Advanced Certificate in Subsea Robotics and AI

Robotics And Autonomous Systems

Actuator – A device that converts electrical, hydraulic, or pneumatic energy into mechanical motion. Related terms: servo, linear actuator, rotary actuator. Explanation: In subsea robotics, actuators drive manipulator arms, thrusters, and valve operators. Example: A hydraulic cylinder opening a subsea valve. Challenges include corrosion resistance, pressure sealing, and limited power availability at depth.

Artificial Intelligence (AI) – Computational techniques that enable machines to perform tasks that normally require human intelligence. Related terms: machine learning, neural networks, computer vision. Explanation: AI algorithms process sensor data from AUVs to detect obstacles, classify seabed types, and optimise mission planning. Practical application: Deep-learning-based object detection for pipeline inspection. Challenges involve limited onboard compute, real-time constraints, and the need for robust training datasets.

Autonomous Underwater Vehicle (AUV) – A self-propelled, untethered robot that conducts missions without direct human control. Related terms: ROV, UUV, mission planner. Explanation: AUVs perform seabed mapping, environmental monitoring, and infrastructure inspection. Example: A glider sampling temperature and salinity profiles. Challenges include energy management, navigation accuracy, and communication latency.

Autonomous Surface Vehicle (ASV) – An unmanned surface platform capable of autonomous navigation and data collection. Related terms: USV, dynamic positioning, heterogeneous fleet. Explanation: ASVs serve as communication relays for submerged assets and conduct coastal surveys. Example: A solar-powered ASV ferrying high-bandwidth data from AUVs to shore. Challenges involve sea state handling, battery endurance, and regulatory compliance.

Backstepping Control – A recursive nonlinear control design method for systems with hierarchical dynamics. Related terms: Lyapunov stability, adaptive control, trajectory tracking. Explanation: Used to stabilise the motion of subsea manipulators with coupled joints. Practical application: Precise positioning of a sampling tool on a moving vehicle. Challenges include model uncertainties and computational load for real-time implementation.

Battery Management System (BMS) – Electronics that monitor, balance, and protect rechargeable batteries. Related terms: state of charge, thermal management, cell balancing. Explanation: In subsea robots, BMS ensures safe operation under high pressure and low temperature. Example: A lithium-ion BMS preventing over-discharge during long-duration surveys. Challenges involve pressure-tight enclosures and reliable communication with the host controller.

Bayesian Filtering – Probabilistic techniques (e.G., Kalman, Particle filters) for estimating system states from noisy measurements. Related terms: sensor fusion, Monte Carlo methods, recursive estimation. Explanation: Employed for underwater navigation by fusing inertial, acoustic, and visual data. Practical use: Estimating AUV pose during a pipeline inspection. Challenges include non-Gaussian noise, computational cost, and limited sensor bandwidth.

Bio-inspired Robotics – Design approach that mimics biological organisms to achieve efficient locomotion or sensing. Related terms: soft robotics, fish-like propulsion, morphological adaptation. Explanation: Subsea robots use fin-based propulsion to reduce noise and improve maneuverability. Example: A robotic manta ray for coral reef monitoring. Challenges consist of material durability, control complexity, and scaling to deep-sea pressures.

Blind Spot Compensation – Algorithms that mitigate areas not directly observable by sensors. Related terms: sensor occlusion, environmental mapping, predictive modeling. Explanation: For manipulator arms, blind spot compensation predicts tool pose when the camera view is blocked. Application: Maintaining constant force while drilling into the seabed. Challenges include accurate modeling of dynamic occlusions and real-time performance.

Boundary Layer Control – Techniques to manipulate the thin layer of fluid near a surface to reduce drag or improve stability. Related terms: hydrofoil, active flow control, vortex shedding. Explanation: Used on AUV hulls to minimise energy consumption during long missions. Example: Suction slots that delay separation on a glider wing. Challenges involve power budget, reliability of moving parts, and fouling at depth.

