STUDY AND SETTING-UP OF AUTONOMOUS TERRESTRIAL ROVER SUITABLE FOR MONITORING ACTIVITIES IN "TENDONE" TRAINED VINEYARDS

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Abstract. According to the Italian National Institute of Statistics (ISTAT, 2023), Apulia (Southern Italy) is the Italian region with the highest production of table grape. The typical vine training system is the "pergolato" or "tendone", whose primary characteristic is the arrangement of the canopy on an unbroken horizontal plane, sustained by a grid of steel wires located at 1.7-1.8 m above the soil, in turn supported by wood stakes placed near the vines. Currently, "tendone" vineyards are covered both with anti-hail nets and sheets that allow them to accelerate or delay the ripening of the bunches, depending on the cultivar of the vine. The presence of the sheets does not allow remote sensing activities using unmanned aerial vehicles (UAVs), aimed at monitoring the canopy condition. In this context, the authors have designed, assembled and fine-tuned an autonomous robotic system prototype for carrying out monitoring activities in such type of vineyards. Practically, contrary to what would be done by UAVs, the robot prototype in question makes it possible to evaluate the conditions of both the vegetation and fruiting from below, by autonomously crossing the inter-rows according to established routes. The evaluation of vegetative indices is performed by RGB and NIR cameras, equipped with active sensors. The acquired images, suitably processed, as well as the data obtained from on-board sensors about soil characteristics, will allow the farmer to assess the possible presence of biotic and abiotic stresses of the plants and then make timely decisions on the action to be carried out. The task that the rover in question performs is very helpful in the current context of sustainable precision agriculture, which requires to integrate innovative technologies (sensors, drones, software, satellites, etc.) to targeted agronomic actions, based on actual cultivation needs.

Keywords: autonomous rover, remote sensing, vineyards, vegetation index.

Introduction

The Italian table grape production in 2023 covered approximately 47,334 hectares, yielding 7.9 million quintals, with Apulia which leads the production [1]. In this region, the most employed vineyard training system is the "pergolato" or "tendone" system; It is characterized by a horizontal canopy arrangement covered by anti-hail nets and sheets supported by wood stakes placed near the vines. The use of nets and sheets is used to protect the fruit and manipulate ripening times, enhancing both yield and fruit quality [2-4]. This training system is designed to optimize grape production under local climatic conditions. In recent years, climate changes are showing clear consequences in viticulture and strongly impact on the yield and the quality of the grapes [5]; much research has dealt with the impact on wine grapes [6], but little attention has been given to table grape. Nowadays, thanks to the development of technologies such as unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs) it is possible to easily monitor crops vigour and the incidence of diseases [7]. Among the different crops, vineyards seem to attract a lot of agricultural robot proposals due to its high market value.

The physical characteristics of "tendone" vineyards pose serious challenges for remote sensing techniques, such as the use of UAVs as the coverage by these sheets does not allow efficient monitoring. On the contrary, UGVs are not limited to remote sensing purposes but they can perform proximal sensing and are tailored to perform some specific agricultural tasks. UGVs can traverse the inter-row, operating below the canopy and providing an optimal point of view for evaluating vegetative indices using proximal sensors, RGB and NIR cameras in conjunction with active sensors, due to poor lighting conditions [8]. Autonomous rovers must be able to manage also many complementary activities to successfully complete the required task, such as localization, trajectory planning and navigation with obstacle avoidance [9]. In vineyards, the collected data could help farmers efficiently quantify spatial variability, yield, vine vigour and evaluate the incidence of disease [10]. This would imply multiple benefits, including an improved production efficiency, a foreknowledge of vineyard yield and more efficient use of pesticides [11]. Through real-time monitoring and data-driven decision-making, UGVs allow to align with the principles of sustainable precision agriculture to optimize agronomic practices [11].

Regarding the viticulture sector, a selective pesticide sprayer for vineyard was designed in [12], some other prototypes were designed for mechanical weeding operations [13], pruning [14] and shoot thinning [15], but at the authors' knowledge no autonomous rover has been developed for "tendone" vineyards.

