

Vineyard Vigilant & INNovative Ecological Rover (VVINNER): an autonomous robot for automated scoring of vineyards

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Abstract

"Vitirover" is a solar-powered autonomous mower. Its role is to control the height of the grass in the vineyards. In doing so, this robot is an alternative to tillage which is a big energy consumer, and to the use of herbicides in the vineyards. This robot is now operational and could be a way to reach sustainability for viticulture.

As Vitirover is moving between and under rows of vines it is in a better position to observe the grapes and the vigor of the vegetation that if it is placed above the vegetation. Its permanent presence in the vineyards and the temporary high frequency passing through the vineyards make Vitirover an optimal platform for carrying sensors for monitoring vineyards.

The project “VVINNER” (Vigilant Vineyard & INNovative Ecological Rover) that we are developing aims to transform Vitirover as a multifunctional robot capable of gathering useful information for monitoring the ecosystem of the vineyard, for early detection of disease risk and pest infestations, for the measurement of meteorological data with high resolution and for early yield estimation.

Our analysis focuses on both the relevance of different measurements to be performed and the feasibility of these measures, both from the point of view of cost of sensors and how these measures could be taken automatically in the vine. Our effort in this project is to find a good compromise between the measurement capabilities of sensors, relevance and ease of interpretation of data provided by the sensors and the price of the system on the one hand, and the weight and energy consumption on the other hand.

The use of a vision system consisting of a camera operating in the visible and near infrared seems mandatory for our project. The main roles of the vision system are the measure of the vigor of plants, the estimation of leaf area, the detection of insects captured in traps and the monitoring of grape evolution (color, diameter,…).

The data collected by the robot is finally recovered by an expert system, which is responsible for interpreting the raw data by transforming them into relevant and easily interpreted information by the winegrowers.

Keywords: robotics, computer vision, proximal sensing, vine status, grape detection
1. Introduction

1.1 Context of innovation

In agriculture we are facing a big change by the adoption of a new paradigm. Long time, optimization of inputs for crops or feeding for animals was based on a balance sheet approach. Amount of inputs is the result of a calculation taking into account what is going in and what is going out of a system. This approach is widely used nowadays for determination of fertilizer rates (Nitrogen, Phosphorus,...), for irrigation supply, feeding animals, and so on.

Despite the particular care that farmers could take, results are often not optimal. This is because some balance sheet items are mispriced; this approach doesn't take into account spatial and temporal variability as well as malfunctioning of farm machinery.

Now, the agronomic reasoning is conducted by the data. We can call this new paradigm "Measured Agriculture", this sentence having a double sense in French: sensors are used in order to make measurements of a great set of parameters, and farmers have to moderate their actions in order to be compliant with sustainability of the farm and of the resources.

The optimization of crop management implies recording of a more and more important amount of data related to different parameters of interest. For a long time the farmers have had to make do with a very small sampling pressure, e.g. only one soil sample per hectare, with a return frequency of 1 to 10 years.

With the development of information and communication technologies and services for agriculture, it is now possible to improve this sampling pressure according to two axes:

- Increasing of spatial sampling using sensors embedded on a farm machine or UAVs, airplanes or satellites (domain of remote sensing). It becomes possible to have a continuous or quasi-continuous coverage of the variables of interest (biomass, yield,...). Most often the return frequency is relatively low, of the order of 1 to 5 times per crop cycle, and measurements generally include only a single variable of interest.

- Increasing of temporal sampling through networks of sensors, which have a daily frequency for repetition. Conversely, the spatial sampling pressure remains low with only a few number of sensors per hectare. Several sensors can be associated with each measurement point, so as to follow a quasi-continuous temporal evolution of several variables of interest. These variables of interest – less than a dozen – are usually of only one type, and the majority are related to meteorological parameters (temperature, rain, wind ...).

A third axis could be reached using a mobile platform, with different sensors embedded onboard, and continuously circulating in a crop.

