Identifying the Technological Needs for Developing a Grapes Harvesting Robot: Operations and Systems

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Abstract. Robots are increasingly entering agricultural fields to support human labor. Heavy tasks like harvesting are assigned to robots due to their advanced modularity, robustness and accuracy that provide automated solutions to tedious and elaborate tasks. In this paper, the technological requirements of a specialized Agrobot (Agriculture robot) for supporting viticulture tasks such as *harvest*, *green harvest* and *defoliation*, are identified. This robot aims at developing on-board intelligent decision making on-the-spot based on commercial hardware, machine vision and innovative computational intelligence algorithms. Design, structures, methods and sensors are briefly discussed. This study delineates a prototype grape harvesting robot, consisting of a reliable information acquisition system that includes sensor-fusion algorithms and data analysis, adopted to the dynamic conditions of agricultural environments such as vineyards.

Proceedings of the 9th International Conference on Information and Communication Technologies in Agriculture, Food & Environment (HAICTA 2020), Thessaloniki, Greece, September 24-27, 2020.

Keywords: Harvesting robot; Agrobot; automation; intelligent system; system design.

1 Introduction

Current practices of grape harvest include human involvement, such as monitoring and specialized manual work, which seems to have reached its limits; young people abandon viticulture because of inherent work difficulties, the increasing age of grape harvesters prolongs harvest duration, therefore reduces the quality of the harvested grapes and of the produced wines. Thus, there is a need to reliably automate grape harvest (Avital Bechar, 2010; Mavridou *et al.*, 2019). Vine harvester combines were a first attempt toward automation. However, the advent of Agrobots has the potential to raise the quantity and quality of grape product in a constant way, reduce production costs and manual labor and compensate for the shortage of specialized workers.

Extensive research has focused on the application of Agrobots to a variety of vineyard tasks (Bac *et al.*, 2014). Kondo (Kondo, 1991) developed a trial robot to harvest individual bunches of grapes, consisted of a hand which could hold and cut rachis, a visual sensor and a crawler type travelling device. Monta et al. (Monta, Kondo and Shibano, 1995) constructed a multipurpose robot for vineyard tasks, consisted of a manipulator, a visual sensor, a traveling device and end-effectors, able to perform several tasks. A research team (Morris, 2007) developed a total vineyard mechanization system of almost all practices, including dormant and summer pruning, leaf removal, shoot and fruit thinning, canopy management, and harvesting. Two harvesting machines functioning under the same principles were developed by Pezzi et al. (Pezzi, Balducci and Pari, 2013); one with horizontal shaking and another with vertical shaking. The machines were tested and compared.

Simplifying the agricultural tasks and enhancing Agrobots with sensors may improve their performance, but this will refer to a non-feasibly constructed Agrobot and it is insufficient for successful implementation in real in-field practices. For this reason, robotics and non-robotics disciplines need to be identified (Burks *et al.*, 2005) so as to address the following requirements: the robot has to be technically capable of performing the defined agricultural tasks, economically feasible, safe and accepted by the farmers. To comprise all requirements successfully, a multidisciplinary team of specialized experts including engineers, viticulturists and agronomists should extract design methods collaboratively. In this work, the technological needs for the development of an "intelligent" wheeled Autonomous Robot for Grape harvest (ARG) are identified. The objective of this study is to delineate optimally the ARG requirements by a group of experts, towards mechanizing grape harvest in a way that, instead of massively harvesting rows of vines, to harvest selected grapes from the vineyard. This study is based on the ongoing work of project POGHAR (Personalized Optimal Grape Harvest by Autonomous Robot)(*Personalized Optimal Grape Harvest by Autonomous Robot (POGHAR)*, 2018). POGHAR regards the development of an autonomous ground robot equipped with a robotic arm to support viticulture tasks such as harvest, green harvest and defoliation.

The rest of the paper is structured as follows. In Section 2 the requirements of the selected agricultural operations are defined. According to these, in Section 3 the corresponding technological needs of the robot, in terms of hardware and software are identified. Conclusions are presented in Section 4.

2 Grapes Harvest Activity Requirements

First, *defoliation* will be automated, followed by *green harvest* in order to optimize grape quality/quantity and prepare vines for the harvest. Finally, homogeneous harvest is automated in the sense that ARG will harvest only grapes of similar degree of ripeness. In what follows, the requirements for the three agricultural tasks are addressed by a group of viticulturists and agronomists.

