Call2_Experiments

Ground Robot for vineyArd monitoring and ProtEction

(GRAPE)

Participants:

Num	Partner Name	Acronym	Type	Country
1/Coordinator	Fundación Privada ALIRA	EURECAT	RTD	Spain
2	VITIROVER SAS	VITIROVER	SME	France
3	Politecnico di Milano	POLIMI	UNI	Italy

Table of contents

1 Scientific and technological quality

The GRAPE project addresses the agricultural and food robotics scenario, focusing on vineyard farming activities and aiming at setting up a robotic manipulation platform able to support lead users to develop a variety of farming applications. Coherently with the research scenario, two application examples are being developed during the experiment. The first one applies advanced perception capabilities to grapevine monitoring, laying the foundations for the development of agricultural robots able to autonomously collect data the agronomist can use to assess and predict plant health status. The second one applies advanced perception and action capabilities, related to navigation and manipulation, to perform a farming task that entails the deployment pheromone dispensers on the plant for mating disruption[1].

1.1 Experiment objective

Precision agriculture practices are the most effective way to significantly reduce the negative environmental impact of farming due to over-application of chemicals, while still producing enough food to satisfy a growing demand. Indeed, turning traditional farming into precision farming, not only lowers the chemical load in food and environment, but also improves profits and harvest yields, giving farmers a return on their investments [Herring]. The introduction of advanced sensing capabilities allows monitoring at plant level, spotting problems before they spread. Furthermore, introducing farming robots, chemicals can be applied with honeybee precision, pesticides and fungicides can be used only when needed and in the smallest necessary amount, or even be substituted by less impacting techniques (e.g., mechanical instead of chemical thinning, biological control instead of chemical pesticides). In brief, the introduction of advanced perception capabilities (i.e., high-tech sensors) and action capabilities (i.e., robotic platforms) brings a leading-edge technological approach into farming, allowing for observing, measuring and acting.

The adoption of such an innovative concept in vineyard farming entails the automation of many tasks, ranging from green pruning and bunch-tip thinning, to precise spraying of chemicals and water, to plant monitoring and protection using integrated biological techniques. In all the envisaged operations, the introduction of a robot can alleviate the human workload, increase yields, and lower production costs. Nevertheless, some of these tasks are still too complex to be automated and current state-of-the-art in research and technology have been proved to be not yet mature to give rise to a commercial product able to compete with a skilled agricultural agent [Vey]. GRAPE project (Ground Robot for vineyArd monitoring and ProtEction) aims at creating the enabling technologies to allow agricultural service companies and equipment providers such as VITIROVER to develop vineyard robots that can increase the cost effectiveness of their products with respect to traditional practices. In particular, the project addresses the market of instruments for biological control by developing the tools required to execute (semi) autonomous vineyard monitoring and farming tasks with Unmanned Ground Vehicles (UGVs) and, therefore, reducing the environmental impact with respect to traditional chemical control. In this scenario two different vineyard applications are considered in order to demonstrate the aforementioned tools:

A grape moth

- The first one concerns (semi) autonomous monitoring of vineyards. In the autonomous case, UGVs travel the vineyard autonomously executing a specific task such as grapes and foliage inspection. In the semi-autonomous case, the UGVs autonomously travel the vineyard sending video streams to the agronomist. If a problem is detected, the agronomist can teleoperate the required analysis.
- The second application concerns the autonomous execution of a farming task, namely the application of pheromone dispensers to protect the grapevine, by way of mating disruption, from the grape moths. The

A pheromone dispenser

[1] Mating disruption is a pest management technique involving the use of synthesized sex pheromones to disrupt the reproductive cycle of insects.

UGVs travel the vineyard, select some target plants, and, by means of an onboard manipulator lightly slide on, or twist around, the dispenser on the branches.

The GRAPE project focuses on the development, demonstration and validation of the enabling technologies for the two aforementioned specific agricultural tasks which have high and proven impact on the growth of the vineyards and represent a business opportunity for the lead industrial partner in the consortium. The enabling technologies for these tasks will be developed following modularity principles to naturally support its extension to a fleet of robots. The GRAPE project focuses on the following general objectives:

O1. Development of a robotic platform for vineyard applications: Key enabling technologies own by the partners in the field of navigation, perception and manipulation are improved and combined to develop a vineyard robotic platform able to navigate on rough terrains, to detect and monitor plant, and to manipulate small objects (i.e., the pheronome dispensers). The resulting capabilities will strength the value chain for agricultural robots in general allowing SMEs working in the fields of agricultural robots, but also in the field of plant protection (e.g., manufacturing and retailing of fertilizers, pesticides, and growth promoters) to develop and commercialize vineyard robots, new services and new products. Means of verification: successful completion of milestones M2 (Vineyard navigation and Monitoring task) and M3 (Dispenser deployment task).

