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# First Release of Farming and Logistic Robot Prototypes

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## History of changes

| Changes in original text | New version | Old Version |
|---|---|---|
| Executive Summary (no. page3) | Includes a link to the updated video file that serves as the main material for this deliverable. | Included a link to the original video file that served as the main material for the first submission of the deliverable. |
| Introduction/ 1st Paragraph (no. page6) | Introduction of the deliverable material and differences between the two deliverable versions and the achieved progress over time. | Introduced the deliverable sections and the originally submitted video material. |
| Video overview/ 2nd Paragraph (no. page7) | Presentation of the data acquisition capabilities of the robot prototypes, including timeline of the activities. | Presentation of the data acquisition capabilities of the robot prototypes. |
| Video overview/ 3rd Paragraph (no. page7) | Presentation of the platform integration activities of the robot prototypes, including timeline of the activities. | Presentation of the platform integration activities of the robot prototypes. |
| Video overview/ 4th Paragraph (no. page7) | Presentation of localization and mapping capabilities of the robot prototypes, including timeline of the activities. | Presentation of localization and mapping capabilities of the robot prototypes. |
| Video overview/ 5th Paragraph (no. page7) | Presentation of the navigation capabilities of the robot prototypes, including timeline of the activities. | Presentation of the navigation capabilities of the robot prototypes. |
| Video overview/ 6th Paragraph (no. page8) | Presentation of the updated version of dual arm and end-effector prototype, including details on the changes, specifications and capabilities as submitted at M25. The new version also includes information regarding the timeline of the activities. | Presentation of the first version of dual arm and end-effector prototype implementation and capabilities as submitted at M14. |
| Video overview/ 7th Paragraph (no. page 9) | Presentation of the updated version of the Box Exchange Mechanism (BEM) prototype implementation and its capabilities as submitted at M25. The new version also includes information regarding the timeline of the activities. | Presentation of the first version of the Box Exchange Mechanism (BEM) prototype implementation and its capabilities as submitted at M14. |

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## Executive Summary

This report describes the composition of a video report defining the first release (M14), and its upgraded version at M25, of the two robotic prototype and presenting their basic autonomous functionality (navigation, data acquisition and transmission), their respected BEM designs, as well as the first and updated versions of farming robot's agronomic dual arm and end-effectors. The video also serves as a proof of the functioning prototypes and is available at the link:

Deliverable_3_2_rev1.mp4 [https://tinyurl.com/2r2jxv7s].

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## Abbreviations and Acronyms

| | |
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| BEM | Box-Exchange Mechanism |
| CAN | Controller Area Network |
| GNSS | Global Navigation Satellite System |
| IMU | Inertial Measurement Unit |
| LIDAR | LIght Detection And Ranging |
| ROS | Robot Operating System |
| WP | Work Package |

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# 1. Introduction

This deliverable describes the first release (M14), and its upgraded version at M25,of the two robotic prototypes. The video serves as a proof of the functioning prototypes presenting that work properly, and can perform the basic autonomous functionality (navigation, data acquisition and transmission). The evolution of the robotic prototypes and their respected components is also presented. That includes the first versions of the BEM design, farming robot's agronomic dual arm and end-effectors that were provided by M14, for which, due to the limitations described in the technical report, not of all the required components were finalized. In this revised version of the deliverable, we also present the second and stable release of the two prototypes.

Due to the continuous development of both prototypes this deliverable is expected to be periodically updated during the project. The video format allows for an easier dissemination of the robotic systems' development in the project. The video is expected to be used in conferences, workshops, as well as, to communicate our research activities through the dissemination channels of CANOPIES.

# 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:

**Data acquisition:** In the beginning of the video the robot is shown in a data acquisition experiment that took place in the fields of Aprilia, Italy in July 2021 (M6). In those experiments, the first phase of robot integration was complete, i.e., all baseline sensors were mounted, powered and they had been integrated through ROS. We consider as baseline sensors, all the required sensor that are needed for navigation and remain the same for both prototypes, such as the LIDARs, GNNS setup and IMU. The video shows the robot moving in the field through teleoperation while being able to collect data from the IMU, GNNS, LIDARs and motor odometry which assisted the research development of the project.

**Integration of a platform that is ready for the field**: the video also shows the hardware integration for the baseline components that are common for both prototypes (M14). The integration was performed by taking into consideration the information gathered from the early integration phase and the field testing (M6). For example, protection from dust and mounting of sensor interface boxes. In this version (M14) the robotic prototypes have secure mounting solutions for all sensor and compute units as well as a casing with resistance to dust and some resistance to water.