Calibration – Process of adjusting sensor or actuator parameters to align measurements with known standards. Related terms: bias correction, gain tuning, in-situ calibration. Explanation: Essential for accurate sonar, pressure, and IMU readings. Practical method: Rotating a magnetometer in a known field to estimate scale factors. Challenges include limited access to reference equipment underwater and temperature-dependent drift.

CAN Bus (Controller Area Network) – A robust serial communication protocol for real-time control of distributed nodes. Related terms: ECU, message arbitration, fault tolerance. Explanation: Provides deterministic data exchange between thrusters, sensors, and controllers on a subsea robot. Example: Sending thruster RPM commands while receiving fault flags. Challenges are ensuring cable integrity under pressure and handling electromagnetic interference from power electronics.

Centroidal Dynamics – Representation of a robot’s motion using the centre of mass and angular momentum. Related terms: whole-body control, momentum mapping, dynamic balance. Explanation: Enables coordinated movement of AUVs with articulated manipulators, keeping the vehicle stable while the arm exerts forces. Practical use: A manipulator extracting a sample without disturbing vehicle attitude. Challenges include solving large-scale optimization in limited compute time.

Closed-Loop Control – Control strategy where sensor feedback is continuously used to adjust actuator commands. Related terms: feedback, PID controller, error correction. Explanation: Maintains depth and heading of an AUV despite currents. Example: A depth sensor feeding back to a thruster controller. Challenges are sensor latency, noise, and actuator saturation.

Computational Fluid Dynamics (CFD) – Numerical simulation of fluid flow around bodies. Related terms: Navier-Stokes equations, mesh generation, turbulence modeling. Explanation: Used to optimise hull shapes and propeller designs for subsea robots. Example: Simulating vortex shedding on a thruster duct to reduce cavitation. Challenges include high computational cost and validation against experimental data.

Cooperative Multi-Robot Systems – Groups of robots that share tasks, data, and resources to achieve collective goals. Related terms: swarm robotics, task allocation, communication protocols. Explanation: An AUV fleet can map a large area faster by dividing the survey grid. Practical application: Coordinated inspection of a subsea pipeline where one vehicle provides lighting while another records video. Challenges are maintaining reliable underwater communication, synchronising clocks, and handling emergent failures.

Control Allocation – Distribution of desired force/torque commands among multiple actuators. Related terms: over-actuated system, pseudo-inverse, actuator saturation. Explanation: Determines how thrusters, control surfaces, and reaction wheels share the workload to achieve a commanded motion. Example: Allocating thrust among four azimuth thrusters to execute a yaw maneuver while maintaining depth. Challenges include solving under-determined equations quickly and respecting actuator limits.

Corrosion-Resistant Coating – Protective layer applied to metal surfaces to prevent degradation in seawater. Related terms: galvanic protection, epoxy paint, cathodic protection. Explanation: Extends service life of robot frames, manipulators, and connectors. Example: A polyurethane coating on a manipulator arm joint. Challenges are ensuring coating adhesion under high pressure and abrasion from debris.

Dead Reckoning – Estimating current position by integrating measured velocity over time from a known start point. Related terms: inertial navigation, error drift, trajectory propagation. Explanation: Provides short-term navigation when GPS or acoustic fixes are unavailable. Practical use: An AUV traversing a canyon where acoustic beacons cannot reach. Challenges are cumulative error, sensor bias, and need for periodic correction.

Depth Sensor – Device that measures hydrostatic pressure to infer water depth. Related terms: pressure transducer, altimeter, temperature compensation. Explanation: Critical for maintaining safe operating depth and for georeferencing survey data. Example: A quartz-based pressure sensor used on a 3000 m-rated AUV. Challenges include pressure-induced drift, temperature effects, and calibration under varying salinity.

Distributed Acoustic Sensing (DAS) – Technique that uses fiber-optic cables as arrays of acoustic sensors. Related terms: Rayleigh scattering, strain measurement, real-time monitoring. Explanation: Enables long-range detection of leaks, marine life, or vehicle movement along subsea pipelines. Practical application: An AUV deploying a fiber line to monitor seabed vibrations. Challenges are interpreting complex signal patterns and ensuring fiber integrity under tension.