O2. Increase robot acceptance by farmers and agronomists: In order to be a successful product, the vineyard robotic platform should be accepted by potential end users. For this reason, particular attention is paid to all the aspects related to the interaction between the farmer/agronomist and the platform. For example, user interface is kept as simple as possible moving the complexity to the control system and making the platform as autonomous as possible. The consortium will maintain a regular contact with stakeholders on the field among which winegrovers such as D.O. Penedès (support letter included), Rotari in Italy and Château Coutet Saint-Emilion in France, among others. The project also counts with the expert support of BIOGARD (letter of support included) for biological control instrumetns deployment. Means of verification: successful completion of milestone M5 (Farmer can satisfactory use the robotic platform)

1.2 Progress beyond the current state of the technology

To address the objectives previously mentioned, GRAPE faces scientific and technological challenges that require a progress beyond the current state-of-the-art.

From the scientific point of view the following issues are addressed:

Advanced action capabilities for vineyard navigation (Task 2), in order to perform any kind of activity in a vineyard, the robotic platform has to be able to safely navigate in an outdoor environment characterized by sloping rough terrains (in Italy and Spain majority of vineyards are located in hilly and mountainous regions). This entails many different scientific challenges that, up to this time, have been only partially solved by the current state-of-the-art technologies. In particular:

- 6DoF localization and 3D mapping with LIDAR in a semi-structured environment fusing information coming from rough terrain odometry, low-cost GNSS receivers, and point clouds acquired by a 2D LIDAR in a push-brum configuration;
- A path planning module considering terrain characteristics (safety) and kinodynamic constraints (feasibility) will be implemented using state-of-the-art search based planning (e.g., with the use of SBPL), but with motion primitives which take into account static (terrain slope) and dynamic (arm motion) platform stability constraints while avoiding unexpected obstacles.

Note that, some of these capabilities are not only essential during autonomous navigation, but they are crucial even during teleoperation as vehicle stability/safety has to be always ensured.

Advanced perception capabilities for plant detection and monitoring (Task 3 and Task 4), plant monitoring is one of the most important activities in farming, and the availability of a device that can autonomously collect data from the field could significantly improve productivity. In order to perform such task, the perception system has to operate in an unconstrained natural environment, such as the vineyard, where the scientific challenges for computer vision techniques are countless. Out of all possible perception tasks to be performed in an agricultural setting, the project will focus on the following challenges:

- Detection of plants structure in highly unstructured scenes with large degree of uncertainty; this will be performed by fusing data collected by the LIDAR and a visual sensor placed on the robot arm; information about the plan structure is the base for the manipulation activity of the project;
- Assessment of crop condition (i.e., grape yield, foliage measurement, etc.) in ever-changing illumination and shadow conditions; different perception modalities will be exploited including colour information and the spatial distribution of acquired points (i.e., isotropic for grapes, planar for leaves and linear for branches).

Advanced perception capabilities are essential in manipulation tasks as well, in order to control (e.g., by way of visual servoing) the manipulator in a complex, unstructured and dynamic environment.

From the technological point of view the most important issue is to obtain a reliable prototype that addresses lead users and end users needs and maximize market adoption. On one side, the development platform have to be in line with lead users' expectations in order to represent an actual starting point to develop further farming activities. GRAPE addresses this problem in Task 1, taking advantage of close collaboration with an industrial lead user, VITIROVER. On the other side, the platform will be designed following end users' requirements in order to be accepted by farmers/agronomists. These are addressed in general in Task 1 and in Task 5 for the operator interface thanks to the cooperation with the lead user and end users (also taking advantage of the support/discussion activities at the RIF).

The aforementioned scientific and technological challenges are closely related to the following System Ability and Technology step changes identified for the Agriculture market domain in the Multi-Annual Roadmap elaborated by the euRobotics AISBL association.

