Ref. Ares(2018)2294876 - 30/04/2018

Project Number: 774571
Start Date of Project: 2017/11/01
Duration: 48 months

Type of document D2.1 – V1.0

Requirements, Specifications and Benchmark

Dissemination level	PU
Submission Date	2018-04-30
Work Package	WP2
Task	T21
Type	Report
Version	1.0
Author	Laura Giustarini
Approved by	Andrea Gasparri + PMC

Executive Summary

This document aims at identifying the requirements for the management of a large-scale hazelnut orchard. This analysis has the purpose to guide the dimensioning of the systems and its functional requirements. The following aspects are considered:

1. Scenario analysis: Identification of requirements for the management of a typical large-scale hazelnut orchard.
2. Functional specifications: The functional specification for the system, including the specification for robots, sensors, and the SCADA system.
3. Performance Indices: Identification of appropriate means to verify the achievement of the project's goals.
4. Possible Ethical, Legal and Societal (ELS) issues.

Here we present a tentative planning of activities and of the benchmarks, which might slightly be adapted and/or developed over time. This Document is to be considered a live-document and it is subject to regular updates, on a 12-month basis.

Table of Content

Abbreviations and Acronyms

LAI	Leaf Area Index
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
IoT	Internet of Things
DB	Database
SCADA	Supervisory control and Data Acquisition
WNB	Wireless Network Backbone
GPS	Global Positioning System
RTK	Real-Time Kinematic
PPP	Precise Point Positioning
GNSS	Global Navigation Satellite System
NDVI	Normalized Difference Vegetation Index
DSM	Digital Surface Model
RGB	Red Green Blue
LoRa	Long Range
ROS	Robot Operating System
RWC	Relative Water Content
ELS	Ethical, Legal and Societal

1 Analysis of the requirements for the management of an orchard

Modern hazelnut farming is generally carried out in well-structured orchards with a regular planting pattern. Typically, plants are organized in a planting scheme of *X* (distance between rows) x *Y* (distance between trees), with *X* x *Y* being one of the following possibilities, in meters: 5x3, 5x4, 5x5, 6x5, 6x4, 6x3. The use of regular layouts allows the mechanization of many field operations, which are carried out through orchard tractors and specialized agricultural machinery.

The main drawback of current hazelnuts farming procedures is that, for plantations larger than 10 ha, performing a per-plant monitoring and responding to the needs of each single plant is very challenging. In current best practices, decisions are made by assessing the status of a few plants considered representative of the orchard and extending the treatment to the entire sector were these plants are located, which in the case of the larger plantations, may mean an area up to 50 ha.

Extensive discussion with the Ferrero agronomists were conducted in order to list the most time consuming and labor-intense agronomical activities, and those that also involve attributing the status of few representative trees to the entire block. In the management of large orchards, several activities can potentially benefit from automation, however, according to the priorities of Ferrero's agronomists the following 5 activities were identified as crucial: **irrigation, pruning, sucker detection and removal, pest and disease detection and harvest estimation**. Focusing on these activities has been estimated as an achievable effort in the duration of the PANTHEON project.

The goal of this project is to take advantage of recent advances in robotics, control, remote sensing and big data to allow the collection of data down to the level of the single tree, in order to automatize and render more productive and more environmentally friendly some agronomical activities. The proposed automation will also have a relevant impact on the environmental and economic sustainability of the orchard, as it will likely result in fewer and better calibrated treatments for the different plants. As a consequence, it will be possible to reduce product waste (economic loss) and pollution. For example, a major beneficial impact is expected in suckers' treatments in small plants: in fact, a better calibrated amount of herbicide will avoid causing damage to plants in the juvenile stage.

In the next subsection we will give an overview of the 5 activities (irrigation, pruning, sucked control, pest and disease detection and harvest estimation) that PANTHEON will focus on.

1.1 Irrigation

Irrigation is the application of controlled amounts of water to plants at needed intervals and it is meant to compensate for water stress. In large plantations, it is usually carried out through fixed equipment and may consists of drippers, or sprinklers, or a mix of both. Typically, for plantations bigger than 50 ha, water treatment is the same for homogeneous portions of 5-10 ha. Water needs are usually regulated through remotely controlled valves. Fertilization is performed also through the irrigation system, which results in a constant input being applied to the same for portions of 5-10 ha. Currently, both irrigation needs, and treatments are decided by the agronomist based on a qualitative evaluation and on quite scarcely sampled quantitative measurements that are performed on some representative trees for each homogenous portion of 5-10 ha. From the literature and based on the agronomists' experience, July appears to be the key month, in the Northern Hemisphere, to estimate the water usage and needs of the plants.