Dynamic Positioning (DP) – Automatic control system that maintains a vessel’s position and heading using thrusters. Related terms: reference frames, environmental compensation, redundancy. Explanation: DP stations serve as launch platforms for ROVs and AUVs, keeping the ship steady despite currents. Example: A 3-thruster DP system supporting a heavy-lift ROV. Challenges include thruster failure handling, power consumption, and integration with motion reference units.

Edge Computing – Processing data locally on the robot rather than sending it to a remote server. Related terms: on-board AI, latency reduction, resource constraints. Explanation: Allows real-time object detection and decision making on a depth-rated AUV. Practical use: Classifying seabed images on-board to trigger adaptive sampling. Challenges are limited CPU/GPU resources, power budget, and thermal management.

Electro-Hydraulic Actuator (EHA) – Actuator that uses electrical power to drive a hydraulic pump, delivering high force output. Related terms: servo valve, hydraulic circuit, force density. Explanation: Provides compact, high-torque motion for subsea manipulators. Example: An EHA operating a clamping tool on a 2000 m AUV. Challenges include sealing hydraulic fluid, controlling leakage, and dealing with pressure-induced stiffness.

End-Effector – The tool attached to the distal end of a manipulator, performing interaction with the environment. Related terms: gripper, sampler, cutting tool. Explanation: In subsea tasks, end-effectors may be suction samplers, coring drills, or acoustic emitters. Example: A rotary corer extracting sediment cores for geological analysis. Challenges involve tool exchange mechanisms, pressure sealing, and force control under variable loads.

Environmental Sensing Suite – Integrated package of sensors that monitor physical, chemical, and biological parameters. Related terms: CTD, turbidity meter, chlorophyll fluorometer. Explanation: Provides context for mission data, such as temperature, salinity, and dissolved oxygen. Practical use: An AUV equipped with a CTD to profile water column during a habitat survey. Challenges include sensor drift, fouling, and power consumption.

Fault-Tolerant Control – Control strategies that maintain safe operation despite component failures. Related terms: redundancy, diagnostic monitoring, graceful degradation. Explanation: Enables an AUV to continue a mission after a thruster loss by redistributing thrust. Example: Re-allocating control effort among remaining actuators using a linear quadratic regulator. Challenges involve rapid fault detection, re-configuration time, and guaranteeing stability.

Fuzzy Logic Controller – Control method that uses linguistic rules and membership functions to handle uncertainty. Related terms: rule base, defuzzification, inference engine. Explanation: Useful for depth regulation where sensor noise is high. Practical application: A fuzzy controller adjusting ballast pump speed based on “high”, “medium”, “low” pressure inputs. Challenges include tuning membership functions and ensuring real-time execution.

Gaussian Process Regression (GPR) – Non-parametric Bayesian technique for modelling unknown functions with uncertainty quantification. Related terms: kernel function, hyperparameter optimisation, prediction variance. Explanation: Employed to model seabed terrain from sparse sonar points, allowing the AUV to plan safe paths. Example: Predicting obstacle height with confidence intervals to avoid collision. Challenges are computational scaling with data size and selecting appropriate kernels for underwater acoustics.

Geophysical Survey – Mapping of subsurface structures using seismic, magnetic, or gravimetric methods. Related terms: multibeam echo-sounder, sub-bottom profiler, magnetometer. Explanation: AUVs can tow sensors to acquire high-resolution bathymetry and sub-surface data for oil-field exploration. Practical use: A side-scan sonar coupled with a sub-bottom profiler to locate buried pipelines. Challenges include data volume, positioning accuracy, and environmental noise.

Gyroscope – Sensor that measures angular velocity around one or more axes. Related terms: rate gyro, MEMS, bias drift. Explanation: Provides orientation information for navigation and attitude control. Example: A fibre-optic gyroscope delivering low-drift heading for a deep-sea AUV. Challenges are temperature-induced bias, calibration under pressure, and integration with accelerometers.