System ability / Technology	Targeted TRL / Ability level	Contribution by GRAPE
Motion Capability	**TRL 5 – Technology validated in relevant environments**	
Safe motion on difficult and dynamic terrain	**Level 9 – Environmental affordance**	The robot safely navigates sloped and rough terrains, taking into account stability and platform kinodynamic constraints
Track and path planning to optimize energy and ecological parameters such as ground compaction	**Level 7 – Position constrained parameterized motion**	Path planning considers platform stability and kinodynamic constraints. Other criteria, such as energy/ecological parameter optimization can be easily taken into account
Perception Ability	**TRL 5 – Technology validated in relevant environments**	
Ability to identify boundaries, crop condition, objects including animate objects in fields, distinguish plant types and pests	***Level 5 – Knowledge driven action***	The robot is able to detect plant boundaries and distinguish between leaf and branch in order to find the best position to deploy the dispenser

A state-of-the-art of the most important scientific and technological challenges, focusing on the specific approaches and solutions proposed in GRAPE, is drawn hereunder.

Autonomous navigation in 6DoF: In GRAPE, the robot navigates and performs complex maneuvers in a hilly environment characterized by substantial terrain roughness (Task 2). The ROAMFREE engine [Cucci.a, Cucci.b, Cucci.c], which relies on a state-of-the-art formulation of the factor-graph-based sensor fusion problem, is adopted. This framework has been designed during the ROAMFREE PRIN2009 project (lead by POLIMI) to perform 6DoF localization, handling an arbitrary number of proprioceptive and exteroceptive sensors, and simultaneously tracking sensor calibration parameters or other unknown quantities such as slippage coefficients. In GRAPE, this framework is extended in order to perform 3D SLAM based on vision and (2D) laser rangefinders, enabling to perform accurate 3D reconstruction and localization of the mobile platform in the vineyard. On the other hand, robot paths are planned taking into account platform kinodynamic constraints (e.g., steering kinematics, actuator bandwidth and saturations, etc.) so as to be feasible, and increase overall tracking accuracy. Moreover, terrain roughness and slope are considered by the planner as well, in order to determine a safe (e.g., with respect to rollover risk) and easily traversable path.

Plant detection and monitoring: A critical task in agricultural robots is to properly perceive the environment, improving the ability to analyze and interpret data. Most of the research in plant detection and monitoring in vineyards has focused on grapes growth estimation [Nuske et al 2011] and foliage size/characteristics estimation [Berenstein et al 2010] [Nuske 2012]. The GRAPE project develops innovative algorithms for plant segmentation aimed at the detection of the foliage and the grapes, but also to detect the trunk so to be able to deploy the pheromone dispensers autonomously. They will aim to detect the best dispenser deployment position, as well as to apply pests by means of noninvasive techniques, i.e., by precise manual servoing (Task 3 and Task 4).

User interface: With the introduction of robotic technology in agriculture, there is an increasing need for appropriate tools to allow the farmer to manage both the information and the robotic assets. The industrial partner VITIROVER is already providing a user-friendly interface for smartphone and tablets. Therefore, GRAPE will integrate with VITIROVER's User Interface to support remote robot supervisory control, as well as teleoperation when the robot is unable to accomplish a task autonomously (Task 5). This development will be based on already existing open-source technology such as [QGROUNDCONTROL] which will feed data to VITIROVER's farm management information system (FMIS) as well. FMIS systems offer a complete range of solutions for the field, including mapping, accounting, water management, etc. Some other examples of commercial FMIS are [TRIMBLE-FMS] and [OMNIAFARM]. There also exist alternative solutions coming from academic research such as [SAFAR].

Vitirover UI

Related projects/prototypes/products: Considering the European scenario related to vineyard robotics, the following prototypes/products have been developed: [Wall-YE], a prototype vineyard robot developed in 2010 by a France software house specialized in distribution of mapping and traceability software for the wine world; [Geisi] a prototype rover designed by the Geisenheim University to crawl up the slippery slopes of Mosel's steepest vineyards and help farmers; [VineyardPruner] a prototype of vineyard pruner developed by Vision Robotics Corporation. The very few commercial products, the presence of prototypes that have difficulties in becoming products and of promising prototypes that have not been approved by the end users, demonstrate that there is still a lot of work to do in order to conceive robust, reliable and easy to use robotic solutions for farming activities, and there are still some activities that are too complex and for which no mature technical solution is available. Concerning research, eight EU projects started in the last five years ([VINEROBOT], [VINBOT], [ROBOFARM], [USER-PA], [CROPS], [RHEA] and [SWEPPER] and [FLOURISH]), focusing on ICT and robotics for precision farming, with direct or indirect application to vineyards, which demonstrates growing interest of research and end user communities in ICT techniques and robotics in farming.

