Chapter 6
Agri.q: A Sustainable Rover for Precision Agriculture

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Abstract In this paper, an innovative mobile and sustainable robot for precision agriculture, named "Agri.q", is presented. Characterized by a peculiar mechanical architecture and provided with specific sensors and tools, the Agri.q is able to operate in unstructured agricultural environments in order to fulfill several tasks as mapping, monitoring, and manipulating or collecting small soil and leaf samples. In addition, the rover is equipped with a top platform covered with solar panels, whose orientation can be exploited both to maximize the sunrays collection during the auto-charging phase and to permit a drone landing over a horizontal surface, regardless of the ground inclination. A particular attention to energy consumptions and sustainability has driven the mechanical design of the Agri.q powertrain: the weight reduction results into a limited number of small size locomotion motors, enhancing the importance of the harvested solar energy on the energy balance of the whole system. In this paper, all these characteristics are described and analyzed in detail. Moreover, some preliminary tests aimed at evaluating the energetic behaviour of the rover under different working and weather conditions are presented.

Keywords Mobile robot · Agri.q · Service robotics · Precision agriculture · PV solar panels

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I. Visa and A. Duta (eds.), *Solar Energy Conversion in Communities*,
Springer Proceedings in Energy, https://doi.org/10.1007/978-3-030-55757-7_6

6.1 Introduction

Precision agriculture aims at improving the sustainability of agricultural production by taking advantage of specialized technological equipment. As a side effect, also profitability and efficiency turn conveniently enhanced [1]. In a few words, the whole precision agriculture paradigm can be summarized in applying 'the right treatment in the right place at the right time' [2]. Many relevant studies demonstrated in the recent past the beneficial effect of such paradigm on environment and economics [3, 4]. The interest demonstrated by private producers and governments is then well understandable. In this technological transition, robotics and automation perform a leading role, which can profit of the advancements of decades of research. Those technologies will produce a significant thrust in the modernization of the agricultural production. Many examples of re-adaptation of agricultural machines are available in the literature: Wang et al. [5], and later Zaman et al. [6], focused on the use of advanced navigation systems; in [7] a cooperative system of aerial and ground vehicles is used for monitoring tasks; Khaliq et al. [8] approached the problem under the point of view of trajectory planning using multispectral imagery. Aside such interesting advancements in the field of control, few examples are available of machines designed to fulfill some specific requirements. Among others, [9] and [10] present two innovative ground robotic units for automated harvesting, while in [11] an aerial robot for mango harvesting is proposed. As a matter of fact, one of the most important features that an autonomous robot should have is to work without human intervention as long as possible. Then, the use of solar panels can allow the robot to have a high exploration capability in open spaces. Many studies focused on motion planning and control to reduce the energy consumption [12, 13], better than increasing the stored energy. At present, two main strategies are in use for battery recharging, based on board solar panels [14] and off board stations [15].

In this scenario, the researchers of the Politecnico di Torino developed a novel wheeled UGV named Agri.q (shown in Fig. 6.1) tailored on precision agriculture tasks and specifically designed for monitoring and sampling of crops and soil [16–18], especially for vineyard cultures. The rover is a small size (approximately 1 m × 2 m × 0.7 m) electric vehicle designed to operate in unstructured environments, to move through the rows of grapes and to cooperate with aerial drones. Moreover, it is equipped with a robotic arm to accomplish sampling tasks. The Agri.q mobile rover has been equipped with an orientable platform covered with solar panels, with the aim of enhancing the battery runtime and therefore the duration of the missions executable by the rover.

6.2 Prototype Description

The actuators of the modular locomotion systems have been carefully chosen considering, as the most burdening condition, a slope of about 15° to be overcome with only

Fig. 6.1 Prototype of the Agri.q mobile robot

two front traction motors (namely the two front driving units) at a maximum speed of about 5 km/h. To achieve such goal, the transmission of each unit is composed by an electric brushless DC motor, connected to a planetary gearbox. A further speed reduction is then provided by a chain system between the gearmotor and a pair of wheel (front left or front right). Some details on the adopted mechanical components are provided in Table 6.1. Each gearmotor unit is also provided with an electric parking brake.

