PANTHEON: A SCADA Architecture for Precision Farming of Hazelnut Orchards

Nicolas Bono Rossello Renzo Carpio Emanuele Garone Andrea Gasparri

***Abstract*— This paper describes the concept of the project PANTHEON. Project PANTHEON aims at developing an integrated system of ground robots, drones, and fixed sensors which, together with a communication infrastructure and a central decision unit, create the agricultural equivalent of a Supervisory Control And Data Acquisition (SCADA) system specifically designed for the management of orchards. The declared aim of the project is to be able to acquire agronomic information and to perform farming operations at the granularity level of the single tree. Following the needs of the end-user FERRERO, the case study is the management of large scale hazelnut orchards. This paper introduces the overall architecture of the envisioned system, the operations it will carry out, and explore the UAV-related research objectives and challenges.**

I. Introduction

This contribution aims at presenting the UAV-related research activities within the H2020 project PANTHEON. The goal of project PANTHEON is to develop the agricultural equivalent of an **industrial Supervisory Control And Data Acquisition (SCADA)** system to be used for the precision farming of orchards.

By taking advantage of the technological advancements in the fields of control, robotics, remote sensing, and big-data management, our objective is to design an integrated system where a relatively limited number of heterogeneous unmanned robotic components (including terrestrial and aerial robots) move within the orchard to collect data and perform some typical farming operations. The information is collected and stored in a central operative unit that will integrate data coming from the different robotic (ground and aerial) vehicles and to the fixed Internet of Thing infrastructure to perform automatic feedback actions (e.g. to regulate the irrigation system) and to support the decisions of the agronomists and farmers in charge of the orchard. Figure 1 illustrates the foreseen concept.

We expect that the development of this concept will be able to ensure an increase of the production, while being at the same time more cost effective and environmentally friendly when compared to the current farming best-practices.

II. Precision Farming of Hazelnut Orchards

Inspired by the real needs of the consortium member FERRERO, project PANTHEON focuses on the management of **large hazelnut orchards**, where, to the best of our knowledge, precision farming techniques have not been applied yet.

Nicolas Bono Rossello and Emanuele Garone are with , Department of Control Engineering and System Analysis, Universite libre de Bruxelles, 50, av. F.D. Roosevelt, CP 165/55 1050 Bruxelles Belgique email: nbonoros@ulb.ac.be, egarone@ulb.ac.be

Renzo Carpio and Andrea Gasparri are with the Department of Engineering, University of “Roma Tre”, 00146 Rome, Italy email: renzo.carpio@uniroma3.it, gasparri@dia.uniroma3.it

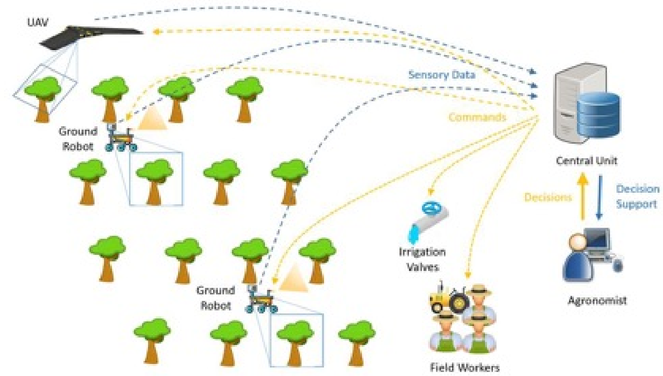

Fig. 1: Idea of the SCADA system for agriculture.

Modern state-of-the-art hazelnut farming is typically carried out in well-structured orchards with a regular planting pattern. Among all used distributions, the most common one contains lines of trees separated by 5m and an intra line separation of 3m. This regular distribution allows the mechanization of certain activities carried out by tractors all along the orchard, such as harvesting of fruits.

The main activities performed in precision farming of hazelnut orchards that will be addressed in the project PANTHEON are:

- Irrigation
- Sucker treatment
- Pest and Disease control
- Fruit production estimation

However, in current best practices decisions are made by assessing the status of a few plants and extending the treatment to the entire sector were these plants are located. This may result in unnecessary/non-calibrated treatments for a large number of plants.

These practices have a relevant impact on the environmental sustainability and economic cost of the orchard, translated into product waste (economic loss) and avoidable pollution.

III. PANTHEON: An Agriculture-Oriented SCADA Architecture

Project PANTHEON proposes the development of a SCADA system able to acquire and elaborate information at the **resolution of the single plant**. This information will be used not only to monitor the state of each plant, but also also to perform focused automatic farming operations.

This will permit to drastically increase the detection of possible limiting factors for each individual plant, such as lack of nutrients, or pests and diseases affecting the plant health, and to react accordingly and in a focused way. Compared to the current state of the art in orchard farming, we believe that the proposed SCADA infrastructure represents a relevant step ahead. In fact, the capability of monitoring the state and the evolution of each single tree will be the enabling-technology to allow more focused interventions. This will result in a better average state of health of the orchard and in an increased effectiveness of Integrated Pest Managements .