1.3 Concept, methodology, and associated work plan

1.3.1 Task list

Task	Task title	Lead Participant	Start	End
T1	Scenario definition and exploitation plan	VITIROVER	M1	M18
T2	Vineyard navigation	POLIMI	M1	M9
T3	Plant detection and monitoring	EURECAT	M1	M9
T4	Dispenser manipulation and deployment	POLIMI	M4	M12
T5	Robot operator interface	VITIROVER	M7	M18
T6	Integration and demonstration	EURECAT	M9	M18

1.3.2 Description of individual tasks

Task 1: Scenario definition and exploitation plan (M1-M18)		
Participant	**Role**	**PM**
VITIROVER	Task coordinator, responsible for the exploitation plan	**2**

POLIMI	Responsible for the definition of the technical requirements for 3D navigation in the vineyard and manipulation of dispensers.	2
EURECAT	Responsible for the definition of the technical specifications of perception algorithms for plant detection and monitoring	2

Objectives: (i) agreement on application scenarios for monitoring and pheromone dispenser deployment, (ii) agreement on platform requirement specifications, (iii) definition of exploitation plan

Description of work and contribution of individual participants:

The first task of the GRAPE experiment aims at the detailed definition of the application requirements and testbed scenarios for the two application examples: (i) monitoring and (ii) dispenser deployment.
This task is led by VITIROVER, the lead user, thanks to his extensive knowledge of market demands. It includes a startup workshop in a real scenario with VITIROVER's platform in order to define all the technical details and provide the input to the definition of the perception, navigation and manipulation capabilities. Out of the startup workshop the other two partners define the technical specifications of the platform to be used in the experiment. EURECAT derives the detailed specifications for the perception capabilities required to accomplish the two targeted tasks (developed as part of Task 3) and the requirements of the user interface, developed as part of Task 5. POLIMI defines the technical specifications for the navigation and manipulation capabilities, developed in Task 2 and 4, respectively.
This task extends along the whole project. VITIROVER, as task leader and lead user, supervises the overall development of platform capabilities, elaborating an exploitation plan ensuring market uptake.
The outputs are the application requirements and the technical specifications (D1.1) and the exploitation plan which is updated during the whole experiment including a patentability study (D1.2).
Partners' agreement on requirement analysis report is the means of verification of milestone M1.

Task 2: Vineyard navigation (3D mapping, localization and motion on rough terrains) (M1-M9)

Participant	**Role**	**PM**
POLIMI	Task coordinator, responsible for platform localization, path planning and tracking on rough terrains	**7**
EURECAT	Responsible for 3D mapping and localization activities	5

Objectives: (i) creation of a 3D map of a vineyard, (ii) platform localization in vineyard environments, (iii) safe path planning and tracking on rough terrains

Description of work and contribution of individual participants:

This task is aimed at the development of the mobile manipulation capabilities for the experimental platform; leveraging from their past experience in navigation and manipulation, the two research partners cooperate in accomplishing the overall goal of the task. .The task is coordinated by POLIMI and faces the following research challenges to comply with the specifications coming from Task 1: [1] creation of a 3D map of the vineyard by using sensor fusion techniques (e.g., odometry, GPS, accelerometers, magnetometers, laser range finders and vision); [2] accurate localization in the vineyard by using the 3D map information acquired in the previous activity and the sensors available onboard and fusing this information with the other sensors on the platform; [3] trajectory planning and execution on rough terrains by using a search-based planner (based on the SPBL library) with custom motion primitives, designed for the specific platform and taking into account the roughness of the terrain. POLIMI and EURECAT are both involved in 1) and 2) combining their previous experiences in the development of a multi-sensor based odometry and the combination with a low-cost precise global positioning technique respectively. EURECAT will coordinate these two tasks and is responsible for collecting a dataset in realistic conditions. Activity 3) involves POLIMI, that designs and tests the planner using a simulation environment, while EURECAT provides support through the identification of the robot model parameters on the targeted test ground robot platform (owned by EURECAT). The robot model will be used both for simulation and generation of the motion primitives. For each activity a set of validation tests in controlled conditions is performed in order to guarantee the required level of performance on all those capabilities. These experiments are recorded in a final video that presents the reached TRL of the navigation capability together with Task 3 results (means of verification, M2).

