simulate resistance when the manipulator contacts a surface, improving precision in delicate operations. Example: a surgeon-style haptic controller alerts the operator when a

gripper contacts a fragile subsea fiber-optic cable, prompting a gentle release. Implementing haptic feedback underwater requires low-latency data paths and accurate force sensing.

Swarm Robotics – The coordinated control of multiple autonomous agents that collectively accomplish a task. In subsea contexts, swarms can perform large-area surveys, cooperative inspection or distributed sampling. Swarm algorithms rely on local communication (acoustic broadcast, optical modems) and decentralized decision making. Example: a swarm of ten small AUVs distributes itself across a 5 km² methane-seeps field, each mapping a sub-area and sharing results to build a unified plume model. Swarm challenges include collision avoidance, consensus under intermittent connectivity, and energy balancing.

Collaborative Robotics – Robots that work alongside humans or other robots to achieve a common goal. In subsea operations, collaborative robots may assist divers, support ROVs or cooperate with surface vessels. Example: an autonomous surface vessel positions a launch platform for an AUV, while the AUV provides live bathymetric data that the vessel uses to adjust its own navigation. Effective collaboration requires standardized communication interfaces and shared situational awareness.

Inertial Measurement Unit – A sensor package that measures linear acceleration and angular velocity, typically using accelerometers and gyroscopes. IMUs provide high-rate motion data for dead-reckoning when external positioning is unavailable. Example: an AUV fuses IMU data with DVL velocity to maintain an accurate trajectory over a 12-hour survey. IMU drift and bias must be regularly calibrated, especially after temperature changes at depth.

Doppler Velocity Log – An acoustic instrument that measures the vehicle's velocity relative to the seabed by analysing the Doppler shift of emitted sound pulses. DVLs are critical for precise navigation in deep water where GPS is inaccessible. Example: a work-class ROV uses a 300 kHz DVL to maintain a constant hover distance of 2 m above a pipeline while a manipulator performs weld repairs. DVL performance degrades over soft sediment or in high-turbulence zones, necessitating fallback strategies.

Acoustic Positioning System – A network of transponders placed on the seafloor or on a surface vessel that triangulates the position of a subsea vehicle using acoustic ranging. Systems such as Ultra-Short Baseline (USBL) and Long-Baseline (LBL) provide positioning accuracies from centimeters to meters. Example: an AUV equipped with a USBL modem receives ranging data from a surface ship, enabling it to correct its SLAM map in real time. Acoustic positioning is susceptible to multipath interference and requires careful calibration of transponder geometry.

Hydrophone – An underwater microphone that captures acoustic signals. Hydrophones are used for passive listening (e.g., marine mammal monitoring), active sonar reception, and as part of communication links. Example: a hydrophone array on a seabed observatory records low-frequency whale calls, which are later analysed by AI classifiers to estimate population density. Hydrophone placement influences signal-to-noise ratio and directional sensitivity.

Pressure Housing – The sealed enclosure that protects electronic components from the high hydrostatic

pressure encountered at depth. Materials include titanium, aluminum, and high-strength composites, often with O-ring seals. Example: a 6000 m rated pressure housing contains the main processing unit of a deep-sea AUV, ensuring operation at pressures exceeding 600 bar. Design must address thermal dissipation, corrosion resistance and accessibility for maintenance.

Corrosion Monitoring – The use of sensors and AI analytics to detect and predict material degradation in subsea structures. Techniques include electrical resistance probes, ultrasonic thickness gauges, and electrochemical sensors. Example: an AUV equipped with an ultrasonic transducer scans a subsea pipeline, and a deep-learning model classifies regions with thinning indicative of corrosion. Early detection enables targeted repair, reducing downtime and cost.

Marine Snow – A colloidal mixture of organic particles that settles through the water column, often interfering with optical sensors. AI-based image enhancement algorithms can mitigate the visual obscuration caused by marine snow, improving the reliability of computer-vision tasks. Example: a machine-learning model trained on synthetic marine-snow images restores contrast in photographs taken by a manipulator's camera during a deep-sea inspection.

Environmental Sensing – The suite of instruments that measure physical and chemical properties of the water column, such as temperature, salinity, dissolved oxygen, pH and methane concentration. These sensors support scientific missions and inform vehicle behaviour (e.g., adjusting buoyancy in response to temperature gradients). Example: an AUV samples water at 10m intervals, feeding the data into an AI model that predicts the location of a methane plume for targeted sampling. Sensor drift and calibration are ongoing challenges.