2.1 Defoliation

Selectively removal of leaves, namely *defoliation*, is suggested in order to improve the microclimate in vineyards (Fig.1). Thus, the quality of the produced wine is increased due to better plant health i.e. better ventilation and due to acquisition of better phenolic characteristics of grapes as a result to their exposure to the sun. The robot must remove carefully and uniformly a percentage of leaves on the crop base, only from the east side of the vineyard.

(a) (b) (c)

Fig. 1. A vineyard (a) before, (b) during and (c) after defoliation.

2.2 Green Harvest

In order to improve the phenolic content of grapes, it is necessary to reduce the load on the vine; a number of grapes are removed from each tree. This process, namely *green harvest*, meliorates taste and aroma of the remaining grapes (Fig.2). The robot must remove a percentage of grape clusters from each vine, in a priority order as follows: sick, malnourished, uneven and immature.

2.3 Harvest

When grapes are ripened, harvesting takes place. At this phase, the robot must remove all ripened grape clusters (Fig.3) and place them in harvesting baskets. Sick/damaged clusters are not collected and either removed or left on the vine.

3 Defining the Technological needs of ARG

The in-field robot must be able to understand the physical properties of each encountered object and be able to work under dynamic conditions. The robot first will acquire raw data about the environment from its sensors, will analyze it for reasoning and will operate based on its perception according to its operation plan.

(a) (b)

Fig. 2. Green harvest for (a) a red and (b) a white grape variety.

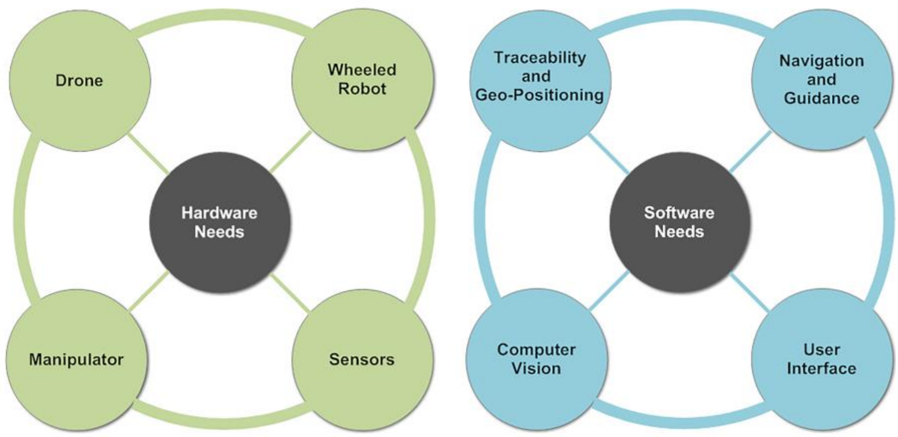
(a) (b)

Fig. 3. Homogenous harvest. Red grapes (a) not fully ripened and (b) fully ripened ready to harvest.

Technically, the ARG will be developed by the integration of a wheeled robot, one robot arm, end-effectors such as a cutter, electronic sensors e.g. cameras, and software that will coordinate the operation of the mechanical and electronic devices. In addition, an aerial drone could contribute to the development of digital maps required for ARG's autonomous navigation. ARG's sensing system needs to be equipped with specialized manipulators and end-effectors able to work under varying conditions, since dust, humidity, heat etc. can easily affect the electric circuits and cause corrosion and, therefore, instability to the system. Regarding reasoning and planning, effective software needs to be developed so as to ensure two basic abilities for ARG; robot functionalities (e.g. obstacle avoidance, self-localization, path planning, navigation) and robot applications (e.g. harvesting, defoliating, handling). Algorithms need to be adaptive and able to deal with object and environment variations such as illumination. In what follows, a group of electrical engineers and computer scientists addresses the hardware (Fig.4(a)) and software (Fig.4(b)) needs for developing the ARG.

3.1 Hardware Needs

Drone. An unmanned aerial vehicle (UAV) will acquire multiple RGB imagery of vineyards, resulting in a large fraction of overlapping between them to derive a binary difference dense model (DDM). The DDM will provide the 3-D macro structure of the vineyard which is necessary for the navigation of ARG.



(a) (b)

Fig. 4. Technological needs in (a) Hardware and (b) Software.

Wheeled Robot. A mobile robotic platform, especially designed for outdoor missions and able to navigate in different types of terrains, will carry all sensors around the field and necessary electronics. It needs to be equipped with sensors such as Global Positioning System (GPS), Light Detection and Ranging (LIDAR), Inertial Measurement Unit (IMU), 3D camera and encoders to facilitate localization, navigation and obstacle avoidance. It needs to be equipped also with an extra battery ensuring the proper operation of the system for a long time, voltage converters and signal processing units.