**Mapping and localization**: having a constant understanding of their position in space is crucial for the autonomous navigation capabilities of the robotic prototypes. To that end, we have modified and implemented the Fast-Lio SLAM algorithm[1]. The algorithm is using IMU and LIDAR to achieve the localization. In the video the robot is shown to achieve good localization results in the maps representing the two Acceptance Test cases (M14). This SLAM algorithm was implemented for the sake of the Factory Acceptance Tests but as expected was not able to perform satisfactory in the relevant environment.

**Execution of navigation goals:** the robot prototypes are able to receive navigation goals, plan a path, as well as convey the required commands to the robot's hardware in order to achieve the desired movement. We have integrated a ROS based navigation (M14) which combines the localization and mapping capabilities with move_base[2] a very well-established framework for navigation. It should be noticed that, as for the SLAM algorithm mentioned above, this navigation framework was implemented mostly for the sake of the Factory Acceptance test and it is not optimal for the operational activities in the relevant environment, for which an effective navigation stack is being developed. We also integrated a ROS-based CAN communication layer (M6, M14) to the platform's motor controllers, thus allowing us to control the platform's motors. For our acceptance tests it is shown the current setup is navigating autonomously in lab conditions, i.e., parking lot at DTI, and in a relevant environment, i.e., forest path close to DTI (M14).

**First dual arm and end-effector prototypes**: The prototype was not able to be finalized in time (M14) mainly due to both the global shortage of the manufacturing of electronic components as stated in the Technical Part of the RP1 done at M18. The longer delivery time for the machined parts again caused by the shortage affecting the raw materials, as specified in the first technical report. Consequently, this involved an unplanned redesign of some electronic components that also caused delays to the firmware development. As a result,

[1] Wei Xu and Fu Zhang, FAST-LIO: A Fast, Robust LiDAR-inertial Odometry Package by Tightly-Coupled Iterated Kalman Filter, 2021, https://arxiv.org/abs/2010.08196

[2] ROS move_base, http://wiki.ros.org/move_base

implementing the software framework within ROS and thus making accessible the joint torque controllers of the robot for implementation of mid-level control was not done in time. However, the prototype has been completed at M25 and the activities has been re-scheduled accordingly as described in the technical report.

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

- 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.

Further improvements that are expected in the duration of the project include:

- Stress tests.
- Implementation of the software framework integration within ROS to make accessible the joint torque controllers of the robot for implementation of mid-level control.
- Development of the 2nd 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.

Once these improvements are completed the deliverable will be updated.

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**Integration of the Box-Exchange-Mechanism (BEM) prototype:** both robotic prototypes include a BEM in their design. According to the most updated specifications of the BEM, we designed a unit that covers the needs of both robotic prototypes in order to reduce the complexity of integration and operation.

In this video we present the first BEM prototype (M14), which can carry and exchange boxes up to 10kgs. The prototype presented has a single box configuration, allowing us to study several design parameters before moving to a multi box configuration. Moreover, the BEM prototype was operated using ROS, which made it easy to integrate with our research activities in mobile robot coordination. However, as also described in the technical report the custom nature of this design did not perform as expected during the FAT tests. Therefore, a new prototype had to be developed.

The updated BEM (M25), shown in the video, carries several elements from the previous design but is now more robust and has a complete sensor suite. The final BEM prototype consists of market-ready Interroll conveyor belts equipped with Interroll drive controller, Pepperl-Fuchs reflective sensors, which are all interfaced to a Moxa IO-logicbox. The IO box provides communication via the RESTful API, which allows us to control the mode, speed, and direction. The code to control the BEM has been written in Python with a RESTful API and has been wrapped in ROS to allow for easy integration with the rest of the components, thus allowing the exchange of boxes to be performed autonomously. The prototype is presented to be successfully tested under laboratory conditions and is expected to be tested in the field in latest the upcoming spring sessions or earlier depending on the lead time for the delivery of the components. This prototype will allow the uninterrupted completion of the upcoming academic activities related to the coordinated maneuvering of the robotic platforms for the box exchange. Finally, the prototype for the logistic robot is already planned to be expanded, adding functionalities such as a storage area for multiple boxes and the offloading of boxes in a predefined position in the field.