Project PANTHEON will rely on an Internet of Things (IoT) sensing infrastructure for identifying water stress at the granularity of the single plant. This will permit to better calibrate irrigation to the specific actual need of the plants.

1.2 Pruning

The hazelnut tree is a suckering plant and its natural growth habit is the bush. To encourage the growth as a tree or as a vase-shaped plant, pruning and suckers' management are fundamental activities. Young plants (and mature ones too in smaller orchards) are usually pruned manually by qualified workers. For what concerns large plantations, pruning of mature plants is usually quite crude: an example of such intervention is the pruning carried out mechanically every 3-4 years using vertical saws towed by tractors which cut all the plants in alternate rows, without the scope of obtaining a specific shape.

According to the agronomists' needs, tree geometry reconstruction should be performed three times a year: two times with bare leaf trees, one before and one after pruning, and a third time during the vegetative period. Reconstructing not only the tree structure, which can be done in winter time with bare leaf conditions, but also the tree structure when leaves are fully developed, will allow computing the Leaf Area Index (LAI), which is a key parameter for pruning and expected production. In other words, obtaining both the naked structure and the one with leaves will permit the modelers to simulate how LAI varies when removing different branches of the tree, to obtain the optimum LAI value that should maximize production.

In the project PANTHEON, tree geometry reconstruction, both with and without leaves, will be carried out to obtain a 3D model of each single tree. Virtual pruning schemes will then be tested to optimize either production or different vegetation parameters, such as LAI.

1.3 Suckers' detection and removal

For what regards suckers' control, the most common method for large plantation management is the administration of herbicides. This is mainly carried out manually by field workers, who walk around the orchard spraying all plants. Sometimes, for the largest orchards, a tractor with a pump for herbicides is used. In both cases, there is no distinction between a plant that actually needs the treatment and a plant that does not require it. Additionally, a constant and non-calibrated amount of herbicide is applied to all plants.

During the so-called vegetative growth period, sucker detection can be carried out from April to August. Suckers emission attitude varies in relation to the specific cultivar and to the tree shape growing system (multi stemmed bush or single trunk). We anticipate that, during the first year of experiment, only sucker monitoring will be automatically performed, while in the following years, also tests on automated sucker removal, in the period mid-May to July, will be started. In the case of automated detection, the agronomists expect that both the volume and the height of each group of suckers is computed. There are essential variables to correctly define the dose of herbicide. For example, suckers shorter than 5 cm are easier to be eliminated and the operation can be performed with a smaller amount of herbicide. The early detection of sucker will help both reducing pollution and product waste, for the joint benefit of the environment and the farm managers.

During the first year of the project PANTHOEN, automated monitoring of suckers will be used to reconstruct their geometry and build an algorithm that quantifies the amount of herbicide needed and the location where to spray. In the following years, tests will be performed to automatically remove the suckers themselves.

1.4 Pest and disease detection

Pest and disease control is traditionally performed by spraying chemical products on the canopy of the trees, using atomizers carried by tractors. To detect the right moment to treat and avoid useless treatments, the various parts of the orchards are inspected regularly by agronomists, who decide whether and when to perform the treatments (again typically for homogeneous areas from 5 ha up to 50 ha).

Automated monitoring activities with the sensors proposed in the framework of PANTHEON will potentially allow detecting pest and disease damage at the pre-symptomatic stage, i.e. when the symptoms are not yet visible to the human eye. This outcome will allow prompter and more efficient treatments, specifically tailored to the needs of each plant.

1.5 Pest and disease detection

Especially for large orchards, production estimation with a consistent lead time is a crucial piece of business intelligence information for the plantation manager. The current procedure requires walking in the field, counting the number of fruit on a “representative branch” of a “representative plant”, and extending the result to a homogenous portion of the orchard, which may be as large as 50 ha. This procedure is time consuming, tedious, and may lack accuracy and objectivity. Additionally, the outcome of the current estimation procedure provides estimated production at the granularity of the block.