The aim of this study is the design and setting up of a novel unmanned ground rover prototype tailored to autonomously cross the inter-rows of "tendone" vineyards, according to established routes, to assess the health and condition of the vegetation, fruiting and soil through the data acquired by several proximal sensors mounted on the rover. The novelty of this work is the development of an autonomous terrestrial rover which operates in "tendone" vineyards and the presence of an articulated passive suspension system that ensures better stability of the rover in uneven outdoor terrains.

Materials and methods

The developed autonomous terrestrial rover prototype is a tracked differential drive robot, driven by two electric motors, one for each truck. The rover's dimensions are $W = 747$ mm, $L = 755$ mm, $H = 480$ mm (without the RTK-GNSS tower), with a payload of 90 kg and a maximum speed of 1 $m \cdot s^{-1}$. Thanks to its large payload and several power outputs, the rover can be equipped with additional sensors.

Thanks to its rubber tracks, the rover is tailored for outdoor applications, in harsh and uneven terrains such that of vineyards. The large ground clearance (268 mm) allows the rover to easily overcome obstacles like rocks and debris. Both the rear wheels and the other free wheels of each rubber track are directly connected to a high efficiency shock absorber with preload adjusters to allow the chassis to adapt to the terrain profile. The suspension system minimizes soil vibrations, resulting in an improved stability of the frame and reducing the noise during sensors' acquisitions.

The rover implements a ROS node, which allows the user to remotely control the robot and easily integrate sensors, devices and actuators. The prototype is provided with a custom defined systems for self-localization composed of an inertial measurement unit (IMU) and a magnetometer; the autonomous navigation is GNSS based with an RTK-GNSS base station that ensures centimetric precision even in absence of the GPS signal, and obstacle avoidance capabilities thanks to the presence of a 360° Light Detection and Ranging (LIDAR) sensor. To continuously monitor the correct state of functioning of the rover, motor encoders and current sensors are present. Moreover, the rover has a powerful controller able to provide multiple interfaces; it includes a radio board with a remote control link up to 150 m with a frequency of 2.4 GHz. Moreover, the rover is equipped with a powerful 20W LED headlight with 1580 lm mounted on its front for inspections in dark light conditions.

Finally, the developed prototype will be equipped with RGB, NIR cameras, with active sensors mounted for the evaluation of vegetative indices and several proximal sensors for the evaluation of the main indicators of soil characteristics (pH, moisture, temperature, electric conductivity, radionuclides) and assessment of the soil texture. In addition, a structure will support UV-C lamps suitably oriented towards the vegetation for sustainable protection against the Downy mildew, which is undoubtedly the most important disease affecting the vine, and which can cause significant vegetative and productive damage of the "tendone" vineyard [16].

The choice of treads is optimal because ensures a better mobility in unstructured environments, having a large contact area with the ground compared to wheels. The peculiarity of the developed rover lies in the presence of an articulated passive suspension system for each side track, allowing the ground wheels to move independently with respect to the vehicle body, ensuring high mobility, while retaining mechanical simplicity. On each side, the robot features a rubber track wrapped around four independently suspended road wheels, an idler wheel, and a sprocket. The passive suspension maintains the contact between the rubber tracks and the terrain surface, providing a better stability of the rover and protects it from all the shocks generated by uneven terrains. The articulated suspension system is depicted in Fig. 1.

The rubber track is wrapped around the drive sprocket, the idler wheel, and the four ground wheels. The drive sprocket is directly coupled to the gearbox output shaft.

The belts of the trucks are made of fiberglass and an inner steel cord all embedded in melted natural rubber. Each belt has the length of ~2000 mm, width of ~127 mm and the height of the treads is 20 mm.

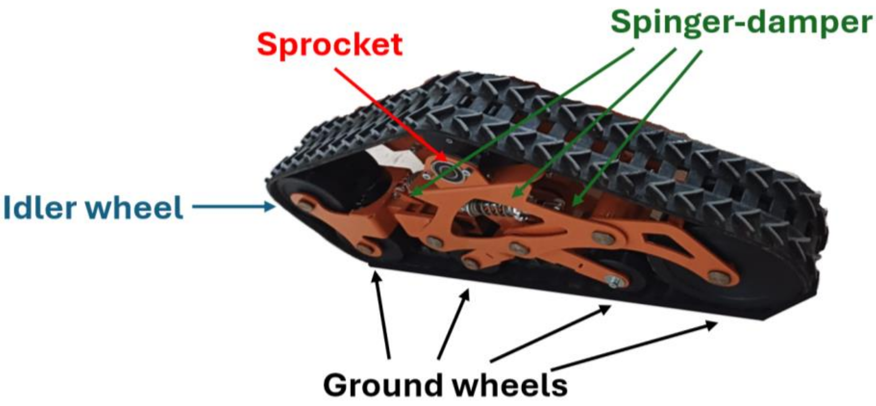

Fig. 1. **Articulated suspension system**

Results and discussion

The developed rover prototype is shown in Fig. 2.