Task 3: Plant detection and monitoring (M1-M9)		
Participant	**Role**	**PM**
VITIROVER	Expert knowledge and contribution to plant detection	1
EURECAT	Task coordinator, responsible for algorithm development and validation	**7**
Objectives: (i) precise plant localization and structural detection (trunk, branches, leaves and grapes) based on segmentation algorithms, (ii) selection of the best location to deploy the dispenser		
Description of work and contribution of individual participants: This task focuses on the development of the robot perception capabilities. Thanks to these capabilities, the robot is able to identify the trunk, branches, leaves and grapes. The following activities are part of this task: [1] multi-sensor data fusion (e.g., vision and range data); [2] development/integration of segmentation algorithms to segment the vineyard leaves, branches and grapes and identify boundaries; [3] detection of dispensers' location and/or selection of the best deployment position; [4] integration of algorithms to evaluate crop conditions and plant health status. At the beginning of this task, EURECAT is going to visit a vineyard in D.O. Penedès and collect data logs for later experimentation and validation. EURECAT contributes with their experience in segmentation and objects detection and identification. The algorithms developed in this task are validated in field experiments and will be based on predictive harvest algorithms already used by VITIROVER for segmentation of vine stock and estimation of grape conditions. These experiments are recorded and they present the TRL of segmentation algorithms. This digital video is the means of verification of milestone M2.		

Task 4: Dispenser manipulation and deployment (M4-M12)		
Participant	**Role**	**PM**
POLIMI	Task coordinator, responsible for the development of manipulation capabilities	**7**
Objectives: (i) selection of dispenser deployment position on the plant, (ii) dispenser manipulation and deployment capability		
Description of work and contribution of individual participants: Within this task POLIMI develops the manipulation capabilities for the platform in order to deploy the pheromone dispensers on the target plants (as detected by the perception module developed in Task 3). This task will select the best suitable robotic arm to integrate with the mobile platform. The considered options are Schunk Powerball LWA 4P, Universal Robot 5 (both ECHORD++ suppliers) and Kinova Jaco arm, which will be tested at RIF in Peccioli (M7-8). The activities of this task are related to the design and development of [1] The manipulation capabilities for dispensers' deployment (e.g., approaching a branch using visual servoing, manipulating the dispenser and executing the task required to lightly twist it around the branch); [2] A dispenser storage on the robot so that the manipulator can take a dispenser without having the need to perceive its presence. Activity 1) is first developed in simulation using a state-of-the-art 3D simulator, then, tested in controlled environment with an stand-alone arm. Once the storage from activity 2) has been developed the overall system is tested on a mock up platform prior to the final integration on the GRAPE platform. These experiments are recorded and a final video presents the TRL of the manipulation capability (means of verification of milestone M3).		

Task 5: Robot operator interface (M7-M18)		
Participant	**Role**	**PM**
VITIROVER	Task coordinator, responsible for the definition of the user interface requirements and design of the adaptation to Vitirover platform	**1**
POLIMI	Responsible for integration and validation of the interface to the manipulator	2
EURECAT	Responsible for the development of robot operator interface	7
Objectives: (i) to enable robot teleoperation and telecommand to control the system providing different autonomy modes, (ii) sensor data and robot state synchronization, storage and analysis to display geo-		

graphical and agricultural information, (iii) data export and reporting to VITIROVER's UI and FMIS
Description of work and contribution of individual participants: This task develops operator functionalities to control and monitor the operation of the GRAPE platform in the agricultural field which will be integrated with VITIROVER's interfaces. The following activities are carried out: [1] implementation of platform and manipulator interfaces for low level monitoring and teleoperation; [2] integration of interfaces related to robot navigation in vineyards, including georeferenced maps, 3D views and robot localization and motion/trajectory planning; [3] development of GRAPE application-specific functionalities: including visualization of plant location, structure and status, and support to dispenser deployment tasks (i.e., remaining dispensers in storage); [4] export/import functionalities to VITIROVER's interfaces based on handheld devices. EURECAT leads this task and carried out most of the developments, while POLIMI is involved in 1) for the interface with the robotic arm and VITIROVER provides the support to integrate with their UI. This UI provides the farmer with easy-to-use functionalities to enable robot-farmer complementary interactions. For instance, the farmer should be able to input or modify the location of dispensers manually deployed. The design of this utilities comes from discussion with potential end users. Finally, a set of experiments are performed in order to test each functionality before iteratively progressing to Tasks 6. The output of this task is a functional HMI and a report supporting its acceptance by end users (M4).