The requirements of the agronomists consist in production estimation per tree, which can then be summarized per block and per field. Both the clusters of nuts visible to the sensors and the total quantity of hazelnut per tree should be computed, according to the requests of the Ferrero’s agronomists.

1.6 Study area

To test the proposed idea, for project PANTHEON 3 fields were selected within the “Azienda Agricola Vignola”, a farm located in the municipality of Caprarola, in the province of Viterbo: they are displayed in Fig. 1 and their characteristics are listed in Tab. 1.

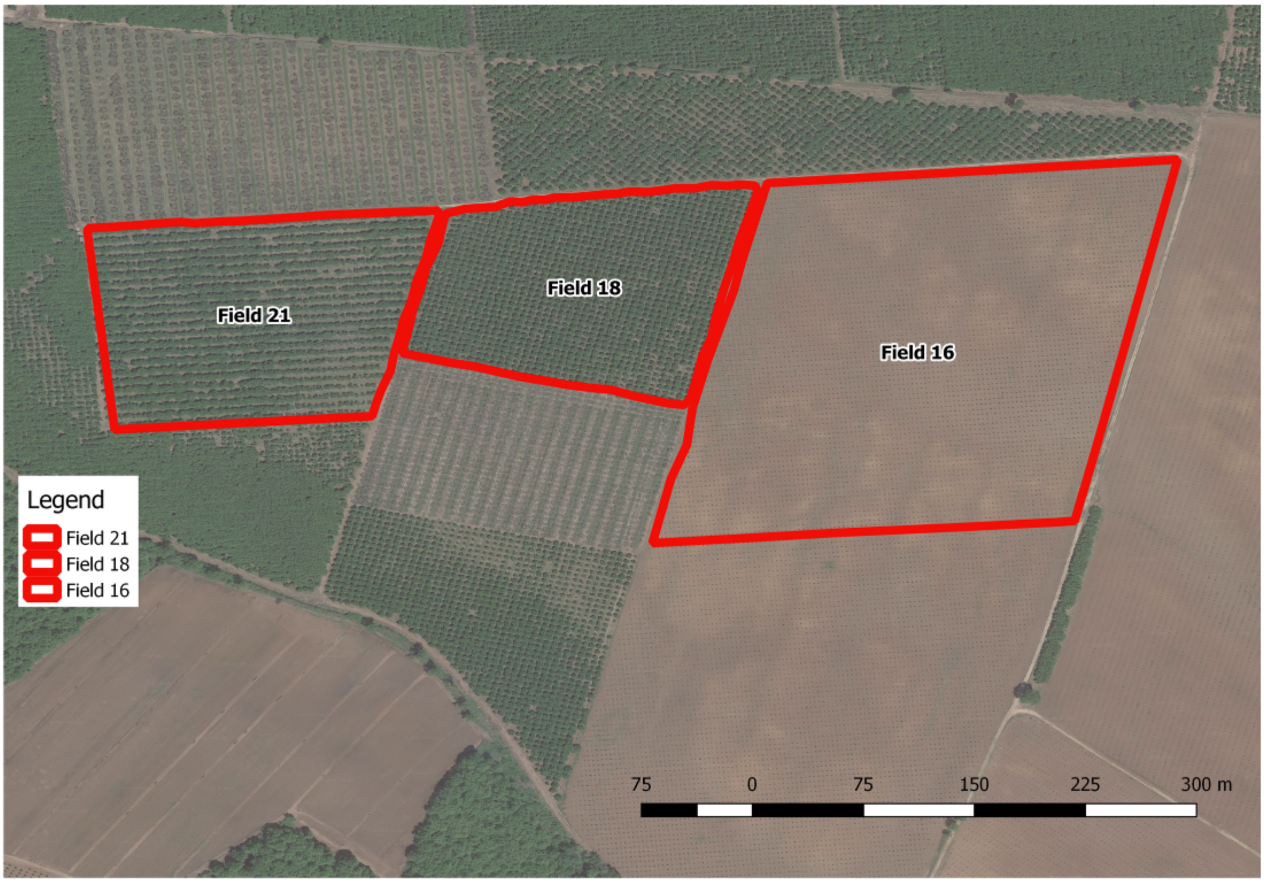

Fig. 1: Selected fields for the PANTHEON project.

