Efficient collaborative mapping in orchards using 3D object tracking and a factor graph with Gaussian belief propagation

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Background

Precision farming and smart agriculture requires an accurate representation or map of each field. However, mapping large agricultural fields remains a challenge due to the computational complexity of traditional representations like point clouds. In this work, we present an efficient object-based mapping based on a factor graph with Gaussian belief propagation and a 3D multi-object tracking, that can map individual trees with up to 11 cm error.

Contributions

- Autonomous mapping of trees in orchards using a mobile robot equipped with RTK-GPS, AHRS and an RGB-D camera.
- Use of a factor graph with Gaussian belief propagation to store robot position and tree detections over time, resulting in a probabilistic estimation of the trees and the robot path.
- Use of a instance segmentation algorithm together with an RGB-D camera to detect the tree trunks and estimate their 3D position.
- Use of a 3D multi-object tracking algorithm, 3D-SORT, to perform data association between the tree detections of multiple time steps.

Methods

We use a Clearpath Husky robotic platform, equipped with an RTK-GPS system, an AHRS (IMU) device and an RGB-D camera. The robot was used to collect data in pear and apple orchards during fall and winter. A photo of the robot during data collection time can be seen in Fig. 1.

A YOLO-v8 instance segmentation model was trained to detect the trunk of the trees as shown in Fig. 2. The resulting masks are used together with the depth image to estimate the cartesian coordinates of each tree with respect to the robot. Later, the RTK-GPS and the IMU data is used to transform the tree coordinates to a fixed coordinate system with respect to the field.

A factor graph (Fig. 3) with Gaussian belief propagation is used to process the robot position and tree detections in a probabilistic manner. The factor graph uses a 3D multi-object tracking algorithm, 3D-SORT, to associate measurements from the same tree over multiple time step.

Figure 1. The mapping robot.

Figure 2. Example detection from YOLO-v8.

Results

Experiments show a detection AP@0.5 of 0.87 and a tracking accuracy above 90%. This allows for a mapping of the trees with an error as low as 11 cm.