Doing that, we can obtain both a high spatial sampling rate - due to the mobility of the sensors - and a high temporal sampling frequency due to the possibility to make measurements regularly on the same points. The sensors may be located close to the plants, allowing a very fine resolution of measurements.

This third axis is the basis for the Vvinner project. This project aims to develop a coherent set - mobile platform, sensors and decision support system - that can meet the needs for precise management of the vineyards, while remaining economically attractive for winegrowers.
1.2 Vitirover: a rover for vineyard management

The VITIROVER multi-functional robot was created in 2009 by a team of engineers who are also wine growers in the French viticultural region of Saint-Emilion (Bordeaux).

Based on the idea that grass must not be seen anymore as an enemy but rather as an ally which can help reduce if not eliminate weed killers, these engineers have introduced the concept of a small robotized mower for vineyards. The VITIROVER robot is an all-terrain mower which can control properly grass height in vineyards, and this robot is working every day in a totally autonomous way.

In the past 5 years, several autonomous lawnmowers for garden have penetrated the mass market. As these existing mowers can only operate on even and well-prepared surface (like gardens and football stadiums), they are not direct competitors of the VITIROVER, which is designed to mow in difficult and uneven surface conditions, with up to 30% slope.

Being designed to remain permanently in the vineyard, it works very slowly (500m/hour) but steadily.

With its small size (75 * 36 * 35 cm) and its low weight (10 kg), VITIROVER can go under cables and get in direct contact with vine stocks under the vine canopies with no risks of damaging the plants. Being under the vine stocks, it is in a better situation to observe grapes and vegetation vigor than if it was positioned above the vegetation.

The main innovative features of the Vitirover robot are related to its power supplying: it is equipped with a solar panel designed to minimize yield losses due to shadows from the vegetation. This specific solar panel associated with an optimized power management allows for a total energy autonomy, the robot does not need any recharging base and can work in the vines during all the growing season.

The GNSS navigation system enables Vitirover to remain in the work area that was assigned to it by the producer of wine. This assignation could be done through a dedicated smartphone app or a computer interface, thus it doesn’t need any special infrastructure to delimit its working area.

During operation, Vitirover knows exactly its geographical position and can also go directly to the location where the farmer is, when this latter called it from his smartphone application during the visit of the vineyard.

In case somebody would be willing to steal the robot, it is designed to stop immediately to operate as soon as its four wheels are not anymore in contact with the ground. Then, a password is needed to make it operating again.

A first round of demonstration campaigns started last year in France on several vineyards such as Medoc, Saint Emilion, Bourgogne and Champagne.

The first results of this campaign show a strong interest of wine growers for this robotized mowing solution. Vitirover can help them at reducing drastically use of herbicides and other pesticides while improving the vineyard's biotope balance. Additionally, wine growers indicate also that they would also be interested by additional functionalities such as a high resolution mapping of vineyard (precise positioning of each vine stocks), and by vineyard monitoring.
1.3 State of the art

The development and deployment of a new agricultural robot in the field is a current concern of many research teams. Using a small robot equipped with several non-invasive sensors to monitor, analyze and optimize vineyard management and improve grape composition and wine quality, is in vogue topic.

We identified two other projects in competition with our:

- The first one is the German project “PHENOvines” (High-throughput phenotyping of yield parameters and mildew in grapevines), under the leadership of the University of Geisenheim, this project runs from November 2011 to October 2014. This project is not really a competitor of Vvinner because the goal of this project is more for research than for farmers' use, and the platform is not at all autonomous (this is a small caterpillar tractor),

- The second one called “VineRobot” is funded from the European Union’s FP7, and aims to develop roughly the same system as planned in the Vvinner project. This project runs since February 2014, and concerns 4 countries (France, Germany, Italy and Spain) and 8 partners. This project is led by the University of La Rioja (Spain)

2. Materials and methods

The VITIROVER is an innovative robotic rover which is designed to operate typically on one vine-planted hectare with the objective not only to mow it but also to monitor the grape growing process and the status of the vineyard ecosystem by recording appropriate data in the future. These data could be used for decision making and for risk estimation and providing alerts in case of diseases.