Tab. 1: Selected blocks for the PANTHEON project and their characteristics.

Name	**Area (ha)**	**Variety (-)**	**Density (m)**	**Age (year)**	**Irrigation (-)**
Field 16	9.1	Nocchione	4.5x3.0	Young: third leaf in the field	Underground drip irrigation: double line between the rows, 0.8m from the tree lines
Field 18	3.1	Tonda Gentile Romana (Nocchione as pollinizers)	5.0x5.0	Adult: 30	Underground drip irrigation: 1 line between the rows
Field 21	3.8	Tonda Gentile Romana (Nocchione as pollinizers)	8.0x4.0	Old: >40	Underground drip irrigation: 1 line between the rows

The shapefiles (see Fig. 1) of the selected 3 fields have been shared with the partners, in order to plan field activities and organize in what portion of the land to perform different experiments. Several trees will be selected for both manual and automated monitoring, in relation to the 5 agronomical activities listed above: irrigation, pruning, sucker detection and removal, pest and disease detection and harvest estimation. In other words, all chosen trees will be regularly monitored by experts to obtain calibration and validation data for the automated detection activities, which will be performed with sensors mounted on Unmanned Aerial Vehicles (UAVs) and Unmanned Ground Vehicles (UGVs).

Manual monitoring activities replicate standard agricultural practices in orchard management, with the added value that in this case the scientific partners will monitor at a higher temporal and spatial sampling rate the selected fields. The dataset outcome of manual monitoring will represent the calibration and validation database for the automated monitoring activities. Manual sampling activities will include the following variables:

- Phenology stages;
- Pest and disease monitoring;
- Additional biometric variables.

Additionally, two yearly activities will regard:

- Innovative pruning for a subset of selected trees;
- Manual or vacuum collection of production per tree, at harvest time, for all trees on which automated fruit monitoring will be carried out.

The same trees selected for manual monitoring will be also monitored automatically with cameras and radars mounted on UAVs and UGVs. Details on the selected sensors are provided in the following Section 2.

2 Analysis of the functional specifications definition

In order to automatize the above described operations up to the resolution of the single plant, project PANTHEON foresee the development of the agricultural equivalent of an industrial Supervisory Control and Data Acquisition (SCADA) system. More specifically, the proposed SCADA system is composed of the following main components which will be detailed in the following:

1. Wireless Backbone Network
2. GPS-RTK Positioning System
3. UGV (RB-SHERPA Robots)
4. UAV (DJI Matrice 600 Pro with RTK)
5. IoT (Interner of Things) Network
6. DB Architecture
7. Central Unit

2.1 Wireless Network Backbone

The Wireless Network Backbone (WNB) is the infrastructure required to keep all the components of the SCADA system interconnected, from the central unit housing the DataBase (DB) to the single robots moving in the field. 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 in the field itself. The two long-distance antennas are required to connect the central unit, stored in a remote warehouse, to the mesh network deployed in the field. For the sake of easy hardware and software integration, we decided to rely on commercial Wi-Fi solutions based on the 802.11 standard, at either 2.4GHz or 5.0GHz.

The WNB consists of eight antennas and one router, specifically:

- 2 AIRMAX antennas (LiteBeam AC GEN2);
- 6 UNIFI antennas (AC MESH PRO);
- 1 router (TP-Link Archer C9).

The router is the main component and it has to be placed inside the control room, i.e., an area dedicated to the project to be defined within the facilities of the farm. The first AIRMAX antenna is wired connected, i.e. through an Ethernet cable, to the router and orientated to the second antenna placed in the field. This allows creating a connection from the control room to the mesh network deployed in the field.

Regarding the mesh network, the first UNIFI antenna is wired connected to the second AIRMAX antenna. Any other UNIFI antenna is wireless connected, i.e. through an uplink-downlink radio connection as specified by the UNIFI Protocol, in order to create a mesh network. In this way, the signal is re-broadcasted through a desired network topology pre-configured from a UNIFI Controller, permitting the connection between all devices in the field.