Haptic Feedback – Tactile information returned to an operator to convey contact forces. Related terms: force feedback, tele-operation, virtual fixture. Explanation: ROV operators feel resistance when a manipulator contacts a delicate coral. Practical use: A joystick with force feedback indicating tool-substrate interaction. Challenges include latency, bandwidth limits, and accurate force estimation from limited sensors.

Hydrophone Array – Distributed set of underwater acoustic receivers used for localisation and beamforming. Related terms: passive sonar, acoustic triangulation, direction of arrival. Explanation: Enables localisation of marine mammals or detection of leaks. Example: A tetrahedral hydrophone array on a subsea platform to locate a leaking valve. Challenges involve array calibration, ambient noise suppression, and data synchronization.

Inertial Measurement Unit (IMU) – Integrated sensor package measuring linear acceleration and angular rate. Related terms: accelerometer, gyroscope, sensor fusion. Explanation: Core component of dead-reckoning navigation and attitude estimation. Practical use: Fusing IMU data with DVL (Doppler Velocity Log) for robust pose estimation. Challenges include bias drift, magnetic disturbances, and pressure effects on MEMS components.

Joint Space Control – Control methodology that directly commands individual joint positions or torques. Related terms: kinematic chain, inverse dynamics, actuator mapping. Explanation: Used for precise manipulation tasks such as screw-driving on a subsea valve. Example: A PID loop on each joint of a 6-DOF manipulator to achieve a desired pose. Challenges include coupling effects, limited bandwidth, and joint limits under high pressure.

Kinematic Redundancy – Situation where a robot has more degrees of freedom than required for a given task. Related terms: null-space motion, task-priority, inverse kinematics. Explanation: Allows an AUV-mounted arm to avoid obstacles while maintaining end-effector position. Practical application: Using redundancy to keep the tool clear of the vehicle hull. Challenges are solving the redundancy resolution efficiently and avoiding singularities.

Laser Scanning Sonar – High-resolution acoustic imaging system that sweeps a fan-shaped beam to generate 3-D point clouds. Related terms: multibeam, point cloud, bathymetry. Explanation: Provides detailed terrain maps for navigation and inspection. Example: A 1° beamwidth scanner mapping a shipwreck. Challenges include acoustic shadowing, processing large datasets onboard, and acoustic interference from thrusters.

Linear Quadratic Regulator (LQR) – Optimal control technique that minimises a quadratic cost function of state and control effort. Related terms: state-feedback, Riccati equation, gain matrix. Explanation: Designs depth and pitch controllers for an AUV to achieve smooth trajectories. Practical use: Tuning LQR weights to balance energy consumption against tracking accuracy. Challenges involve modelling uncertainties and ensuring real-time solvability.

Localization – Determination of a robot’s position and orientation within a reference frame. Related terms: SLAM, acoustic positioning, GPS. Explanation: Combines sensor data (e.G., DVL, IMU, acoustic beacons) to estimate pose. Example: A particle filter fusing DVL velocity and long-baseline (LBL) range measurements. Challenges include multipath acoustic errors, sparse beacon geometry, and time-varying currents.

Long Baseline (LBL) Acoustic Positioning – System of fixed transponders that provide range measurements to a vehicle for precise localisation. Related terms: ultra-short baseline (USBL), time-of-flight, baseline geometry. Explanation: Enables sub-meter accuracy for deep-sea interventions. Practical use: An AUV receiving acoustic pings from a network of seabed beacons during a pipeline inspection. Challenges are deployment logistics, clock synchronisation, and acoustic noise.

Machine Vision – Use of cameras and image processing algorithms to interpret visual information. Related terms: feature extraction, object detection, stereo vision. Explanation: Allows an ROV to recognise valve handles or identify marine fauna. Example: A convolutional neural network classifying seabed textures. Challenges include low lighting, turbidity, colour distortion, and limited bandwidth for transmitting images.

Manipulator Kinematics – Mathematical description of the relationship between joint parameters and end-effector pose. Related terms: forward kinematics, inverse kinematics, Denavit-Hartenberg parameters. Explanation: Essential for path planning of subsea tools. Practical use: Computing joint angles required to align a sampling needle with a target. Challenges involve accounting for compliance in hydraulic joints and handling singular configurations.