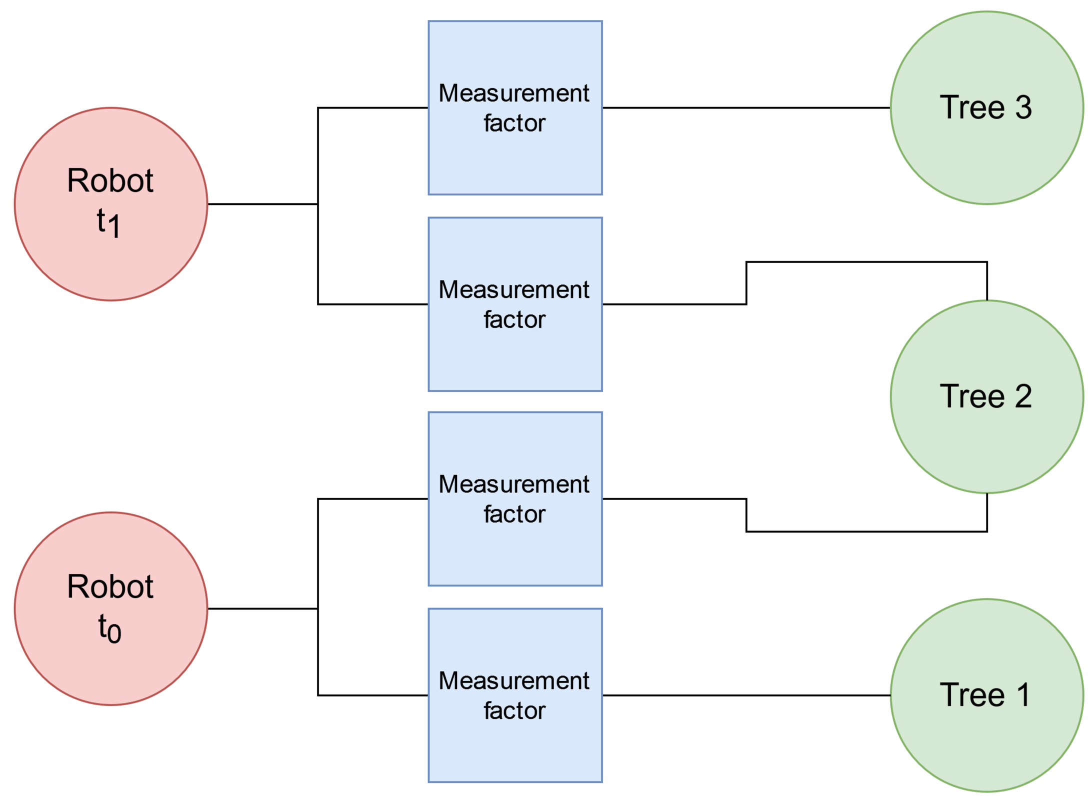

Figure 3. Factor graph example.

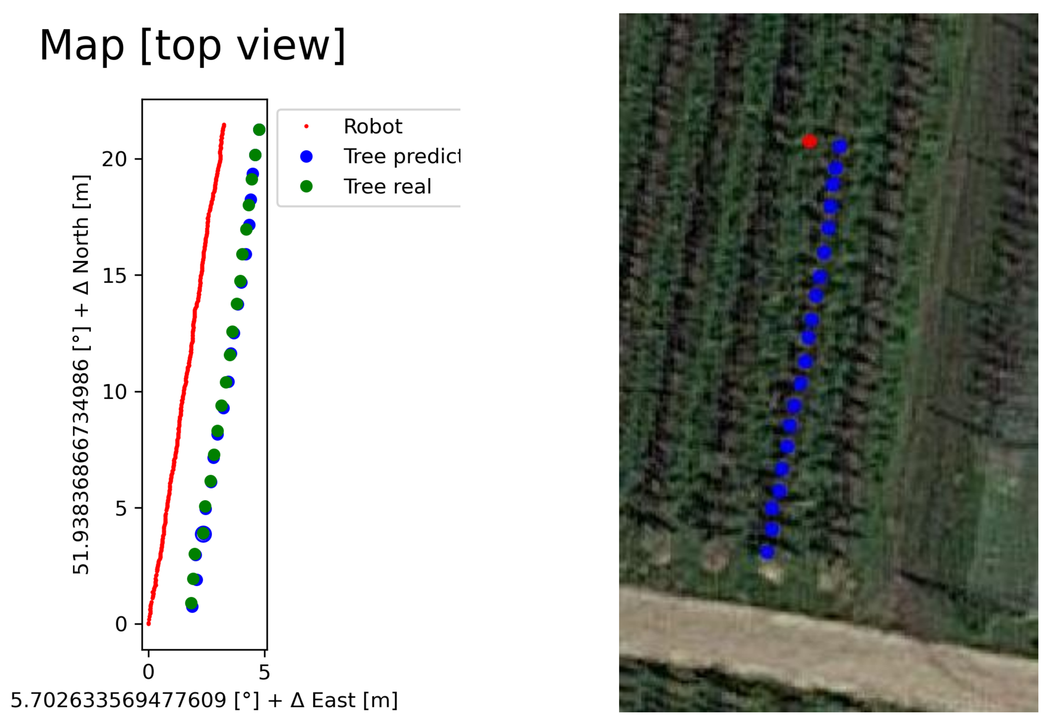

Figure 4. Resulting path and map with ground truth tree positions.

Discussion & Conclusions

- The system is able to accurately map and geo-localize trees in real-world orchard environments with an error as low as 11 cm.
- Errors and noise coming from the sensors can generate false positive tree detections after tracking that increase the counted trees on a row. A tracking algorithm with context of the scene might help preventing these errors.
- The factor graph can at the same time correct the noisy detections and the noisy robot position estimation that happen when RTK correction is lost.
- The factor graph can be stored and shared between diffrent autonomous vehicles such as drones.

Acknowledgements

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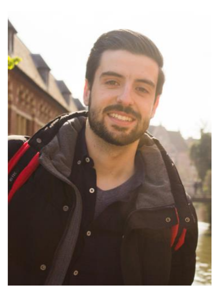

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Advancing Precision Agriculture through an Integrated ICT Framework – Enabling Data Synergy with Digital Twins and Smart Farming Technologies.