Recording all kinds of data can be a very time-consuming, the functioning of embedded devices (sensors, computer, communication and data transfer systems) can be power-hungry and the high price of some sensors (hyperspectral camera, thermal camera, ..) can be an inhibiting factor.

To be able to commercialize this robot in the shortest delay, the first step of our project was to identify comprehensively the different variables that could be measured in a vineyard, such as variables related to soil, climate, plants and different diseases or insects.

Once this is done, we discriminate the following variables according to several criteria:

- The first criterion was the priority given by users on the importance of the frequent and exhaustive measuring of these variables. The information regarding the disease development and insect populations appear as priority because these temporal changes can be very rapid and it is important to get an immediate alert. Conversely, the extent of the soil characteristics is not at all pertinent here, because these variables are very stable over time.

- The second criterion relates to the existence of alternative solutions to embedding sensors on the Vitirover. For example, measuring the variables related to the soil by sensors on board of the robot doesn’t seem useful because other more effective and less costly solutions are already operational (EM 38, Geocarta ...). In the meantime, there aren’t any real competitors for regular monitoring of the maturation of the grapes (color, size, ...). This function - very important for winegrowers - has been chosen as a priority

- The third criterion is related to the sensor and to the measuring means. The main selection criteria for these sensors are their weight and size, ease of implementation and ability to operate in a fully automatic way, with low energy consumption and,
course, price. Some variables important to monitor, such as water stress in case of non-irrigated vineyards, could be measured thanks to very sophisticated, bulky or expensive sensors (e.g. thermal camera). Developments and progress in the design of sensors offer the promise of miniaturization and lower prices of these sensors in the coming years. Such sensors have not been selected yet, but in the future they will be certainly embedded on Vitirover in the future.

The second step was to determine the possibilities of implementation of the measures. In its initial version, the robot travels in a pseudo random manner in the vineyard, so it can go everywhere: both between the rows and below them.

To perform regular measurements, and with a high degree of repeatability, we must change the navigation strategy: the robot must move in the direction of the rows so as to repeat day after day the measurements in the same orientation conditions and distance to the target. This implies a navigation system with accuracy of a few centimeters, but its price must be around a few hundred Euros. The design of such a navigation system is another part of the project, and will not be detailed here. We can just say that the results are consistent with the initial ambitions.

3. Results and discussion

Applying the methodology described above allowed us to define four groups of variables of interest whose characteristics are the following:

- **Group 1**: variables of great interest for the management of the vineyard, and for which the sensors are available on the market. These sensors are inexpensive and easy to board the robot, information collected are easy to process on board or easy to transmit to an expert which can provide an accurate advice to the farmer. These are the variables that were selected for version 1 Vvinner project,
- **Group 2**: variables of great interest for the management of the vineyard, but for which the sensors are not yet available, or too expensive or not very easy to embed in the robot. As these sensors develop, they can be selected as part of a next version of the Vvinner robot,
- **Group 3**: variables of great interest for the management of the vineyard, but which still pose many questions about the possibility to embed in the robot. It is not sure yet that we will have a sensor for measuring these variables, so we don’t make any assumptions yet about measuring these variables by the robot.
- **Group 4**: variables are not of great interest for the management of the vineyard, but the Vitirover robot is not the appropriate vehicle to board these sensors. A priori, these sensors will never be on board the robot.

From this classification we have determined the first set of features of the robot dedicated to the Vvinner project. We selected three broad categories of variables:

- **Meteorological variables**: temperature, humidity, solar radiation, wind. The local microclimate can have a great influence on the behavior of the vine and winegrowers are interested by mapping these variables (especially temperature and humidity at the vegetation level). The sensors are available, well known, easy to implement and inexpensive. The analysis of information from these sensors is not straightforward due to the regular movement of the robot in the vineyards, and high temporal variability of these variables. We must therefore have fix sensors in order to correct the data by differential calculations,
- **Variables related to the development of the vines**: NDVI, biomass, and yield. The NDVI measures are well known (Rousseau 2013), and the sensors to perform such measurements (camera with red and NIR channels) meet the criteria noted above. Measurements of biomass and those on variations of grapes development can be obtained by means of a conventional RGB camera. The difficulty come from the analysis of images obtained in order to quantify the variables of interest. Previous
work (Grenier 2008, Grossetete 2012, Nuske 2013, and Roscher 2014) allow us to be optimistic about the feasibility of these measures on biomass and grapes. There are very high expectations of winegrowers for having early estimation of yield. Some previous work has already provided solutions (Serrano 2005, Grossetete 2012), and it seems of great interest for us to embed this function on the robot.