Task 6: Integration and demonstration (M9-M18)		
Participant	**Role**	**PM**
VITIROVER	Support to integration and demonstration phase	1
POLIMI	Responsible for demonstration in Italy	4
EURECAT	Task coordinator, responsible for integration and demonstration in Spain	**4**
Objectives: (i) iterative integration of the different components into a single integrated system, (ii) validation of the different scenarios to be demonstrated in the GRAPE experiment		
Description of work and contribution of individual participants: The integration plan foresees the following three phases: 1) Phase I (M9-12) led by POLIMI: A mockup of a grapevine is made available in the laboratory. The robotic manipulator is operated from the robot operator interface to validate the dispenser deployment. This exercise does not involve the mobile platform. 2) Phase II (M12 - 16) led by EURECAT: The autonomous navigation in agricultural terrain is validated in a real scenario in a vineyard owned by D.O. Penedès (Spain). This exercise validates both teleoperation and autonomous navigation on different terrains. The detection and localization of plants is also validated in this activity. End users join the validation to provide feedbacks. 3) Phase III (M16-18) led by VITIROVER. The full system integration is again carried out in a real scenario in a vineyard (Italy, Spain and/or France). This exercise involves all GRAPE components and validates the two proposed scenarios: vineyard monitoring and the application of pheromones dispensers to protect grapevine. A final demonstration is also held in Peccioli RIF.		

1.3.3 List of Deliverables

No.	Deliverable name	Task	Nature	Diss. level	Date
SB	Story Board		O	RE	M16
MMR	Multi-Media Report		O	PU	M18
RIF	Report on RIF visit outcome and demo results		R	RE	M18
D1.1	Scenarios and requirement specifications	1	R	RE	M3
D1.2	Exploitation plan and commercial agreements	1	R	RE	M18
D2.1	Vineyard navigation (methods and algorithms)	2	R	RE	M6
D2.2	Vineyard navigation (results)	2	R+O	RE	M11
D3.1	Vineyard monitoring technique	3	R+O	RE	M11
D4.1	Pheromone dispenser manipulation techniques	4	R+O	RE	M14
D5.1	Vineyard robotic platform HMI	5	R+O	RE	M16

1.3.4 Summary of experiment effort (in person months, PM)

Participant name	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Total PM
VITIROVER	**2**	0	1	0	**1**	1	5
POLIMI	2	**7**	0	**7**	2	4	22
EURECAT	2	5	**7**	0	7	**4**	25

1.3.5 List of milestones

Nº	Milestone name	Tasks	Date	Means of verification
M1	Agreement on scenario definition and requirements' specification	T1	6	Scenario definition and requirements agreed with end users
M2	Robot navigates in a vineyard and performs a monitoring task	T2, T3	9	Video (see description of Task 2 and Task 3)
M3	Robot performs a dispenser deployment task	T4	12	Video (see description of Task 4)
M4	Farmer can satisfactorily use the robotic platform	T5	18	Tests executed with end users on the interface effectiveness

1.3.6 Time plan (GANTT chart)

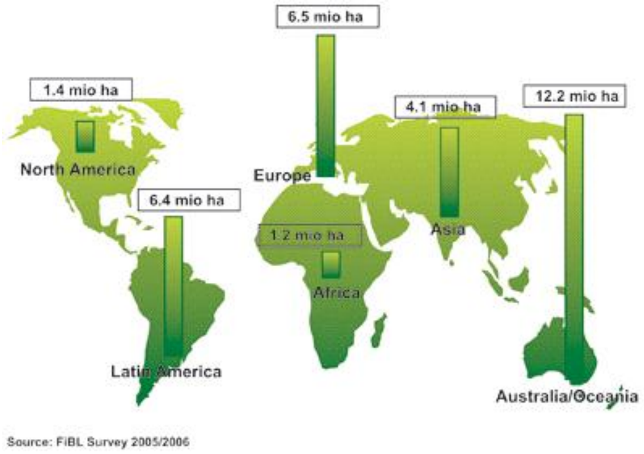
Tasks		Months																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
T1	Scenario definition [...]			D1.1			M1										SB		MMR
T2	Vineyard navigation						D2.1			M2		D2.2							D1.2
T3	Plant detection and monitoring									M2		D3.1							
T4	Dispenser manipulation [...]												M3		D4.1				
T5	Robot operator interface																D5.1		M4
T6	Integration and demonstration																		RIF