The AIRMAX LiteBeam AC GEN2 is an ultra-lightweight airMAX ac CPE device, that can provide 23 dBi of gain for long-distance connectivity and which uses a directional antenna pattern for improved noise immunity.

The UNIFI AC MESH PRO is an access point wireless dual-band 802.11AC 3x3 MIMO with two Gigabit Ethernet port and an integrated omni-directional antenna, ideal to cover ample external zones.

2.2 GPS-RTK Positioning System

The GPS-RTK positioning system provides accurate location information. Indeed, this capability is required to collect geo-referenced data, such as images or 3D laser cloud-points. Furthermore, it facilitates the development of safe and autonomous guidance algorithms for the unmanned vehicles. The selected GPS-RTK positioning system relies on the availability of the WNB infrastructure for transmitting GPS corrections over the field.

The GPS-RTK positioning system consists of the following elements:

- 1 base station, Trimble BX982 GNSS receiver;
- 3 GPS antennas, GPS Zephyr (one for base and one for each robot);
- 2 GPS module Trimble MB-Two (one for each robot).

The base station should be connected to the WNB in order to transmits GPS L1/L2/L5 and GLONASS L1/L2/L3 signal corrections. After receiving these corrections, the GPS module mounted on-bard each robot applies them to an initial localization provided by the GPS antenna, generating a final more accurate localization.

The GPS module provides faster dual frequency-based heading acquisition and an improved RTK/PPP positioning engine. In this way it permits the use of use a Global Navigation Satellite System (GNSS) configuration with dual antenna/frequency (GPS, QZSS, GLONASS, Beidou, Galileo). In addition, Ashtech's patented Z-Blade technology drives a powerful GNSS agnostic engine, allowing the GPS module to use any combination of GNSS system for positioning. The Trimble BX982 receiver enclosure is a multi-channel, multi-frequency GNSS receiver, it is suited for applications that require precise heading and attitude information in addition to position. This combination of technologies, using L1 and L2 signals, allows reaching the following specifics:

- Accuracy (High-resolution mass spectrometry): < 8 mm + 1 ppm
- Initialization time: < 1 min typical
- Operating range: > 40 km

2.3 RB-SHERPA Robots (UGV)

Two UGVs are required for the activities of the projects, namely robot A (R-A) and robot B (R-B). Both robots have the same sensorial equipment and share a common localization, safety and navigation system.

In particular, the following onboard sensors are mounted on both robots: high accuracy gyro, laser scanners (SICK 300), GPS module (Trimble MB-Two), and 3D Lidar (Velodyne).

The main task of R-A is to collect sensorial data for tree geometry reconstruction, for the assessment of the phytosanitary status of the plants and to mark branches for pruning.

The following onboard sensors/devices are mounted only on R-A to facilitate activities in the field:

- 3D Laser scanner (Lidar);
- Sony a5100;
- RedEdge-M;
- DJI Ronin MX.

The 3D Lidar scanner provides 360°, 3D distance and calibrated reflectivity measurements allowing a graphical reconstruction of trees geometry at a later phase. The Sony a5100 provides High resolution RGB Images. The RedEdge-M sensor generates Chlorophyll maps, NDVI maps, Digital Surface Models (DSMs), and RGB Images. The Chlorophyll map is obtained using also the red edge spectral band, that works in conjunction with the other bands to provide a measure of plant vigor and health. The NDVI maps is obtained comparing the reflectance of the red band with that of the near-infrared band. A DSM is a product used to evaluating surface properties and water flow. The RGB Image is processed aligning all visible bands. The DJI Ronin MX is required to facilitate target aiming on scanning and marking phases.

The main task of R-B is to apply chemicals on suckers with the scope to remove them and any related features. For this purpose, an agricultural atomizer has been integrated with electrical driven pump. The sprayer is mounted on a Pan-Tilt mechanism to facilitate target shooting. This Pan-Tilt mechanism is based on Dynamixel motors.

Two different kinematics models have been chosen for the two robots, according to the specific applications to be carried out:

- Omnidirectional, 4x Multidirectional wheels, on R-A;
- Ackerman, 2x Multidirectional wheels, on R-B.

In addition, each robot has a Wireless Emergency Stop for safety reasons, i.e. a button which can stop the robot's engines, in case of malfunction.