Thus, the proposed architecture has the potential to increase the production of the orchard while, at the same time, being more cost-effective and environmentally-friendly.

The proposed SCADA system is composed of the following main components:

- A Wireless Backbone Network
- A fleet of Unmanned Ground Robots (UGVs)
- One or more Aerial Robots (UAVs)
- An IoT (Internet of Things) Network infrastructure
- A Central Unit

A. Wireless Network Backbone

The **Wireless Network Backbone (WNB)** is the infrastructure required to keep all the components of the SCADA system interconnected. The selected WNB architecture is based on a set of mesh antennas and two long-distance antennas. The former is required to create a mesh network on the field, so that UGVs and UAVs can operate and communicate. The two long-distance antennas are used to connect the central unit, stored in a remote warehouse, to the mesh network deployed in the field. ROS will be used as an interface to make communicate the WNB with all the components of the SCADA system.

B. Unmanned Ground Vehicles

The **ground robots units** are composed of two customized Robotnik-SHERPA, namely robot A (R-A) and robot B (R-B). Both robots have the same navigation equipment. The main task of R-A, which is equipped with a high resolution Lidar, an RGB camera and a multispectral camera to collect sensorial data for tree geometry reconstruction and for the assessment of the phytosanitary status. The robot is also equipped with a paintball marker to mark branches for pruning. The main task of R-B is to apply treatment on the plants, e.g. to apply erbicides on suckers.

C. Unmanned Aerial Vehicles

The **aerial unit** consists of a customized DJI Matrice 600 Pro UAV. This drone is equipped with a thermal camera, an RGB camera and a multispectral camera installed on a stabilized gimbal.

D. IoT-based agro-meteorological monitoring network

Environmental variables such as: precipitation, wind direction and wind speed, air temperature, relative humidity, air pressure and solar radiation, are going to be acquired through a meteorological station. The moisture of the soil in different positions of the orchard and different depth in the ground will be collected by a network of custom made sensors. All these fixed sensors which are distributed in the plantation are connected to form an **IoT-based agro-meteorological monitoring network**, based on the LoRa communication protocol. The modules of the network will collect data from the sensors at a desired rate and send them to the Gateway, which is responsible for converting data into the ROS standard for storage in the primary DB server. The gateway interfaces the LoRa network with the WNB, creating a convenient decoupling between the IoT network and the ROS network infrastructure.

E. Central Unit

The **central unit** is the workstation where the main software components run. This includes the ROS core, the DB server where all the collected information will be stored using a NoSQL database, and the support decision system. This workstation will be installed on the control room, it will run a Linux-based system and it will be the main point of control of the SCADA architecture.

IV. SCADA Functionalities

In the foreseen SCADA system, **Unmanned aerial and ground robots** will move within the orchard to collect data from the plants status and, in the case of the ground robots, perform some farming operations. Each unit performs different measurement activities depending on their characteristics and requirements. The idea is to collect diverse data from the orchard, augment them when relevant/possible with the data coming from the ground sensors, and extract relevant features for the agronomic analysis.

In particular, using the data coming from the robots and from the IoT network, the central unit will elaborate synthetic indicators for each tree, concerning:

- Water stress.
- Presence of pests and diseases.
- Geometry of the tree, including the possible presence of suckers and their size.
- Estimated number of nuts on the tree (in the relevant season).

Based on these synthetic indicators, the system will elaborate a synoptic report for the agronomist in charge of the orchard, putting in evidence possible situations that may deserve attention, providing suggestions of intervention and, if requested, providing a historical view of the status of the plant and of the treatments already performed. For some interventions, algorithms to perform automatic decisions based on these indicators are envisioned and in particular: the control of the levels of irrigation, automatic suckers' treatment, and pruning marking.

A. Water Stress

For what concerns **water stress**, the objective is to detect plant stress induced by limited water [1]. From the sensing viewpoint the goal is to develop techniques able to use the information collected by the aerial vehicle [2], and fuse them with the measurements of the IoT network. It is also foreseen that these estimation can be used in conjunction with a model of the irrigation in the orchard, to automatically regulate the irrigation system.

B. Pest and Disease control

For what concerns **Pest and Disease control** the goal is to detect the presence (or the suspicion) of pest infestations and plant diseases using multispectral visible and near infrared (VNIR) and thermal data collected from the UAV and the ground robots [3], [4]. This will be achieved by linking changes in reflectance patterns to reference data collected by experts on the field to confirm the presence of pests and diseases. The objective is to develop a sound classification model to identify the different sources of stress.

C. Tree Geometry Reconstruction

Tree Geometry Reconstruction will be carried out using data acquired from ground robot LiDAR sensor to reconstruct the geometry of the tree and extract synthetic indicators/parameters describing the structure of the tree and the presence of suckers. This activity involves the definition of a synthetic formalism to describe tree structure and suckers, and the adaptation of existing algorithms [5] for tree reconstruction (such as the VecTree algorithm [6]) to the specific case of hazelnut trees. These indicators will be used by the system to automatically decide if some branches need to be pruned or if they need to be sprayed. In the first case the ground robot will mark with paint the branch to be cut, in the second case it will administer a calibrated dose of herbicide.

