# Design and Navigation Concepts of an UGV for Orchard Management

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***Abstract*—We present a ground robot tailored for agricultural applications. The general design and logical architecture concepts are presented, as well as emphasizing the aspects that make the platform particularly suited to operate in “all-terrains”. We also present the implementation of the localization and navigation algorithms designed to autonomously operate both outside and inside the rows of an orchard. Experimental results are shown in the attached video.**

***Index Terms*—precision orchard management, autonomous navigation, orchard navigation, agricultural robotics**

## SUPPLEMENTARY MATERIAL

A video demonstrating autonomous navigation capabilities of the robot is available at https://youtu.be/vUQtdlYi3Go.

## I. INTRODUCTION

Robotics and automation are constantly increasing their influence in agricultural context, to improve productivity and quality. Indeed, vineyard growers have increasingly adopted technology to automate crop yield estimation [1], [2] and multi-spectral monitoring and mapping [3]. Today, researchers are looking forward to making this technology suitable also for other agriculture fields, such as orchards, where profit margins are smaller, but still automation can be of paramount importance to increase efficiency and competitiveness.

In this context the concept of Precision Agriculture arises, in which robots perform tasks according to environment conditions, distributing fertilizers or water only where/when necessary, thereby optimizing treatments and energy resources [4], [5]. To maximize exploitation of these procedures, it becomes crucial to develop versatile robotic platforms, able to perform a wide range of tasks and overtaking the principal drawbacks of standard tractors like excessive weight and size, pollution and soil compaction [6].

The main goal of this paper is therefore to present a new design concept of Unmanned Ground Vehicle (UGV) for agriculture. We present concepts that have inspired the design, the main mechanical features that make the platform particularly robust and suited to operate in variegated conditions. We also present the navigation algorithms implemented to operate autonomously within rows. In this respect experimental results are presented here, as well as in the attached video.

## II. DESIGN AND LOGICAL ARCHITECTURE

As far as orchard agriculture is concerned, effective in-field operations require machines able to go in the field even if terrain conditions are not optimal (e.g. after a storm) and without damaging the terrain, both in terms of soil compaction and displacement. Standard orchard tractors are heavy and massive, causing soil degradation and thereby reducing traversability. Consequently, a lightweight tracked machine represents the best option to spread weight over a wider area, with appropriate traction and maneuverability, preserving soil conditions and reducing compaction, [7]. On the other hand, smaller tractors bear less available power and therefore, optimization becomes a key step in the development of UGVs for orchard agriculture.

In particular, the design procedure leverages the dynamic model developed in [8], studying power consumption accordingly to the variation of design parameters, such as:

- Vehicle mass or normal pressure
- Track to track distance
- Length and Width of the tracks
- Number and radius of the track rollers

As shown in [9], Hardware (HW) and Software (SW) architecture of the designed vehicle, can be divided into High Level (HL) components and Low Level (LL) ones. LL is designed specifically to be as reliable as possible, both in terms of Electro-Magnetic Compliance (EMC) and in terms of safety. It is in charge of collecting data from the sensor suite, composed by a GNSS receiver, a 3D LiDAR, an Inertial Measurement Unit (IMU) and one motor encoder for each one of the two tracks. Aside this, it also provides a reliable communication between the heterogeneous components of the vehicle, which is achieved using industrial-standard communication protocols such as CAN-bus and Modbus. This is used to manage I/O peripherals, reserving high-priority channels for critical components such as motor drivers and safety devices.

On the other hand, the HL part is characterized by higher computational burden, therefore the components selected focus more on performance than reliability. In particular, this logical level has to perform all data processing on measurements, and then use them in order to provide autonomous navigation capabilities to the robot. HL is responsible for sensor fusion,

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navigation and trajectory following control loops.
The attached video shows the final prototype assemble accordingly to the described design procedure.

## III. LOCALIZATION, NAVIGATION AND SENSOR FUSION

Accurate pose estimation is obtained by means of a multi-rate Extended Kalman Filter (EKF), which merges the set of available sensors, accordingly to the navigation scenario considered:

- **Open-field navigation** - move from the base station to the entry point of the orchard. The EKF, in this scenario, relies heavily on global positioning (GNSS), using the 3D laser scanner for detection and avoidance of possible unexpected obstacles.
- **Orchard navigation** - perform farming tasks inside the orchard. In this case, the GNSS is not used and the LiDAR measurements are processed to provide relative pose with respect to the orchard rows, using the Hough Transform algorithm.

### *A. Open-field navigation*

In this scenario, the sensor fusion algorithm [10] is used to merge together GNSS data, encoders and IMU readings.
Indeed, path planning exploits the semi-structured nature of the environment, relying on *ROS navigation stack* [11], and taking advance of a known map of the farm, either achieved via reconnaissance activities or available a-priori. This is a waypoint-based navigation, which are interpolated using graph optimization algorithms, such as A*, [12].
The static map, is refined using the LiDAR sensor, which is also used to detect obstacles, and consequently update the set of waypoints leading to the final goal: the entry point of the target orchard lane. Once the robot has reached its target, the controller switches to the *in-row* navigation.

### *B. Orchard navigation*

In this navigation scenario, GPS data are not used, since their reliability is reduced by the canopy and by the orchard structure itself. In the proposed work, in-row navigation mainly relies on the detection of tree rows, modeling them as lines and using Hough Transform (HT) algorithms to detect them, [13], [14]. Then, processing LiDAR pointclouds it is possible to obtain the local pose of the robot with respect to the surrounding tree rows.
It is possible to consider the HT output as a *new custom sensor* measuring the relative angle between the robot heading direction and the orchard row orientation, as well as the lateral distances from the tree rows. Thus, in this scenario, the EKF fuses together the HT measurements, IMU readings and motor encoders information. Notice that the proposed approach allows for accurate navigation within orchard lane, exploiting the available knowledge of the orchard structure, and overcoming the need of mapping also in the environment within orchards, which is extremely variable throughout the four seasons.
As shown in [9], one of the contribution is the optimization of the HT algorithm, making it lighter from a computational point of view and more robust with respect to misdetections caused by missing trees along the lane.
The outcomes of this work are mainly reported in the attached video, which shows the capability of the vehicle to navigate autonomously, both in open field scenario and within orchard rows. In particular, the behaviour of the algorithms is shown side-by-side to real world frame of the robot while autonomous navigating.

## IV. CONCLUSIONS

This work presents design concepts and architecture of an agricultural tracked UGV. Details regarding the localization and the navigation in both the open-field and in-row scenarios have been provided. The video attached shows experimental results. Future works will focus on energy-efficient trajectory planning.

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