- Variables related to pests and diseases of the vine: these measures may be more difficult to perform correctly, but they can be obtained with the same camera that we used to monitor the biomass and the ripening of the grapes, requiring only the development of appropriate algorithms for image processing.

According to these functionalities, the first version of Vwinner system is fitted with a small meteorological station, a high-resolution RGB camera (5 MP), a lower resolution R/NIR camera (2 MP), a telemeter, and a wireless system to communicate with stationary in-field sensors and with the expert system. A low-power ARM computer controls all these devices, and it is in charge to process on board the acquired data.

During the growing season 2013, we have used this system for validation of the concept, not yet for large scale testing and data recording. In our tests we have used the robot to take images in different conditions: when robot is moving or after stopping, during day and at night, with sun illumination and with artificial lightning.

Another problem to solve is to take images of the same target in similar conditions and to be able to detect and compare objects visible in these images (e.g.: for counting and sizing of grapes). The goal is to be able to detect variation in shape and color of these objects and to be able to count the number of objects and to measure their diameter.

Examples of results obtained are the NDVI images acquired by the system. These images show the health and the stress of the vegetation. The results prove the interest of the high spatio-temporal sampling frequency provided by the Vitirover to monitor plant vigor.

![Image](image.png)

Figure 2. The grayscale image and NDVI of a vine taken by the robot

The high resolution RGB camera is used for pre-harvest yield estimation and to determine the date of mi-veraison. The system is coupled with a telemeter, so it is possible to estimate the diameter of the detected grape berries.

As only a part of the grapes can be seen on the captured images, a statistical method is used to extrapolate the detection results to yield estimation (Grossetete et al, 2012).

The following image shows the result of the grape color detection used to determine the date of the veraison, an important indicator of the harvest date.
The results of the automated grape color detection show a good correlation with the logistic regression we used to model the change of the color of the berries ($R^2>0.8$). The speed of the change of the berries and the date of the mi-véraison (when half of the berries changed color) helped us to predict the date of the harvest.

The high temporal frequency allows sampling the parcels every second day and the high spatial resolution helped us to build a maturity map with a sub-parcel resolution.

4. Conclusions and further work

In this paper we presented the steps to transform the solar-powered autonomous mowing robot Vitirover into a platform to carry different sensors, capable to monitor the vineyards.

First we made an extensive analysis of the different sensors we can attach to an autonomous robot, the advantage, disadvantage and the feasibility of every sensor group, the required frequency of acquisition, and the methods for processing the data.

Finally, we decided to equip the robot with a small and low-powered ARM computer which can control a vegetation camera, a high-resolution camera and a telemeter. It is also able to communicate wirelessly with fixed sensors in the vineyard.

The system was used mainly for plant vigor measurements, and the grape detection. Our application could detect on board the quantity, color and diameter of the berries in the image. The results are encouraging in yield and maturity estimation.

The tests also proved the usefulness of the system: the constant monitoring and the high spatial and temporal frequency of the data allow us to monitor closely the health of the plants.

Another important point concerns the sampling pressure: the initial idea was to have information on every vine stock, for having both a comprehensive view and a daily monitoring of the vineyard.

This is possible but severely limits the vineyard surface that can monitor a robot. One part of our work will now be for seeking to reduce this sampling pressure to obtain the best compromise between cost / efficiency, i.e. increasing the area monitored by a robot without significantly degrading performance of monitoring. This will be one of the main actions of the 2014 campaign.
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6. References


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