Markov Decision Process (MDP) – Formal framework for modelling decision-making where outcomes are partly random and partly under control. Related terms: policy, reward function, state transition. Explanation: Used to plan energy-optimal routes for AUVs under uncertain currents. Example: An RL-derived policy that decides when to surface for re-charging. Challenges include state-space explosion, accurate modelling of environmental stochasticity, and computational tractability.

Marine Snow – Aggregates of organic particles that drift through the water column, affecting visibility and sensor performance. Related terms: turbidity, optical backscatter, particle concentration. Explanation: Increases noise for optical cameras and laser scanners. Practical impact: Reduced image contrast during coral surveys. Challenges involve adaptive exposure control, using acoustic alternatives, and filtering techniques.

Modular Architecture – Design approach that separates system functions into interchangeable modules. Related terms: plug-and-play, hardware abstraction layer, software framework. Explanation: Allows rapid reconfiguration of a subsea robot for different missions (e.G., Swapping a sampling module for a sonar module). Example: A common bus with interchangeable sensor pods. Challenges include ensuring mechanical sealing, power budgeting, and interface compatibility under pressure.

Monte Carlo Localization (MCL) – Probabilistic method that represents possible robot poses with a set of weighted samples (particles). Related terms: particle filter, resampling, sensor model. Explanation: Provides robust pose estimation for AUVs in feature-poor environments. Practical use: Fusing DVL dead-reckoning with acoustic range data to maintain localisation. Challenges include particle depletion, computational load, and designing accurate sensor likelihood models.

Multibeam Echo-Sounder (MBES) – Sonar system that emits multiple beams to map seafloor topography. Related terms: bathymetry, swath width, beamforming. Explanation: Generates high-resolution digital terrain models for navigation and scientific analysis. Example: A 400-kHz MBES mounted on a survey AUV. Challenges involve motion compensation, water column sound speed corrections, and data volume management.

Neural Network Accelerator – Specialized hardware (e.G., FPGA, ASIC) that speeds up AI inference. Related terms: edge AI, low-power inference, quantisation. Explanation: Enables real-time object detection on a depth-rated AUV without exceeding power budgets. Practical use: A Tensor Processing Unit (TPU) executing a YOLO model on-board. Challenges include radiation tolerance, thermal management, and development of efficient model architectures.

Non-linear Observer – Estimator that can handle non-linear system dynamics to reconstruct unmeasured states. Related terms: extended Kalman filter, high-gain observer, state reconstruction. Explanation: Used to estimate vehicle drag coefficients from limited sensor data. Example: An observer that infers hydrodynamic parameters during a straight-line run. Challenges are ensuring convergence under model uncertainties and tuning observer gains for fast response.

On-Board Diagnostics (OBD) – System that monitors health of hardware components and reports fault codes. Related terms: self-test, fault isolation, telemetry. Explanation: Provides early warning of thruster degradation or sensor failures. Practical implementation: Periodic self-checks of pressure transducers with reporting via CAN bus. Challenges involve designing fault-tolerant protocols that operate under limited bandwidth.

Optical Backscatter – Light reflected from particles in water, used to infer turbidity. Related terms: laser scattering, turbidity sensor, attenuation coefficient. Explanation: Helps adjust camera exposure and informs navigation decisions. Example: A backscatter sensor triggering a switch to acoustic imaging when turbidity exceeds a threshold. Challenges include calibration across wavelengths and temperature dependence.

Path Planning – Computation of a feasible trajectory from start to goal while respecting constraints. Related terms: A*, RRT*, cost map. Explanation: Generates safe routes for AUVs avoiding obstacles and high-energy zones. Practical use: A D* Lite algorithm updating the path in real time as new sonar data arrives. Challenges include dynamic currents, limited sensor range, and computational efficiency.

Photonics-Based Pressure Sensor – Uses changes in light transmission through a cavity to measure pressure. Related terms: Fabry-Perot interferometer, optical fiber sensor, high-resolution depth. Explanation: Offers high accuracy for deep-sea depth measurement with immunity to electromagnetic interference. Example: A fiber-optic pressure sensor on a 6000 m AUV. Challenges involve ruggedising the optical components and ensuring stable temperature compensation.