Mission Re-planning – The capability of a vehicle to modify its planned trajectory in response to new information or unexpected events. Re-planning algorithms must be computationally efficient and respect mission constraints (e.g., remaining energy). Example: an AUV encounters a dense kelp forest not present in its original map; it invokes a re-planning routine that generates a new avoidance path while preserving coverage goals. Robust re-planning demands reliable perception and fast decision loops.

Adaptive Control – Control strategies that adjust parameters in real time to cope with changing dynamics, such as varying payload, water currents or actuator degradation. Model-reference adaptive control and reinforcement-learning-based controllers are emerging in subsea applications. Example: a thruster allocation controller learns to compensate for a partially failed thruster by redistributing thrust among the remaining units, maintaining stable hover. Ensuring stability during adaptation is a primary safety concern.

Reinforcement Learning – A branch of AI where an agent learns optimal actions through trial-and-error interactions with its environment, receiving rewards for desirable outcomes. In subsea robotics, reinforcement learning can teach an AUV to optimise energy usage while following a complex survey pattern. Example: a simulated training environment allows an AUV to experiment with different speed-depth profiles; the learned policy is then transferred to the real vehicle using domain-randomisation

techniques. Real-world deployment must address safety, sample efficiency and the risk of unexpected behaviours.

Transfer Learning – The practice of adapting a model trained on one dataset or domain to another, reducing the amount of new data required. For underwater applications, models pre-trained on terrestrial image datasets can be fine-tuned with a limited set of sonar images to recognise subsea objects. Example: a convolutional network trained on large-scale aerial imagery is fine-tuned on 500 labelled sidescan patches to detect pipelines. Transfer learning accelerates development but may introduce bias if source and target domains differ significantly.

Domain Randomisation – A technique used to bridge the reality gap by exposing AI models to a wide variety of simulated conditions during training. Parameters such as sound speed, seabed texture, and sensor noise are varied randomly. Example: an AUV's obstacle-avoidance network is trained in a physics-based simulator where water turbidity, acoustic interference and vehicle speed are randomly altered; the resulting policy performs robustly in real-world deployments. The approach relies on sufficiently diverse simulations to cover real-world variability.

Simultaneous Localization and Mapping – (SLAM) Reiterated here to emphasise its importance in subsea contexts. In addition to sonar-based SLAM, hybrid approaches combine inertial, acoustic and visual data. Example: a hybrid SLAM pipeline fuses DVL velocity, IMU acceleration and forward-looking imaging sonar to generate a 3-D map of a wreck site while maintaining pose accuracy within 0.5 m. Maintaining loop closure in feature-sparse environments remains a research focus.

Fault Detection and Isolation – (FDI) Systems that monitor sensor and actuator health, detect anomalies, and isolate the faulty component to prevent cascading failures. Model-based FDI uses system equations, while data-driven FDI employs machine-learning classifiers. Example: an AUV's FDI module flags an abnormal current draw in one thruster, isolates it, and reconfigures the control allocation matrix to continue the mission with reduced thrust. Timely fault detection is essential for safe operation in inaccessible underwater settings.

Energy Budgeting – The practice of allocating available energy to various subsystems throughout a mission timeline. Accurate budgeting requires models of propulsion power, sensor consumption, processing load, and communication overhead. Example: a mission planner reserves 30 % of battery capacity for propulsion, 20 % for computing, and the remaining 50 % for contingency, ensuring the AUV can return to a charging station with a safety margin. Unexpected currents or higher-than-expected processing demand can upset the budget, requiring dynamic adjustments.

Modular Architecture – A design philosophy where hardware and software components are interchangeable, facilitating upgrades, repairs and mission-specific customisation. Standardised interfaces (e.g., Ethernet, CAN bus) and plug-and-play modules enable rapid integration of new sensors or payloads. Example: a modular AUV chassis allows operators to swap a multibeam sonar module for a chemical sensor

pack within an hour, adapting the vehicle for a different survey type. Modularity must be balanced against added connectors that can be failure points.

Standardised Communication Protocols – Protocols such as ROS (Robot Operating System) messages, DDS (Data Distribution Service) and MAVLink provide a common language for inter-module data exchange. In subsea robotics, adaptations are made to handle high latency and low bandwidth. Example: a lightweight DDS profile is used for acoustic telemetry, compressing messages to fit within a 5 kbps link while preserving essential state information. Protocol selection influences interoperability and future scalability.