1.3.7 Risk and contingency plans

Risk	Risk description	Task	Contingency plan
1	3D mapping is too computationally complex or not robust/reliable	2	Switch to 2D mapping algorithms
2	Localization accuracy is too low Localization is not robust/reliable	2	Add more sensors or replace the current sensors with more expensive/accurate ones
3	Planning algorithm requires too much time to compute a plan	2	Use a different technique or plan without considering platform kinodynamic constraints
4	The on-board sensor cannot see the plant	3	Relocate the sensor: multi-sensor approach vs camera on the manipulator end-effector
5	The assessment of crop condition requires higher resolution and different types of cameras	3	Higher resolution cameras and other cameras (NVIR, hyper spectral) are used during the data collection phase for comparison
6	Perception cannot detect the plant (part) to deploy the dispenser	3	The user manually select the plant/plant part using the operator interface
7	A strategy to deploy the dispenser on the plant cannot be determined	4	The user manually select the deployment position using the operator interface
8	Manipulator cannot slide/twist the dispenser on the branch	4	Make a hook with dispenser, the manipulator simply hangs the dispenser on the branch
9	Manipulator is not able to take the dispenser from the storage	4	A suitable ad-hoc tool is designed in order to simplify this operation
10	The dispenser deployment is not reachable	4	A mechatronic device extends the working space of the system above the mobile robot
11	VITIROVER's FMIS interface for data interoperability is not standard	5	Data protocols and formats are specifically adapted to VITIROVER's FMIS with end users as the reference to prove the GRAPE concept
12	Peccioli RIF does not provide access to an adequate vineyard scenario	5	Final demo is organized in an alternative vineyard in D.O. Penedès in Spain

2 Impact

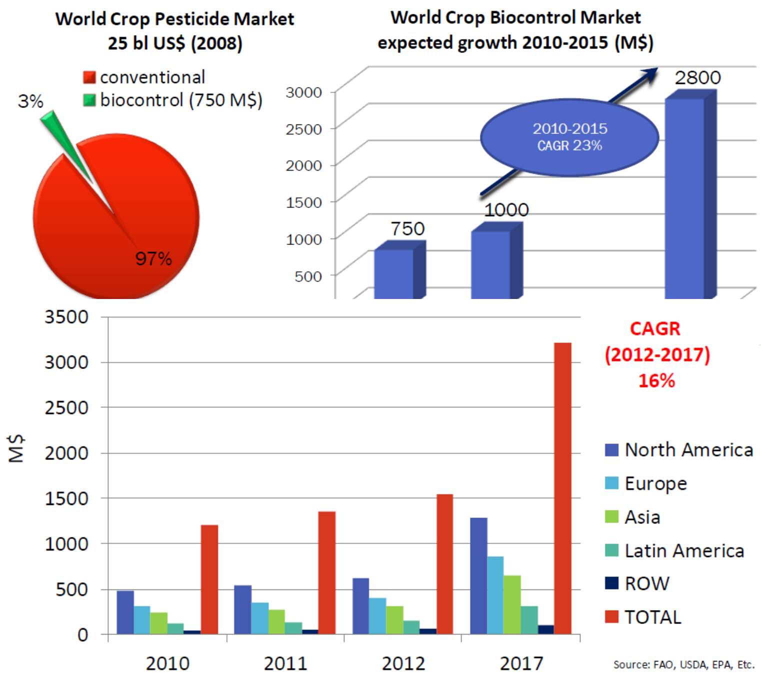
2.1 Expected results



Global certified organic production (2005/2006)

The global market of Integrated Pest Management (IPM) has been rapidly expanding with an increase of more than 150% over the last decade. This growth has been mainly driven by an increase in consumer's awareness of the importance of food quality and dangerousness of chemical treatments. This has led to a global consumer market demand for high quality food, reduced pesticide exposure and organic produce. As a consequence, analysts have foreseen a remarkable expected growth in the IPM market and, in particular, in the crop biocontrol market. Considering now only pheromone-based control products, in 2010 they were used to treat 780,000 ha, while in 2012 the market was about 200 M$ world-wide, growing at over 10% per year (Suterra LLC data). Though this amount was still under 3% of the world-wide insecticide market (9 B$), its rapid growth will soon take the biocontrol over the 15% of the crop pesticide market.