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Introduction

The adoption of precision- and smart farming, along with emerging trends like the fusion of proximal sensing and robotics, is set to significantly increase the time or money farmers spend on measurements, managing diverse data sources, and processing complex information systems. This surge in data and measurement systems necessitates enhanced support systems and improved information analysis. However, a significant opportunity lies in harnessing and combining the existing data from various smart-farming applications to not just streamline these processes, but also to advance the automation and autonomy in farming operations.

To **counteract** the rising **demands on farmers' time for semi-manual measurements and manual data processing**, an Open Automated Precision Farming Framework is proposed. This framework integrates cooperative autonomous vehicles, vessels, drones, and smart-devices installed on standard agricultural machinery, streamlining the farming process and making precision agriculture more accessible and efficient.

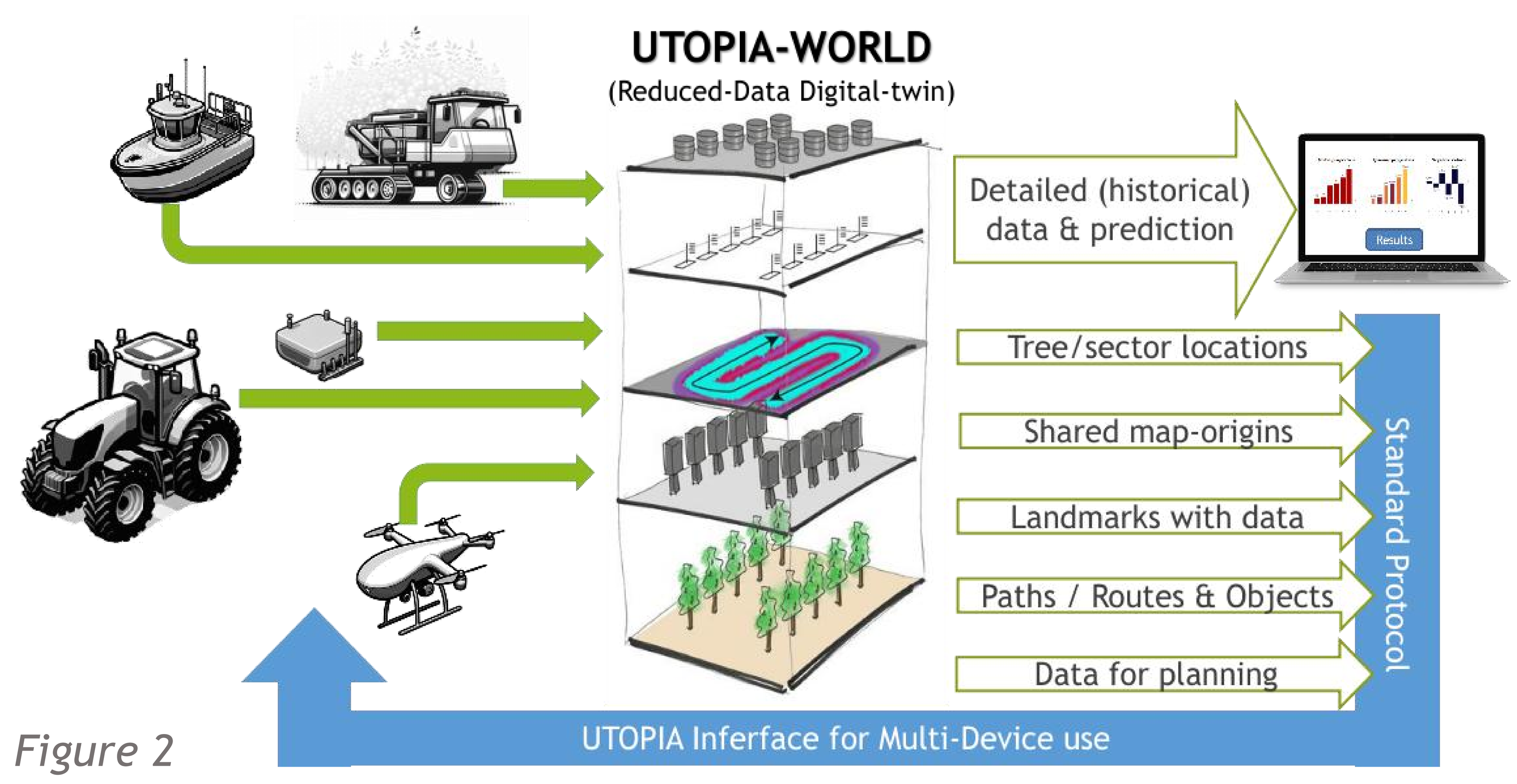


Figure 2

Figure 2: Multiple Smart Devices Enhancing a Shared World by Continuously Building upon Previously Contributed Data.

Figure 3: High-Level Overview of SW Architecture as an Add-On to the Widely-Used ROS(2) Middleware.

