Ref. Ares(2024)7561255 - 24/10/2024



This project is funded by the European Union
G.A No 101016906

Project Number: 101016906
Start Date of Project: 2021/01/01
Duration: 48 months

Type of document D3.3 – V1.0

# Final Release of Farming and Logistic Robot Prototypes

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|---|---|
| Dissemination level | PUBLIC |
| Submission Date | 2024-10-24 |
| Work Package | WP3 |
| Task | T3:1 – T3:5 |
| Type | Report, Video |
| Version | 1.0 |
| Author | Tsampikos Kounalakis |
| Approved by | UNIROMA3, UNICLAM |

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History of changes

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## Executive Summary

This report outlines the creation of a video presentation detailing the final release of two robotic prototypes. The video showcases the full autonomous functionalities of the robots, including navigation, and transmission. It also highlights the final version of their respective BEM (Box-Exchange-Mechanism) designs, the dual-arm robot, and the final versions of the farming robot's agronomic dual arm and end-effectors. This video serves as proof of the operational prototypes and can be accessed via the following link:

Deliverable_3_3.mp4

(https://tinyurl.com/3kbvcdd5)

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## Abbreviations and Acronyms

| | |
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| BEM | Box-Exchange Mechanism |
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# 1. Introduction

This report is a support document for Deliverable 3.3. This deliverable presents the final release (M40) of the two robotic CANOPIES prototypes. The accompanying video demonstrates the functioning prototypes, showcasing their ability to perform fully autonomous operations such as navigation, data acquisition, and transmission. The video highlights the robotic prototypes and their respective components, including the final versions of the BEM design, the farming robot's agronomic dual arm, and the end-effectors.

The video format facilitates easier dissemination of the robotic systems' development within the project. It is intended for use at conferences and workshops and to communicate our research activities through the CANOPIES dissemination channels.

# 2. Video Overview

This video deliverable was developed to communicate the capabilities of the robotic prototypes, that are verified to operate under relevant environments and navigate autonomously. In detail, the robotic prototypes are shown to cover the following requirements:

Final dual arm and end-effector prototypes:

The video presents the current and final version (M25) of the agronomic dual-arm system, featuring an actuated torso and end-effector prototypes. Starting with the existing TIAGo++ mobile manipulator platforms produced by PAL Robotics, we implemented the following hardware customizations:

- Design of a stand-alone torso, removing the base of the mobile manipulator that is mainly made for indoor environments.
- Addition of the torso yaw joint respects the TIAGo++ robot so to have 2 DoF (yaw+lift) for the torso.
- Integration of the RGBD Intel RealSense D435i camera in the head of the robot.
- Design of the NVIDIA Jetson Xavier support on the back.
- Integration of the Intel NUC 11 Pro Kit NUC11TNKi7 in the robot torso in order to have a dedicated computer for performing the perception algorithms.
- Integration of a 48V battery for power supply in the torso.
- New redesign of the arms (2 x 7DoF arms, 3kg payload) to include the following new features:
    - New modules and kinematics
    - SEE (Series Elastic Element) for torque sensing in each joint to make the arms compliant
    - High torque density of the new modules (high torque in a really small space)
    - Brake system in the joints for safety
    - EtherCAT communication to get a higher bandwidth control
    - Velocity control interface
    - Cables for cameras on the end-effector
- Prototype of the agronomic customized gripper
    - Capable of holding and cutting for harvesting.
        - Two independent movements.
        - Fingers to hold.
    - Blades for pruning.
    - Intel RealSense D435i support on the end-effector.
    - Dimensions: small enough to reach the peduncles.
    - 2 kg payload.

Before the final release of the prototype (M40), the following activities were conducted:

- Stress tests for robot arm and torso operations.
- Updated version of the prototype for improving robustness.
- IP rating evaluation.
- Field validation of the gripper and evaluation of the topology of the end-effector towards the development of a robust end-effector for pruning.

**Integration of the Box-Exchange-Mechanism (BEM) prototype:** Both robotic prototypes incorporate a BEM system in their design. To streamline integration and operation, we developed a BEM unit that meets the requirements of both prototypes based on the final BEM specifications.

In this video, we present the BEM prototype for the farming variant of the robot, which can carry and exchange boxes weighing up to 10 kg. The final BEM prototype includes two components of market-ready Interroll conveyor belts equipped with Interroll drive controllers and Pepperl-Fuchs reflective sensors, all interfaced with a Moxa IO-logic box. The prototype demonstrated features a single-box configuration with attachments for additional sensors, such as GNNS antennas. The BEM prototype includes a fully developed state machine that facilitates usability and exchange actions between the two robots. Additionally, the BEM has a ROS interface, enabling integration with the overall robot software architecture.

The logistics BEM, also shown in the video, shares the same hardware and software architecture but includes a complete sensor suite for docking operations. This BEM prototype consists of two elements using the same conveyor and sensor models as the farming BEM. These elements provide additional functionalities such as multiple box storage, transfer, and exchange. The logistics BEM is equipped with a state machine that controls its components and provides necessary docking functionalities, such as monitoring its capacity, acknowledging exchanges, and recovering from alignment issues that may arise internally or from external misalignments between the two robots due to unfavorable terrain conditions. Furthermore, the logistics BEM module features a ROS interface for seamless integration with the overall robot software architecture.

These prototypes enable uninterrupted academic activities related to the coordinated maneuvering of robotic platforms for box exchange.

During the final release of the two prototypes in M40, several issues were identified during field testing. Specifically, the margins for misalignment did not accurately reflect the requirements derived from the operational conditions. Consequently, several hardware modifications were implemented and remedied the issue. Additionally, there were issues with the BEM's recovery behavior during movement processes, which were addressed through software fine-tuning. These critical fixes were successfully completed by M43. Following these improvements, our focus shifted towards the final demonstration activities. This shift in priorities, while necessary, contributed to a delay in the submission of the deliverable.

**Mapping and localization**: in the video we present the final solution for the SLAM algorithm that was specifically developed for the CANOPIES prototypes. Since both robots are based on the same sensor suite, the algorithm covers the needs of both prototypes without any need for further modification.

**Execution of navigation goals:** in the video we present the final solution for the CANOPIES robot motion planner, showcasing the real-time obstacle avoidance as well as the developed A* based algorithm that allows a customized cost function that is unique to each robot prototype.