Semiochemical pheromones, a typical biocontrol instrument, can achieve in some cases up to double-digit improvements in reduction of damage produced by the grape moth to vineyards. Even though the cost of this treatment is a bit more than conventional pesticides, they rapidly pay off, reducing the number of spraying campaigns during the season. The use of GRAPE results in the automatic deployment and monitoring of biocontrol instruments will further decrease the costs, improving farmers working conditions and efficiency.



Biocontrol market growth

Increasing market adoption of agricultural robots: the lead user VITIROVER was created to foster the adoption of energy and cost-efficiency agricultural robots for vineyards as substitution of current oversized agricultural equipment putting data driven agronomy in the farmers' hand. VITIROVER's team has a wide experience in robotics, agronomic business and farm management as well as a wide network of wine stakeholders (producers, equipment companies, associtations, etc.) to offer not just a potential market validation network for their products but the necessary commercialization channels to ensure market uptake. Additionally, GRAPE project will count with the support of well known wine producers (DO Penedès in Spain and Rotari in Italy) as well as with BIOGARD, a leader company in the biological control instruments in the Italian market and among the top in the world. GRAPE represents the third product line in VITIROVER's robots catalogue as they already launched the commercialization of a mower robot and have a monitoring robot in production phase.

Table below summarizes GRAPE results and their long term technological/scientific/economic effects.

Experiment result	Impact[2]	Long term effect	Indicator
Vineyard navigation capabilities (D2.1-D2.2)	T/E	Creating new job positions and/or new product lines at lead users	Number of new job positions/product lines created three years after the end of the project
Robust 3D SLAM (D2.1-D2.2)	S	Conceiving new self-calibrating 3D SLAM algorithms for large environments and long-life operation based on multisensory fusion	Number of accepted scientific publications / patents
Safe path planning with stability and kinodynamic constraints (D2.1-D2.2)	S	Conceiving new path planning techniques focused on navigation and mobile manipulation on sloping rough terrains	Number of accepted scientific publications / patents
Safe path following and manipulation with stability constraint (D2.1-D2.2)	S	Conceiving new path following techniques focused on navigation and mobile manipulation on sloping rough terrains	Number of accepted scientific publications / patents
Vineyard monitoring capabilities (D3.1)	T/E	Creating new job positions and/or new product lines at lead users	Number of new job positions/product lines created three years after the end of the project
Grapevine detection and classification (D3.1)	S	Conceiving new classification algorithms for detection and classification of grapevine parts	Number of accepted scientific publications / patents
Pheromone dispenser deployment techniques (D4.1)	T/E	Increasing the impact of robotics on vineyard applications	Number of new vineyard robotic applications
Vineyard robotic platform HMI (D5.1)	T/E	Increasing the impact of technological devices on farming applications	Positive feedback from potential end users (farmers/agronomists)
Vineyard robotic platform (D5.1)	T/E	Widespread availability of off-the-shelf robotic platforms to easily develop agricultural applications	Positive feedback from potential lead users and end users

Indicators to evaluate the impact of the experiment:

Nº	Description of indicator	Intended impact of the experiment	Way to measure the impact achieved	Impact achieved at the end of the runtime of the experiment	Impact achieved one year after the end of the runtime of the experiment
1	Journal / conference papers	Dissemination	Number of published papers	At least 3 conference papers	At least 1 journal paper
2	Meetings/demos with lead users	Dissemination	Industry interest in GRAPE platform	Interest by lead users	Exploitation of GRAPE robotic platform
3	Meeting/demos with end users	Dissemination	End user satisfaction	End user positive feedbacks	Prototype complete for real operations 24/7
4	Patents	Exploitation	Research patentability	At least one patent	The patent is taken for commercialization
5	Jobs/product lines creation	Exploitation	Number of new positions/product lines	One new position created	One new product line created for VITIROVER

2.2 Proofs-of-concept, prototypes, products

[2] Scientific (S), Technological (T), Economical (E)