Manipulator. A robotic arm will perform all agricultural operations. The arm should be lightweight, at least of 6 Degrees-Of-Freedom (DOF) and able to carry the weight of a big grape cluster. The arm will be equipped with adequate end-effectors such as two fingers to hold a stem and a cutter to cut it off.

Sensors. Cameras are the most important external sensors for a harvesting robot as they replace human's eyes for discrimination, recognition and distance measurements. The two RGB cameras mounted on the robotic arm will provide stereoscopic vision and a near infrared (NIR) and a thermal camera will provide additional information for the spectral characteristics of vines.

3.2 Software Needs

Traceability and Geo-positioning. The Agrobot must navigate between the lines of the vineyard and sample. The maps of the vineyards must first be extracted from the drone information (Fig.5(a)). Then, a wireless positioning system based on GPS needs to be developed so as to provide positioning information of the robot and use it to support real-time precision navigation between specific geographic coordinates of the map.

Navigation and Guidance. An algorithm must be developed to extract the navigation path in the vineyard (Fig.5(b)), including the headland turns between the vineyard lines. The algorithm needs to combine machine vision and both global and local positioning information from the mounted sensors, so as to determine the navigation paths, and execute path planning along with obstacle avoidance.

(a) (b)

Fig. 5. (a) Extracted grapevine map from multiple UAV RGB images and (b) robot's trajectory between the lines (red color) of the vineyard.

Computer vision. Computer vision algorithms (Fig.6), based on in-field images (Fig.7(a)), need to be developed to support the following tasks:

1) Leaves detection (Fig.7(b)) so as to define the position and percentage of leaves to be removed during the defoliation process.
2) Grape clusters detection (Fig.7(c)) so as to define the position and percentage of grape clusters to be removed during green harvest, giving priority to the malnourished, uneven and immature.
3) Ripeness estimation during harvest. Only fully ripened clusters will be removed. The rest will remain on the vines or removed separately from the healthy ones.
4) Stem detection (Fig. 7(d)). The stem of leaves and grape clusters needs to be detected, approached and cut-off by the end-effector.
5) Harvesting baskets detection. The baskets need to be located and filled with the collected clusters up to a certain point.
6) Movement of the robotic arm toward a target point. Stereoscopic vision will be used to locate the exact distance of an object.
7) Movement of the robotic arm by avoiding collisions. Cameras mounted on the robotic arm will be used as real-time collision detectors. Manipulators and sensors must be able to cope with various geometries of obstacles and targets. Detection and motion planning algorithms have to generate new manipulator trajectories adapted to every target in a short time horizon.

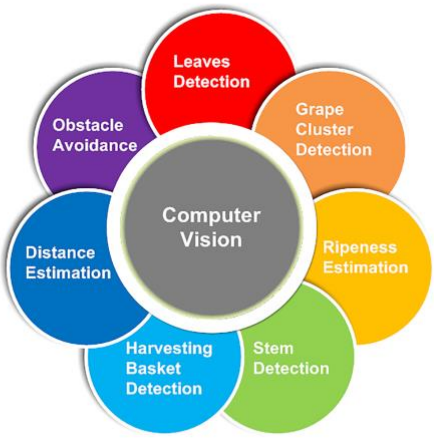


Fig. 6. Computer vision algorithms need to be implemented into the ARG.

(a) (b) (c) (d)

Fig. 7. (a) Original RGB image and segmented grape (b) leaf, (c) cluster, (d) stem.

User Interface. A user-friendly interface needs to be developed for establishing the communication between user and robot. The user needs to: have access to the vineyard map, create the navigation path, select exact points on the map where the Agrobot will perform selected tasks and define the tasks. The user interface should permit personalized changes for each agricultural task, e.g. percentage of leaves/clusters to remove. Moreover, it must provide monitoring information for the robot, e.g. battery level, current position, status of sensors and live streaming.

4 Conclusions

This work addresses the technological needs for the development of an Agrobot that deals with three vineyard tasks; *defoliation*, *green gravest* and *harvest*. The objective of this study is to delineate optimally the ARG requirements by a group of experts, towards mechanizing effectively the aforementioned tasks. Identifying the technological needs of ARG contributes to a more realistic system design. The literature indicates that systematic design process techniques can contribute to the technical and economic feasibility of a robot (Angeles and Park, 2008). After identifying the needs, the next phase of the ARG development is the electric and mechanical connection of sensors combined with effective algorithms (Kaburlasos *et al.*, 2019) towards implementing the above-mentioned agricultural tasks.

Acknowledgments. This research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH – CREATE – INNOVATE (T1EDK-00300).

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