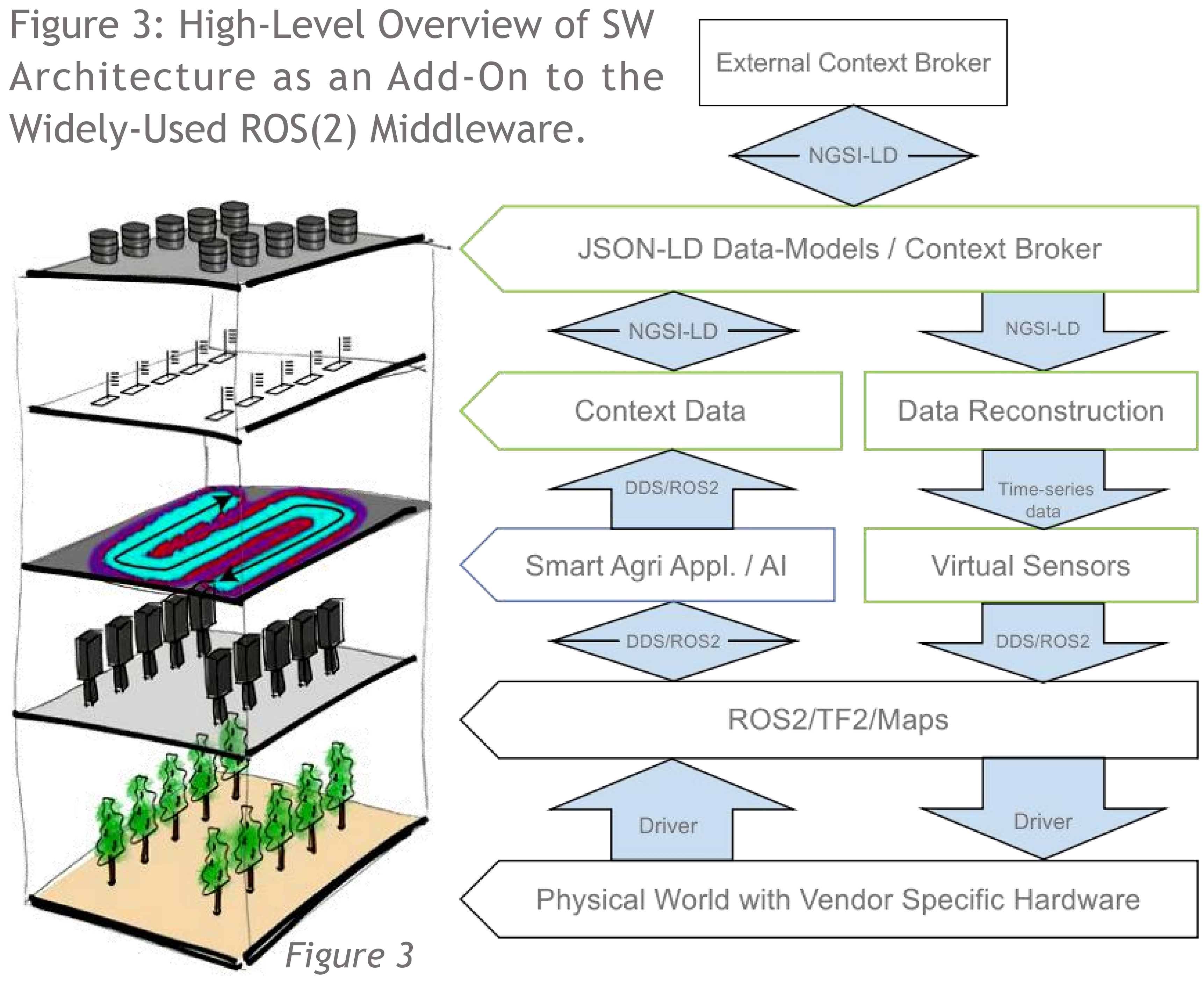


Figure 3

Objectives

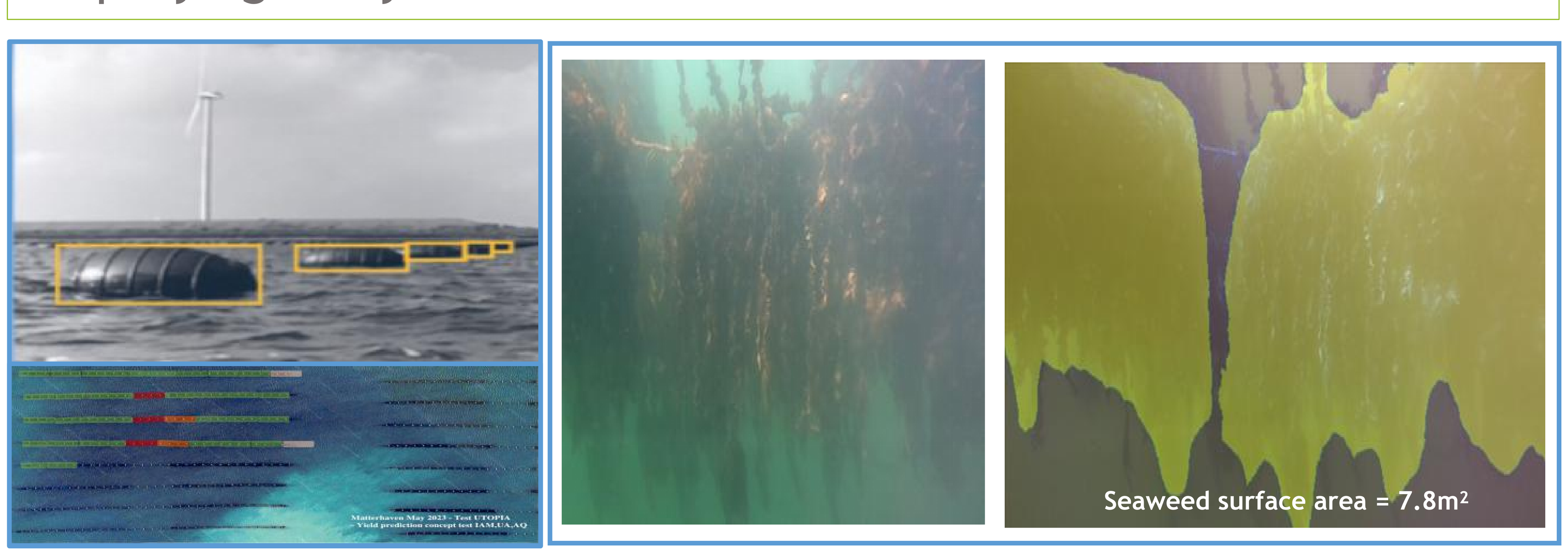
- Development of an ict-framework that assists farmers using data-linked drones and vehicles, reducing the expected additional labor or tech skills. Simplifying precision agriculture for farmers and other stakeholders.
- Providing an open source framework for machinery manufacturers, start-ups and robotic start-ups.