From a software standpoint, every main component of each robot is integrated and managed within the ROS environment, thus making it easier to manage, control, and save to the DB infrastructure all real-time data captured by robots or ioT sensors.

2.4 UAV

The selected aerial platform is the DJI M600 Pro with RTK which will be customized in order to perform hazelnut remote sensing using high level sensors. The reasons for this choice are here listed:

- Affordability;
- Robustness of the platform;
- Widespread technology: in particular, the fact that this platform is becoming a state-of-the-art solution all around the world, which will potentially maximize the impact of the developments carried out in the PANTHEON project.

The robotic platform consists of five functional elements:

- DJI M600 PRO drone;
- DJI RTK system;
- DJI Manifold;
- DJI Ronin MX;
- The payload.

The Matrice 600 Pro is a six-rotor flying platform designed for professional aerial photography and industrial applications. This model is equipped with a DJI A3 Pro triple-modular redundancy system and advanced intelligent flight functions. The A3 Pro flight controller provides three GPS modules and IMUs which add triple modular redundancy to reduce the risk of system failure.

This system is complemented with an RTK module which, using a ground station, provides corrected GPS signals to improve its accuracy. To control the high level behavior of the drone, this will be augmented with a DJI Manifold added on the top of the aircraft.

The DJI Manifold will be connected with all the components of the system and with a long-range high-speed communication radio that communicates with the rest of the SCADA system.

A gimbal Ronin MX has been installed to host, orient, and stabilize the payload. The gimbal Ronin MX has its own intelligent battery and compensation system. The performance of this gimbal can be also controlled either with the DJI radio controller or with the DJI manifold computer.

The payload consists of 3 different sensors attached to the gimbal, specifically:

- 1 multispectral camera Tetracam MCAW 6 + filter;
- 1 thermal camera ThermalCapture 2.0 640;
- 1 RGB camera Sony α5100.

The functional specifications for the overall system are the following. The system must be capable of navigate autonomously on the orchard with a precision of less than 15 cm. The system must be capable of triggering all the camera of the payload, if needed in a synchronized way, and to record all the relevant telemetry data of the UAV and of the gimbal at the moment of the triggering. The system must be provided with a path planner able to design the mission (trajectories to be followed and triggering point) and to execute it autonomously. The system must be compliant with Italian Laws and Rules on Unmanned Aerial System.

2.5 IoT Network

An IoT-based agro-meteorological monitoring network, based on the new LoRa communication protocol, will be deployed in the field. It consists of the following modules:

- 1 station for the survey of meteorological data;
- 9 LoRa nodes to record humidity and temperature data of the soil; -
- 1 LoRA/RoS Gateway of the network.

The modules of the network 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.

The meteorological station acquires several environmental variables: precipitation, wind direction and wind speed, air temperature, relative humidity, air pressure and solar radiation. The station is powered by a 12 V - 7.2 A battery and a 10W solar panel, which allows continuous data collection.

LoRa nodes represent peripheral units installed in the field for the acquisition of high-resolution soil moisture and temperature data, which will be collected at two depths, using capacitive SDI12 sensors. Nodes are based on a Teensy microcontroller that uses a 72 MHz Cortex-M4 processor and an RF transceiver module RFM95W that features an LoRaTM long range modem at 868 MHz. In particular, such modem provides ultra-long range spread spectrum communication and high interference immunity while minimizing current consumption. Nodes will have an estimated consumption of about 20-30 mA and will be powered by a 7.2V lithium battery at 6800 mA and a 5W solar panel. Thanks to high gain antennas and to the installation on special poles, the nodes will have a stable communication range of a few kilometers.

The Gateway will be based on Raspberry Pi 2 microcontroller with ARM Cortex-A7 quad-core 900MHz CPU, 1GB RAM, an Ethernet Port, a WiFi module, a LoRa RFM95W module and a high gain antenna for receiving data sent from the nodes. A RoS node will be implemented on the Gateway to allow communication between the LoRa network and the Mesh Network of the WNB.