Regulatory Compliance – The set of standards and certifications that subsea robotic systems must meet, covering safety, environmental impact and operational procedures. Relevant bodies include DNV GL, ABS and IEC. Example: a work-class ROV must comply with IEC 60945 for underwater equipment, which mandates pressure testing, electromagnetic compatibility and documentation of risk assessments. Compliance adds documentation overhead but is essential for commercial deployment.

Lifecycle Management – The systematic approach to handling a robot from design through operation, maintenance and eventual decommissioning. Lifecycle considerations include spare-part logistics, software updates, and end-of-life disposal. Example: a fleet of inspection AUVs follows a maintenance schedule where batteries are replaced every 500 cycles, firmware is updated quarterly, and de-commissioned units are recycled according to marine-environmental guidelines. Effective lifecycle management reduces downtime and total cost of ownership.

Data Integrity – Ensuring that collected data remain accurate, complete and uncorrupted from acquisition through storage and transmission. Techniques include checksums, error-correcting codes and redundant storage. Example: an AUV writes sonar frames to dual SSDs with RAID-1 mirroring; each frame includes a CRC checksum that is verified on surface reception. Data integrity is critical for scientific analyses and for training AI models.

Real-Time Operating System – (RTOS) Software that guarantees deterministic task execution, essential for control loops and safety-critical functions. Popular RTOS choices for subsea platforms include VxWorks, QNX and FreeRTOS. Example: a VxWorks-based controller ensures that thruster commands are updated every 10 ms, providing stable flight dynamics even under variable load conditions. Selecting an RTOS involves trade-offs between performance, licensing cost and community support.

Edge Computing – Processing data locally on the vehicle rather than transmitting it to a remote server. Edge computing reduces bandwidth usage, lowers latency, and enables immediate decision making. Example: an AUV runs a lightweight object-detection network on its onboard GPU to identify and log instances of marine debris, transmitting only the detection metadata via acoustic link. Edge devices must be energy-efficient and capable of handling the harsh temperature and pressure environment.

Latency Compensation – Strategies to mitigate the effects of delayed communication, especially in teleoperation. Predictive display, command smoothing and model-based extrapolation are common

techniques. Example: a tele-operated manipulator uses a Kalman filter to predict the vehicle's pose during the 1.5-second round-trip acoustic delay, allowing the operator to see a smoothed preview of arm motion. Effective compensation improves operator confidence and reduces the risk of collisions.

Multibeam Echo-Sounder – A sonar system that emits multiple beams to cover a swath of the seabed, generating high-resolution bathymetric maps. Multibeam data are often processed into digital terrain models (DTM) for navigation and inspection. Example: a survey vessel deploys a multibeam echo-sounder to produce a 0.5-meter resolution DTM of a subsea cable route, which is later used by an AUV for precise trenching operations. Beam-forming accuracy depends on precise motion compensation and sound-speed profiling.

Side-Scan Sonar – A sonar that sweeps the seafloor laterally, producing images that highlight shadows and textures. Side-scan is valuable for detecting objects, wrecks and seabed anomalies. Example: an ROV towed side-scan sonar identifies a protruding valve cover, prompting a dive for visual inspection. Side-scan data require careful post-processing to correct for platform motion and to georeference the imagery.

Imaging Sonar – High-frequency sonar that produces detailed acoustic images, often used for navigation in turbid water where optical cameras are ineffective. Imaging sonar can resolve objects as small as a few centimeters at a range of several metres. Example: an AUV uses an imaging sonar to navigate through a dense kelp forest, detecting clear passages and avoiding entanglement. AI models trained on imaging-sonar data can classify marine life, rocks and artificial structures.

Acoustic Modem – A device that encodes digital data onto acoustic waves for underwater transmission. Modems support both point-to-point and broadcast communication, with configurable data rates and error-correction schemes. Example: an AUV equipped with an acoustic modem exchanges mission updates with a surface vessel every 10 minutes, ensuring that any new waypoints are incorporated into its navigation plan. Modem performance is influenced by carrier frequency, transmission power and ambient noise.

Underwater Acoustic Positioning – The broader discipline that includes USBL, LBL, and Short-Baseline (SBL) techniques for determining vehicle position using acoustic ranging. Positioning accuracy is essential for tasks such as precision pipe laying or subsea construction. Example: a construction ROV uses an LBL network of four seabed transponders to achieve centimeter-level positioning while installing a manifold. Calibration of transponder locations and sound-speed profiles is critical for achieving high accuracy.

