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| Test Name | Description | Objective | tools | Covers (needs,  requirements) |
| Software simulation test | Entire system simulated in software (tool) | Validate system logic, signal processing, FDMA, and 3D positioning algorithms | MATLAB/Python/C++ simulation, ROS, SLAM toolbox | R1.1–R1.4, R1.6, R1.7, N1, N3, N4 |
| Tank test  (single beacon) | Physical sonar test in a water tank using only one stationary beacon | Validate sonar signal transmission, water noise resistance, and ranging accuracy in a small aquatic setting | Oscilloscope, hydrophone, STM32 with sonar sensor | R1.2, R1.8, R1.9, R1.10, R2.2, N1, N2, N4 |
| Ground integration test (multi-beacon) | Full system test on dry land with real hardware and multiple beacons | Integrate all system components STM32, beacons, IMU, GPS on dry land | Full hardware stack including STM32, GPS, IMU, sonar, logging system | R1.1–R1.6, R1.7, R2.3, R2.5, R2.6, N1–N4, N6 |
| Underwater test | Final system test in real freshwater environment with robot and all beacons | Full system test in freshwater with robot navigating underwater using all sensors and beacons | Deployed system, backup data logger, telemetry system | All requirements,  All needs |

Detail testing plan

**Test 1: Software Simulation Test**

**Objective**: Validate system logic, signal processing, FDMA, and 3D positioning algorithms.

**Environment**: Computer-only; simulate sonar pulses, beacon response, IMU and GPS data.

**Key Tests**:

Simulated sonar time-of-flight measurements

FDMA signal processing

Kalman filter for fusion of GPS + IMU + sonar

SLAM data format validation

**Success Criteria**: 3D position converges within ±50 cm in simulation; data structure matches SLAM requirements.

**Covers**: R1.1–R1.4, R1.6, R1.7, N1, N3, N4

**Test 2: Controlled Tank Test (Single Beacon)**

**Objective**: Validate sonar signal transmission, water noise resistance, and ranging accuracy in a small aquatic setting.

**Environment**: Water tank, 1 fixed beacon, robot tethered or stationary.

**Key Tests**:

Signal strength and clarity underwater

Single-beacon ranging accuracy (±50 cm)

Impact of water turbulence

**Success Criteria**: Reliable detection of beacon distance; noise-resilient signal; data logged with timestamps.

**Covers**: R1.2, R1.8, R1.9, R1.10, R2.2, N1, N2, N4

**Test 3: Ground Integration Test (Multi-Beacon)**

**Objective**: Integrate all system components—STM32, beacons, IMU, GPS—on dry land.

**Environment**: Open field or lab, with robot and 3+ beacons placed at fixed positions.

**Key Tests**:

Real-time 3D position estimation (simulated motion)

FDMA signal decoding from multiple beacons

Sensor synchronization and data logging

**Success Criteria**: Multi-beacon positioning within ±50 cm; synchronized logs; CPU usage acceptable for STM32.

**Covers**: R1.1–R1.6, R1.7, R2.3, R2.5, R2.6, N1–N4, N6

**Test 4: Field Underwater Test**

**Objective**: Full system test in freshwater with robot navigating underwater using all sensors and beacons.

**Environment**: Lake or large water tank (freshwater), depth up to 50m, 3+ beacons.

**Key Tests**:

Accurate, real-time tracking in 3D

Continuous operation for 10+ hours

Performance under depth, flow, and real underwater conditions

Compliance with safety/environmental standards

**Success Criteria**: No system failures; accurate tracking; logs complete and redundant; stable performance.

**Covers**: All requirements R1.1–R2.7, All Needs N1–N6