D. Fruit detection

Finally, **fruit detection** is going to be performed using the number of fruit visible on the tree. For the counting we will rely on the adaptation of standard object detection algorithms, this information will be used together with other information measured from remote sensing (such as leaf area index, gap fraction, tree height and geometry) to estimate the current number of hazelnuts on a tree. It should be noticed that, during the maturation period, this activity results in a spatial and temporal sampling of the trees of the orchard. To estimate the total orchard yield an estimator (see e.g [7], [8]) will be developed, able to take into account that the expected losses that occur over time during the maturation stage.

V. UAV-Related Research Challenges

This project presents a number of research challenges concerning the aerial robot unit. In the first phase of the project, the most crucial aspect is the **remote sensing part**, and in particular the development of algorithms able to automatically extract meaningful information from the acquired data/images. Although the literature on remote sensing of hazelnuts is quite scarce, the recent advances obtained for other crops represent a promising indication for this crop too.

Another important research aspect is to determine which are the optimal trajectories to be followed by the UAVs to collect a sufficient amount of data to evaluate the state of each plant. To carry out these activities, we face the problem of determining what are the necessary performance factors to satisfy the utilization of the collected data. Terms like altitude, flight speed or picture overlapping have to be analysed and determined for a correct definition of the problem. Concerning the aerial remote sensing, the use of classical techniques for orchard coverage implies an excessive amount of time and pictures for a single hectare, due to the high percentage of overlap required, resulting very inefficient for large scale orchards. Taking this into account, one of the first actions is to verify the use of a precise localization methods to reduce this inherent overlap.

A second important research aspect concerns the nature of the data used for the analysis, as it does not require a complete overview of the plantation, since trees are going to be treated as single cases. Adding this consideration to the fact that hazelnut orchards follow a regular plantation pattern where lines of trees are sufficiently separated, results in the conclusion that complete orthomosaic pictures are not necessarily required and that the use of multiple orthomosaics - not related between them - could mean a possibility to be exploited. This approach can also lead to non-balanced measurement strategies [9], as the information density map is known a priory, focused on covering only areas where trees are distributed, obtaining less resolution in the other regions of the orchard.

Finally, we will also evaluate the use of Information Adaptive UAV trajectory planning using different altitudes, scanning large portions at high altitude in terms of detecting possible anomalies. Thanks to following coverages, we would proceed to identify the specific problem of the plant, as expecting a reduced area to cover and where altitude and speed can be lowered.

Acknowledgement

Pantheon project is supported by European Union's Horizon 2020 research and innovation programme under grant agreement no 774571.

References

[1] Alderfasi, A. A., Nielsen, D. C. (2001). "Use of crop water stress index for monitoring water status and scheduling irrigation in wheat." Agricultural water management, 47(1), 69-75.

[2] Rock, G., Gerhards, M., Schlerf, M., Hecker, C., and Udelhoven, T. (2016). "Plant species discrimination using emissive thermal infrared imaging spectroscopy", International Journal of Applied Earth Observation and Geoinformation, Volume 53, December 2016, Pages 1626

[3] Mahlein, A. K. (2016). "Plant disease detection by imaging sensorsparallels and specific demands for precision agriculture and plant phenotyping." Plant Disease, 100(2), 241-251.

[4] Hernandez-Clemente, R., Navarro-Cerrillo, R. M., Suarez, L., Morales, F., and Zarco-Tejada, P. J. (2011). "Assessing structural effects on PRI for stress detection in conifer forests" Remote Sensing of Environment, 115(9), 2360-2375.

[5] Lamprecht S, Stoffels J, Dotzler S, Ha E and Udelhoven T (2015), "aTrunk—An ALS-Based Trunk Detection Algorithm", Remote Sensing. Vol. 7(8), pp. 9975.

[6] Liang X, Kankare V, Hyypp J, Wang Y, Kukko A, Haggrn H, Yu X, Kaartinen H, Jaakkola A, Guan F and et al. (2016), "Terrestrial laser scanning in forest inventories", ISPRS Journal of Photogrammetry and Remote Sensing., May, 2016. Vol. 115, pp. 6377. Elsevier BV.

[7] Sinopoli, B., Schenato, L., Franceschetti, M., Poolla, K., Jordan, M. I., and Sastry, S. S. (2004). "Kalman filtering with intermittent observations." IEEE transactions on Automatic Control, 49(9), 1453-1464.

[8] Garone, E., Sinopoli, B., Goldsmith, A., and Casavola, A. (2012). "LQG control for MIMO systems over multiple erasure channels with perfect acknowledgment" IEEE Transactions on Automatic Control, 57(2), 450-456.

[9] Patrick Nolan, D. A. Paley, and K. Kroeger. "Multi-UAS path planning for non-uniform data collection in precision agriculture." IEEE Aerospace Conference (2017): 1-12.