PID Controller – Control loop that combines proportional, integral, and derivative actions to minimise error. Related terms: tuning, gain scheduling, steady-state error. Explanation: Widely used for depth, heading, and speed regulation in subsea robots. Practical example: A PID controller maintaining a constant altitude above the seabed using a DVL. Challenges include dealing with non-linear hydrodynamics, time delays, and actuator saturation.

Power Management Unit (PMU) – System that distributes, monitors, and protects electrical power across the robot. Related terms: DC-DC converters, circuit protection, load shedding. Explanation: Balances power between propulsion, sensors, and compute modules. Example: A PMU that reduces non-essential sensor sampling when battery voltage drops below a threshold. Challenges are ensuring reliability under high pressure and handling transient loads from thruster commands.

Pressure Compensation – Technique of equalising internal and external pressure to protect components. Related terms: oil-filled housings, flexible bellows, hydrostatic balancing. Explanation: Prevents volumetric collapse of electronics enclosures at depth. Practical implementation: Oil-filled compartments for high-density batteries. Challenges include sealing moving parts, managing thermal dissipation, and ensuring long-term reliability.

Proportional Navigation (PN) – Guidance law that steers a vehicle to intercept a moving target by maintaining a constant line-of-sight rate. Related terms: missile guidance, lead angle, closed-loop guidance. Explanation: Adapted for AUVs to intercept drifting objects such as oil plumes. Example: An AUV adjusting its heading to stay on a plume centreline. Challenges include estimating target motion in a noisy flow field and handling actuator limits.

Propulsion System – Assembly of components that generate thrust to move the robot through water. Related terms: thruster, propeller, pump-jet. Explanation: Determines vehicle speed, manoeuvrability, and energy consumption. Example: A four-thruster vector-controlled pod on a survey AUV. Challenges involve cavitation, efficiency at varying speeds, and integration with control allocation algorithms.

Quasi-Static Control – Approach that assumes system dynamics are slow enough to be approximated by static relationships. Related terms: slow-varying, steady-state assumption, linearisation. Explanation: Used for positioning a subsea tool where motion is minimal. Practical use: Adjusting a valve actuator based on pressure feedback assuming negligible inertial effects. Challenges arise when unexpected disturbances introduce dynamic behaviour.

Range-Based Localization – Determining position by measuring distances to known reference points. Related terms: triangulation, time-of-flight, acoustic ranging. Explanation: Core of LBL and USBL systems for underwater vehicles. Example: Computing a 2-D position from three acoustic ranges to seabed beacons. Challenges include geometric dilution of precision, multipath errors, and synchronization.

Reactive Planning – Real-time generation of actions based on current sensor data, without a pre-computed global plan. Related terms: behaviour-based control, potential fields, event-driven. Explanation: Enables an AUV to avoid unexpected obstacles detected by forward-looking sonar. Practical implementation: A potential-field controller that repels the vehicle from sonar returns. Challenges include local minima, tuning of repulsive gains, and ensuring mission progress.

Redundant Architecture – System design that duplicates critical components to improve reliability. Related terms: dual-thruster, hot-swap, fail-over. Explanation: Allows continued operation after a component failure. Example: An AUV with two independent navigation subsystems (IMU-DVL and acoustic) that can cross-check each other. Challenges involve added weight, increased power consumption, and complexity of fault detection.

Remote Operated Vehicle (ROV) – Tethered underwater robot controlled by a surface operator. Related terms: tether, pilot station, man-in-the-loop. Explanation: Provides high-resolution manipulation capability for tasks such as valve turning or connector plugging. Example: A 6-tonne work class ROV with a 2-meter manipulator. Challenges include tether drag, limited depth, and reliance on surface communication bandwidth.

Robust Control – Control design that maintains performance despite bounded uncertainties and disturbances. Related terms: H∞ control, mu-synthesis, gain margin. Explanation: Ensures stable depth regulation in the presence of unknown current profiles. Practical use: An H∞ controller that attenuates the effect of unmodelled hydrodynamic forces. Challenges include model identification, computational cost, and conservatism of the design.