Fig. 2. **Developed robot prototype**.

The battery pack of the rover is a 24VDC 30Ah lithium-base battery, which ensures autonomy of 6 hours of continuous work.

The rover prototype has two electric motors, one for each truck; the chosen motor is the EC180.24EX produced by Transtecno, Anzola dell'Emilia (Italy). Its main specifications are reported in Tabke 1.

Table 1

Main specifications of the chosen electric motors

Specification	Value
Power, W	250
Voltage, V	24
Current, A	15
Rotational speed, rpm	3000
Output Torque, Nm	0.8

Moreover, two gearmotors MV 30, produced by Ghirri Motoriduttori, Formigine (Italy), have been employed to reduce the rotational speed of the motor and increase the output torque. In this case, the rotational speed is reduced of a factor of 30, becoming 100 rpm but the torque is increased of the same factor, reaching 48 Nm. The autonomous navigation will be possible thanks to the Velodyne Puck VLP-16 (Ouster, San Francisco, USA) LiDAR sensor, an ultra-compact 16-channel LiDAR, with 360-degree coverage and capable of capturing up to 300,000 points per second, ensuring a complete reconstruction of the point cloud of the surrounding environment.

The rover will be equipped with several sensors:

- the HydraProbe sensor (Stevens Water Monitoring Systems, Inc., Portland, USA), through the dielectric impedance measurement principle, simultaneously measures three of the most significant soil parameters, as moisture, salinity and temperature [17].
- The Medusa MS-350 (Medusa Radiometrics, Groningen, The Netherlands) is a gamma ray spectrometer able to measure soil radionuclides like potassium (K-40), uranium (U-238), thorium (Th-232), and cesium (Cs-137). It is used to measure soil composition and diverse soil properties including soil texture, minerals, and soil pollutants like heavy metals [18].
- The Altum-Pt camera (AgEagle Aerial Systems Inc., Wichita, USA) integrates a 12 MP high-resolution panchromatic sensor, 5 spectral bands (Blue 475 ± 32 nm, Green 560 ± 27 nm, Red 668 ± 14 nm, Red Edge 717 ± 12 nm, Near-IR 842 nm ± 57 nm) and a FLIR LWIR thermal infrared camera 7.5 -13.5 μm [19].
- The CMD Mini Explorer (Codevintec Italiana Srl, Milano, Italy), which is a contactless electromagnetic conductivity meter able to simultaneously measure at 0.5 m, 1.0 m and 1.8 m full depth ranges [20].

Conclusions

In this paper the design and setting up of an unmanned ground rover prototype with an articulated passive suspension system, designed to autonomously traverse the inter-rows of “tendone” vineyards, was presented. To assess the health and condition of both the vegetation and fruiting from below, the robot will be equipped with several sensors. The gathered data from the mounted sensors, suitably processed, will allow the construction of georeferenced thematic maps concerning vegetation, soil, and environmental parameters.

Author contributions

Conceptualization, S.P.; methodology, S.P., F.P, V.P.; validation, S.P., F.P., A.F., G.P., T.Q., F.V.; formal analysis, S.P., F.P., A.F., G.P., T.Q., F.V.; investigation, S.P., F.P., A.F., G.P., T.Q., F.V.; data curation, S.P., F.P., A.F., G.P., T.Q., F.V.; writing – original draft preparation, S.P., F.P., G.P.; writing – review and editing, S.P., F.P., A.F., G.P., T.Q., F.V.; visualization, S.P., F.P., A.F., G.P., T.Q., F.V.; project administration, S.P.; funding acquisition, S.P. All authors have read and agreed to the published version of the manuscript.

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