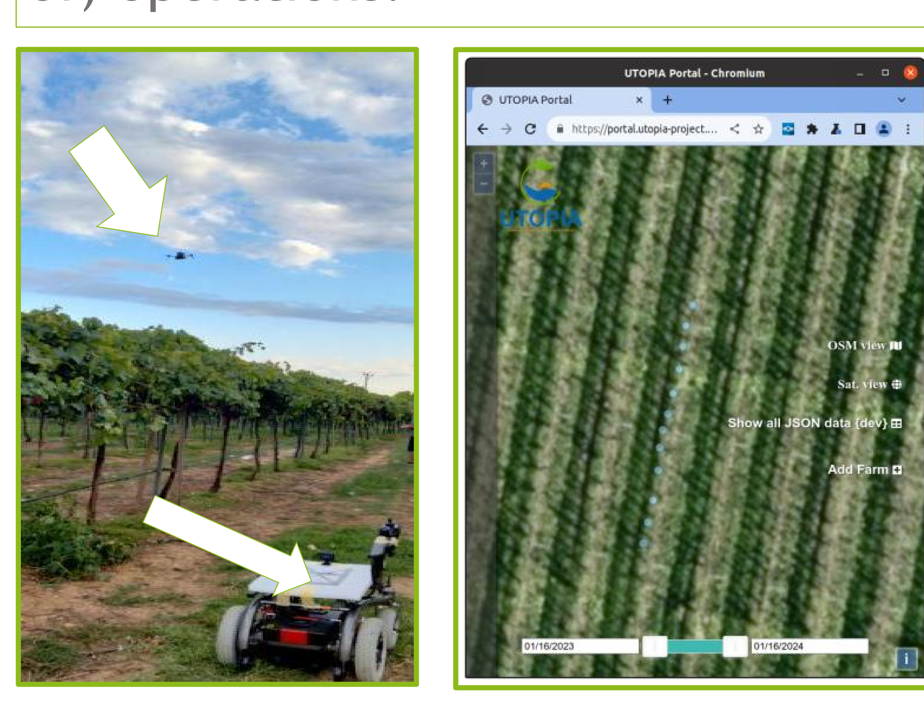
Method

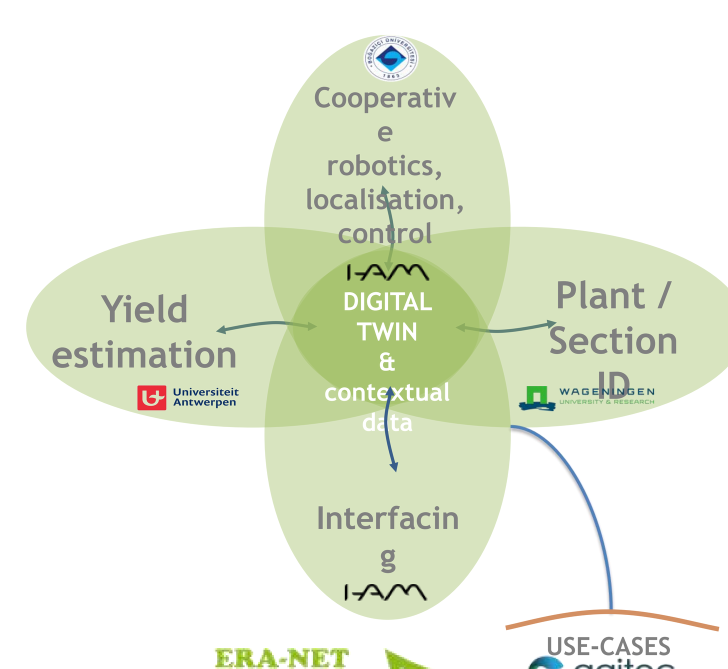
The framework employs a multi-layered 'Publish and Subscribe' model at a real-time robotics level, enabling seamless sharing of critical information among devices over a Digital Twin of the farm. Key data like tree locations with IDs, landmarks, paths, and yield metrics are distributed efficiently between devices. This model not only facilitates real-time collaboration among various agricultural tools but also ensures that less-critical, shared information is effectively utilized across different farming applications, harmonizing data interpretation across applications, simplifying analysis.

Special (use-)case: Seaweed

In ongoing engagement with the seaweed industry, it is learned that there are still a number of primarily **technical challenges** in the production of algae and seaweed before **offshore** production can be developed on a commercial scale. **Enabling** developments for commercial offshore seaweed cultivation include: *Multi-use of the farm design (including for example fish, shellfish and energy), and ***Farm automation & remote monitoring to reduce time at sea.** Smart farming is recognized as valuable for offshore production. Potential reducing time-at sea and improving (timing of) operations.







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