Roll-Pitch-Yaw (RPY) Angles – Representation of orientation using three sequential rotations about the vehicle axes. Related terms: Euler angles, quaternion, gimbal lock. Explanation: Commonly used for describing AUV attitude. Example: A navigation filter outputs roll, pitch, and yaw for mission planning. Challenges include singularities at ±90° pitch and the need for conversion to quaternions for smooth interpolation.

Sampling Strategy – Plan for acquiring physical specimens or sensor data during a mission. Related terms: adaptive sampling, spatial coverage, triggered acquisition. Explanation: Determines where a coring tool is deployed or when water quality sensors are activated. Example: A greedy algorithm directing the AUV to regions of high chlorophyll concentration. Challenges involve balancing scientific value against energy constraints and ensuring repeatability.

Scalable Communication Network – Architecture that supports increasing numbers of nodes without performance degradation. Related terms: acoustic modems, mesh topology, bandwidth allocation. Explanation: Enables fleets of AUVs to exchange data while operating over large areas. Practical use: A time-division acoustic network allowing up to ten vehicles to share a common channel. Challenges include latency, interference, and limited acoustic bandwidth.

Sea-State Adaptive Control – Adjusting controller parameters in response to wave-induced disturbances. Related terms: gain scheduling, wave spectrum, disturbance observer. Explanation: Improves surface vehicle stability during rough conditions. Example: A PID gain that increases derivative action when wave height exceeds a threshold. Challenges include accurate sea-state estimation and avoiding excessive control effort.

Sensor Fusion – Combination of data from multiple sensors to produce a more accurate estimate of a quantity. Related terms: Kalman filter, complementary filter, data assimilation. Explanation: Merges DVL velocity, IMU acceleration, and pressure depth to obtain a reliable pose estimate. Practical implementation: An Extended Kalman Filter (EKF) that accounts for sensor noise characteristics. Challenges are handling asynchronous data rates and calibrating inter-sensor biases.

Simultaneous Localization and Mapping (SLAM) – Process of building a map of an unknown environment while concurrently estimating the robot’s pose within that map. Related terms: graph SLAM, pose graph, loop closure. Explanation: Enables an AUV to navigate in feature-poor seafloor regions. Example: A sonar-based SLAM that creates a 3-D occupancy grid of a wreck site. Challenges include drift over long distances, computational load, and dealing with sparse acoustic features.

Soft Robotics – Use of compliant materials and structures for safe interaction with delicate environments. Related terms: elastomeric actuators, pneumatic networks, bio-mimicry. Explanation: Allows manipulators to grasp fragile coral without damage. Practical example: A silicone gripper that conforms to irregular shapes. Challenges involve achieving sufficient force, controlling deformation precisely, and protecting soft components from high pressure.

Sonar Imaging – Generation of visual representations of underwater scenes using acoustic reflections. Related terms: synthetic aperture sonar, forward-looking sonar, echogram. Explanation: Provides situational awareness when optical visibility is poor. Example: A forward-looking sonar guiding an AUV around a submerged pipeline. Challenges include interpreting speckle noise, resolution limits, and processing speed.

Space-Time Adaptive Processing (STAP) – Advanced signal processing technique that jointly adapts in spatial and temporal dimensions to suppress interference. Related terms: adaptive beamforming, clutter rejection, radar-like processing. Explanation: Enhances detection of weak acoustic targets in the presence of strong multipath. Practical use: Improving sonar detection of small objects near a noisy thruster. Challenges are high computational demand and requirement for precise array calibration.

State Estimation – Determination of the full set of variables describing system condition (position, velocity, etc.) From measurements. Related terms: observability, filtering, estimator. Explanation: Core to navigation, combining IMU, DVL, and acoustic data. Example: An EKF producing a 12-state vector for an AUV. Challenges include handling non-linearities, sensor drop-outs, and model mismatch.

Surface Wave Modeling – Prediction of wave characteristics that affect surface vehicle dynamics.