2.6 DB Architecture

DB Architecture is composed of 2 DB servers: a primary DB server and a secondary DB server. The primary DB server is placed on the control room near the field, and its main task is to store real-time data provided by the IoT network, through a dedicated ROS node. The secondary DB server is positioned at the facilities of UNIROMA3, and its main task is to allow storage and computation capabilities for analyzing all data collected by the UAV/UAGs and by the IoT network. In particular, we decided not to rely on the ROS network for storing large data, such as 3D Lidar point clouds, coming from the sensors onboard the UAV/UGV. This decision has been made considering the following two factors: size of the data and the fact that the data will not be collected continuously over time (as per the IoT network).

The PANTHEON project will rely on NoSQL database technology for the realization of the DB architecture.

2.7 Central Unit

The central unit is the workstation where the main software components run. This includes the ROS core, the primary DB server, 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. The central unit will be interconnected with the server at the UNIROMA3's Robotics Lab. This will allow, for instance, the availability to the central unit located in the farm of the results of the computational-intensive tasks to be carried out in the main, more powerful workstation available at the UNIROMA3 facilities, where the secondary DB server is located.

3 Identification of appropriate means to verify the set of benchmarks

In the following Tab. 2, we describe the set of benchmarks that will be used to measure the project advancement and assess the effectiveness of the obtained results.

Tab. 2: Reasonable benchmarks that will be used to measure the project advancement and assess the effectiveness of the obtained results.

Objective	**Benchmarks**
SCADA Infrastructure Development	
1.1 Ground Robot Navigation, Sensing and Actuation	1. Safe autonomous navigation within the selected fields for the experimental validation. 2. Tree branch marking with an accuracy of ~4 cm at distance of ~2 m.
1.2 Aerial Robot Navigation, and Sensing	1. Automatic mapping with multispectral sensors of an orchard of 3ha in less than 20 minutes with a precision of 5 cm/pixel
1.3 Data Collection, Storage and Analysis	1. Average query time of the analytical engine less than 10 seconds.
Hazelnut Remote Sensing	
2.1 Tree Geometry Reconstruction	1. Automated Lidar co-registration with an accuracy of 2 cm. 2. Algorithm capable of detecting branches with a minimum diameter of 2 cm.

	3. 3D model representing at least 80% of the input point cloud for bare-leaf plants. 4. Automated detection of Presence/Absence of suckers: omission error below 20% and commission error below 20% for suckers longer than 5 cm; omission error below 25% and commission error below 25% for suckers shorter than 5 cm. **VALIDATION measure A**.
2.2 Water Stress	1. Accurate radiometric and geometric pre-processing of the remote sensing data to allow a reliable retrieval of vegetation indices and geolocalization of the pixels (1 m accuracy). 2. Overlay the seven image bands from the multispectral sensor with a total accuracy <2.5 pixels. 3. Differences between the automatic water stress evaluation performed through remote sensing and through direct measurements below 10%. **VALIDATION measure B.**
2.3 Pest and Disease Detection	Automated detection of Presence/Absence of diseases (pests+pathogens+bacteria) with false positive below 35% and false-negative below 35% with respect to human inspection. **VALIDATION measure C.**
2.4 Fruit Detection	1. Automatic counting of the number of visible nut clusters with accuracy of at least 80%. **VALIDATION measure D.** 2. Estimation of the total value of nut kilograms on the plant with accuracy of at least 70%. **VALIDATION measure E.**
Agronomic Decision-Making	
3.1 Pruning Plant Policies	1. Discrepancies between the automatic sucker treatment decision and the decision that would have been taken by an expert human in less than the 15% of the cases. **VALIDATION measure F.** 2. Substantial differences between the application of the automatic pruning protocol against the human application of the same protocol in less than the 30% of the cases. **VALIDATION measure G.**
3.2 Plant Phytosanitary Status	1. The SCADA is able, based on the water stress indices, to regulate the irrigation levels in a way that is, in the 90% of the cases, in line with the human decision. **VALIDATION measure H.** 2. Based on measurements and historical data, the expert system suggests phytosanitary interventions for pest infestation/disease infection that in the 75% of the cases are in line with the prescription of human agronomists. **VALIDATION measure I.**
3.3 Fruit Production Estimation	1. Differences between fruit production estimation, over the monitored trees, and the harvested product of the same trees below 30%. **VALIDATION measure L.**

VALIDATION measure A: any time the automate sucker monitoring is performed, a technician will collect, per each single monitored tree, measurements in terms of number, volume, height and diameter of suckers.

