HELLENIC REPUBLIC
MINISTRY OF DEVELOPMENT AND INVESTMENT
GENERAL SECRETARIAT FOR RESEARCH AND INNOVATION
**HELLENIC FOUNDATION FOR RESEARCH AND INNOVATION**

This project is carried out within the framework of the National Recovery and Resilience Plan Greece 2.0, funded by the European Union – NextGenerationEU (Implementation body: HFRI)

**Greece 2.0**
**Basic Research Financing Action**
**(Horizontal support of all Sciences)**
**Sub-action 1**
**Funding New Researchers**

Project Title

**SLAM AND PATH PLANNING MIDDLEWARE PACKAGE FOR ROBOTS IN CHALLENGING ENVIRONMENTS**

Project Duration

**20 November 2023 – 19 November 2025**
**24 Months**

| Project Acronym | Project No |
|---|---|
| **LEARNER** | **015339** |

| Deliverable No | Deliverable Title |
|---|---|
| **D3.1** | **Integration and testing results** |

Deliverable Completion Date

**19 September 2025**

## Table of Contents



## Document Revision History

| Version | Date | Notes |
|---|---|---|
| 1.0 | 19/09/2025 | First version document describing the integration actions for combining all the developed technologies into a common Middleware package. |

## List of Acronyms

| Acronym | Meaning |
|---|---|
| **IMU** | Inertial Measurement Unit |
| **Nav2** | Navigation 2 in ROS 2 |
| **ONNX** | Open Neural Network Exchange |
| **ORB-SLAM3** | Paper Title: Oriented FAST and Rotated BRIEF – Simultaneous Localization and Mapping, third major release |
| **QoS** | Quality of Service |
| **ROS 2** | Robot Operating System 2 |
| **SLAM** | Simultaneous Localization and Mapping |
| **TF** | Transform Frames |
| **YOLOv8** | "You Only Look Once" Version 8 |

## 1. Introduction

This deliverable presents the integration results of the LEARNER middleware package, which unifies the SLAM, perception, and navigation subsystems into a single ROS 2 program running on the target robotic platform. While each subsystem was initially developed and validated as a standalone module, Task 3.1 focused on assembling them into a coherent, real-time capable system with consistent interfaces and synchronized data flow.

The resulting middleware serves as the backbone for Task 3.2 (Validation) and subsequent deliverables (D3.2, D3.3). It is released as an open-source ROS 2 package to ensure reproducibility, transparency, and extensibility by the robotics research community.



Greece 2.0 NATIONAL RECOVERY AND RESILIENCE PLAN
Funded by the European Union NextGenerationEU
H.F.R.I. Hellenic Foundation for Research & Innovation

## 2. Integrated Middleware Overview

At the heart of the middleware lies the SLAM subsystem, which is based on ORB-SLAM3 but extended with a SuperPoint-based feature detector to achieve robust keypoint extraction even under challenging lighting conditions. Both architectures developed in D2.3 were incorporated, allowing the system to benefit from illumination-invariant features and RL-based feature prioritization. Long-term SLAM capabilities were also added, including dynamic object filtering, relocalization after tracking loss, and incremental map updates that distinguish between stationary and movable objects.

The perception subsystem employs a YOLOv8 detector, optimized for real-time inference on edge hardware, to identify humans, doors, and other relevant movable or static objects. Its outputs are fused with the SLAM pipeline to semantically filter transient features during mapping and are published as ROS 2 topics for downstream consumption. The social-awareness module developed in D2.4 was integrated at this stage, enabling the system to classify human actions and adapt navigation policies accordingly.

Navigation and planning rely on the Nav2 stack, which receives robot poses from SLAM and consumes dynamically updated costmaps that combine geometric, semantic, and social information. These costmaps incorporate the hybrid representation described in D2.2, extended to reflect human activity and object affordances. As a result, the planner can avoid dynamic obstacles such as moving people or chairs, recognize navigable structures like doors, and adjust safety margins according to human presence and motion.

## 3. ROS 2 Wrapping and Containerization

To integrate the individual algorithms, each was encapsulated as a ROS 2 node with standardized inputs, outputs, and parameters. ORB-SLAM3 was compiled as a library and wrapped in a node that accepts image and IMU streams and publishes robot pose, map points, and TF transforms. SuperPoint inference was invoked within this wrapper to preprocess incoming frames before feature matching. YOLOv8 was converted to an ONNX model for efficient runtime execution, with a dedicated ROS 2 node subscribing to RGB images and publishing structured detections.

This modular wrapping ensured that each subsystem remained self-contained but interoperable. The complete pipeline was then containerized in a ROS 2 workspace, allowing deployment through a single launch file while preserving modularity for debugging. This approach resolved dependency conflicts between different libraries and ensured reproducible execution across development machines and the target robot platform.

The resulting node and topic architecture maintains a clean separation of concerns. The SLAM node publishes localization estimates and map points, the perception node provides object detections, and Nav2 subscribes to both streams to maintain a semantically enriched costmap and compute motion commands. A consistent TF tree was established (map → odom → base_link → camera_link → camera_optical_frame), with appropriate corrections applied to align SLAM's coordinate frames with ROS conventions.

## 4. Integration Challenges and Solutions

Integrating the three subsystems introduced several challenges, primarily related to timing synchronization, message transport overhead, and real-time performance. Early prototypes exhibited latency due to repeated conversions between OpenCV matrices, PyTorch tensors, and ROS 2 messages. This was mitigated by adopting zero-copy data transport and direct tensor access.

Synchronization between IMU and camera data was achieved through message buffering and timestamp alignment, ensuring SLAM received temporally consistent input.

Another difficulty involved fusing semantic detections into the SLAM map without degrading performance. We introduced filtering mechanisms that exclude dynamic objects from map point insertion and directly feed their positions into the costmap layers used by Nav2. Finally, computational load was optimized by throttling visualization topics and tuning QoS profiles: high-frequency streams such as IMU and image data use best-effort delivery, whereas pose and map updates use reliable transport.

## 5. Deployment on the Robotic Platform

The final stage involved deploying the middleware on the target robot running Ubuntu 22.04 and ROS 2 Humble. The system was configured to interface directly with the robot's onboard RGB camera and IMU, remapping their topics to match the SLAM node inputs.

Because the platform does not include a physical LiDAR, we implemented a depth-to-laserscan conversion node that synthesizes a 2D scan from the SLAM depth map, enabling Nav2's local planner to function as if a laser sensor were present. For global navigation, ORB-SLAM3's sparse map was first converted to an OctoMap, then projected into a 2D occupancy grid suitable for global PP. Both the synthetic scan and the occupancy grid were fused into Nav2's layered costmap, allowing for consistent planning and local obstacle avoidance.

Real-world trials confirmed that the integrated middleware runs in real time, with ORB-SLAM3 providing stable localization and mapping using the weights developed by our team, our social-aware perception system successfully detecting humans and their actions, and YOLOv3 detecting doors and dynamic objects updated the hybrid map. Based on the above, Nav2 computed socially compliant paths that adapted properly to dynamic obstacles. These results validate the integration methodology and confirm that the middleware is ready to support the validation activities of WP3.



Greece 2.0 NATIONAL RECOVERY AND RESILIENCE PLAN
Funded by the European Union NextGenerationEU
H.F.R.I. Hellenic Foundation for Research & Innovation