Bathymetric Mapping – The creation of detailed depth maps of the seafloor. Bathymetry informs navigation, hazard avoidance and scientific research. AUVs equipped with multibeam or interferometric sonar can autonomously generate bathymetric surveys over large areas. Example: a coastal monitoring program deploys a fleet of AUVs to map seabed changes after a storm, feeding the data into coastal-erosion models. Data consistency across multiple passes requires careful overlap planning and sensor calibration.

Marine Habitat Monitoring – The use of subsea robots to observe and record the health of underwater

ecosystems. Sensors may include cameras, acoustic recorders, and environmental probes. AI can automate species identification and quantify habitat coverage. Example: a long-duration AUV patrols a coral reef, capturing video that is processed by a deep-learning classifier to estimate coral bleaching extent. Challenges include limited power for long deployments and the need for low-impact sensing to avoid disturbing wildlife.

Payload Integration – The process of attaching and interfacing mission-specific equipment to a vehicle. Payloads must be mechanically secured, electrically connected and software-wise compatible with the host platform. Example: a chemical analysis payload consisting of a mass-spectrometer is mounted on an AUV's foredeck, with data routed through the vehicle's Ethernet bus to the onboard processor for real-time analysis. Integration must respect weight, centre-of-gravity and power constraints.

Hydraulic Actuation – The use of pressurised fluid to drive manipulator joints and other moving parts. Hydraulic systems provide high force density, suitable for heavy-duty subsea tasks. Example: a work-class ROV's manipulator uses hydraulic cylinders to apply torque to a subsea flange bolt. Hydraulic lines must be sealed against leaks, and fluid temperature management is required to maintain viscosity at depth.

Electric Actuation – The use of electric motors and gearboxes for motion control. Electric actuation offers finer positioning, lower maintenance and less environmental risk compared to hydraulics. Example: a small inspection AUV uses brushless DC motors for its thrusters, achieving precise speed control and reduced acoustic signature. Electric systems must be protected from corrosion and may require additional thermal management in cold water.

Acoustic Imaging – The generation of visual-like representations from sonar data. Acoustic imaging techniques include beamforming, synthetic aperture sonar (SAS) and frequency-modulated continuous-wave (FMCW) processing. Example: a SAS system mounted on an AUV creates high-resolution seabed mosaics that rival optical imagery, enabling detailed inspection of buried pipelines. Acoustic imaging demands significant computational resources and careful motion compensation.

Synthetic Aperture Sonar – A form of acoustic imaging that synthesises a large aperture by moving the sensor along a trajectory, achieving finer resolution than conventional sonar. SAS is particularly effective for detecting small objects on the seafloor. Example: an AUV performs a straight-line SAS pass over a pipeline route, detecting cracks as narrow as 2 cm. Accurate navigation and platform stability are prerequisites for successful SAS processing.

Machine Vision – The application of computer-vision techniques to underwater imagery. Machine vision pipelines often involve pre-processing (colour correction, de-hazing), feature extraction and classification. Example: a manipulator camera captures an image of a valve face; a machine-vision algorithm detects the bolt pattern and guides the robot to align the wrench correctly. Robustness to lighting variations and turbidity is a key research area.

Acoustic Shadowing – The phenomenon where objects block acoustic waves, creating regions of reduced

signal strength behind them. Shadowing can be exploited to infer object size and shape, but it also complicates sonar interpretation. Example: a side-scan sonar pass over a large pipeline shows a shadow region; analysts use the shadow width to estimate pipe diameter. AI models trained on simulated shadow patterns can improve automatic object detection.

Acoustic Backscatter – The portion of acoustic energy that is reflected back to the sonar receiver. Backscatter intensity provides information about seabed material properties (e.g., sand versus rock). Example: an AUV analyses backscatter strength to classify seafloor type, informing the selection of appropriate anchoring points for a subsea structure. Calibration against known reference sites is required to translate raw backscatter values into meaningful classifications.

Seafloor Classification – The process of assigning labels to different seabed types (e.g., mud, sand, rock, vegetation). Classification can be performed using sonar backscatter, multibeam intensity, and optical imagery. AI classifiers, such as random forests or deep-learning segmentation networks, improve accuracy. Example: a survey