VALIDATION measure B: a technician will collect leaf samples the same day of the automated monitoring to compute leaf Relative Water Content (RWC):

$$RWC\ (\%) = [(W-DW) / (TW-DW)] \times 100$$

where

W: Sample fresh weight

TW: Sample turgid weight

DW: Sample dry weight

as ground truth data; additionally, soil moisture contents will be used to potentially help differentiating water stress from pest and disease stress.

VALIDATION measure C: an entomologist will be present in the field the same day of the automated monitoring to evaluate pest and disease condition of each plant (see protocol of Tab. 3); additionally, the evolution of the health state of the same plants in the following days/weeks will be monitored by the entomologist.

VALIDATION measure D: the result of the automated count will be compared against the manual count, performed on the same image as the one given as input to the automated algorithm.

VALIDATION measure E: for the trees selected in field 18, based on knowledge of average nut weight per variety and on the manually counted nuts/clusters on the plant, an expert agronomist will make an estimation of the total quantity of nuts present on each tree, to be compared against the value obtained from automated monitoring.

VALIDATION measure F: the result of the automated decision will be compared against the decision that an expert would have made, on the basis of the same inputs, i.e. image(s), used by the automated algorithm.

VALIDATION measure G: the result of the automated decision will be compared against the decision that an expert would have made, on the basis of the same inputs, i.e. image(s), used by the automated algorithm; comparisons will be performed on the number of branches selected for pruning both manually and automatically, and on the overlap of the manual and automated suggested pruning policies.

VALIDATION measure H: the result of the automated decision will be compared against the decision that an expert would have made, on the basis of the same inputs, i.e. water stress indices, used by the automated algorithm.

VALIDATION measure I: the result of the automated decision will be compared against the decision that an expert would have made, on the basis of the same inputs, i.e. measurements and historical data, used by the algorithm.

VALIDATION measure L: on the trees selected in field 18, manual harvest will be performed per plant according to what depicted in Fig. 3.

4 Ethical, Legal and Societal (ELS) issues

The project will deploy human resources to carry out both research and experimental activities: UAV pilot operators, UGV pilot operators, Manual Data Acquisition technicians, Agronomists and agriculture experts. All automated monitoring activities will be performed in accordance to the regulations of the country in which they are carried out. There will always be pilots present at any time to ensure that a human can always override the UAV and/or the UGV and halt the activities in case of any danger.

A common concern related to the introduction and uptake of precision agriculture is that it might lead to loss of jobs, with human labor potentially being increasingly replaced by robots and computers. However, we do believe that investments in research and development in precision agriculture will be the key driving force for bringing about the agricultural jobs of tomorrow. A conversion of low skilled workforces into technologically skilled farmers in the role of sustainability shepherds is the future envisioned in this project. This will lead to more efficient production and new employment opportunities because of the new technologies of precision agriculture.

For what concerns data collection and privacy, no tracking or observation of participants is foreseen, and no personal data will be collected willingly. The datasets of interest, collected either manually or automatically, regard orchards and trees. In other words, these data will not contain any personal information except a progressive identification number. The identity of the expert, which will be hidden by the identification number, will be known only to the leader of WP5, who will store it in a physical repository for his eyes only.

In relation to Section 7.1 of D8.1, we would like to reiterate the fact that the project does not pose any relevant risk or harm for the environment. Given their small dimensions, it is extremely unlikely that both UAVs and UGVs may cause harm to the plantations. The majority of the time, these robots will capture data in a non-invasive way. During the minimal part dedicated to active operations (irrigation, branches marking and spraying of the herbicide), in the PANTHEON project, water will be used instead of herbicide and non-toxic substances will be employed for marking and irrigation. Additionally, it is important to underline the fact that the whole scope of the project is to reduce the impact and the invasiveness of agricultural activities, with respect to the current standard practices. For example, as anticipated in Section 1.3, the early detection of suckers will help reducing the amount and the concentration of herbicide. Moreover, a more efficient detection of localization and dimension of suckers is a key information to help reducing waste and pollution, improving at the same time the plants' health.

For more details about the ethical aspect concerning the collection and usage of data, the informed consents that will be signed by the people involved in the measurement and benchmarking activities, and on the procedures for the management of the robots, please refer to Deliverable D8.1.