In addition, the rover is equipped with two rear locomotion units that are used only when the slope exceeds 15% or when the adherence condition requires to pass from the 2 to the 4 driving units architecture; in this second case, the power transmission is distributed to the eight wheels in contact with the soil (Fig. 6.2).

The powertrain layout was completed by a battery able to feed the adopted locomotion systems, and by a solar panel whose dimension was reasonably chosen to ensure the recharge of the battery during the idle time between missions. Details about the rechargeable battery are provided in Table 6.2.

The solar panel was chosen to meet the needs deriving from the mobile application.

In particular, two flexible light-weighted panels were installed, able to guarantee an adequate recharging capability without affecting the robot dynamics with an excessive weight. Some technical details are shown in Table 6.3 and Fig. 6.3. The data refers to a perpendicular solar irradiation of 1000 $\mathrm{W/m^2}$ at the working temperature of 25°.

Table 6.1 Front and rear driving modules functional parameters

		Front driving units	Rear driving units
Motor nominal power	$P_{M,Nom}$	120 W	120 W
Motor nominal torque	$C_{M,Nom}$	0.38 Nm	0.38 Nm
Motor nominal speed	$\omega_{M,Nom}$	3000 rpm	3000 rpm
Motor nominal current	$I_{M,Nom}$	10 A	10 A
Motor maximum current	$I_{M,\mathrm{Max}}$	20 A	20 A
Motor torque constant	K_I	0.055 Nm/A	0.055 Nm/A
Gearbox reduction	τ_1	1 : 15.88	1 : 28.93
Chain system reduction	τ_2	1:3	1:1
Total reduction	τ	1:47.64	1 : 28.93
Wheels radius	r_w	0.200 m	0.200 m

Fig. 6.2 Usage of the orientable upper panel during solar recharge (**a**) and for safe drone landing (**b**)

Table 6.2 Battery technical specifications

Battery voltage	29.7 V	Maximum current	128 A
Battery capacity	56 Ah	Total stored energy	4.84 MJ

Table 6.3 Solar panel technical specifications

Peak power	154 W	Maximum tension	18.2 V
Dimensions	1046 mm × 996 mm	Maximum current	8.5 A
Mass	2.40 kg	Working temperature	−45/ + 85 °C

6.3 Photovoltaic Potentiality of the Agri.q

As well known, solar tracking strategies can substantially increase the efficiency of the energy harvesting capability of a solar panel (up to 40%). In general, the idea is to optimize the direct absorption of the solar radiation by reorienting the panels so that the sunrays turn to be perpendicular to them [19].

In order to get an effective solar tracking, the rover can take advantage of two expressly conceived degrees of freedom able to orientate the upper platform around two independent axes. In particular, the pitch and the roll angles of the solar panel can be modified (as shown in Fig. 6.4a), so that the reference frame $\xi - \psi - \zeta$ solid with the panels assume a non-identical rotation matrix with respect to the rover reference frame $x - y - z$.

As shown in [16–18], the Agri.q upper plane pitch mechanism can provide a rotation of $\gamma = -5° / + 40°$. The plane can also roll of $\alpha_R = -20° / + 20°$. Such degrees of freedom can orientate the solar panels so that the perpendicular unit vector ζ is:

$$\zeta = R_y(\gamma) R_x(\alpha_R) \left[0\ 0\ 1 \right]^T \quad (1)$$

where $R_y(\gamma)$ and $R_x(\alpha_R)$ represent two rotation matrices respectively around the y and the x axes of the reference frame $x - y - z$. These ranges of rotation allow the rover to point the solar panels towards a relevant section of the sky (red spherical cap in Fig. 6.4b). The minimum pointing angle $\varphi_{\min}$ that the platform can perform is $\varphi_{\min} = 46.04°$.

Moreover, thanks to its maneuverability in the plane $x - y$, the rover can assume whatever orientation around the axis z, so increasing the number of possible poses of the platform. Figure 6.3b shows through the gray spherical cap the reachable orientations of the solar panel.

6.4 Consumptions Estimation

The average power consumption can be estimated monitoring the mechanical power absorbed by the front left (W_{FL}) and right (W_{FR}) traction motors in different conditions. In the following, four tests are analysed (see Fig. 6.5): Test 1 to 3 refer to straight trajectories on non-sloped surfaces at different velocity levels (details are shown in Table 6.4), while Test 4 refers to a constant curvature trajectory. Aside the

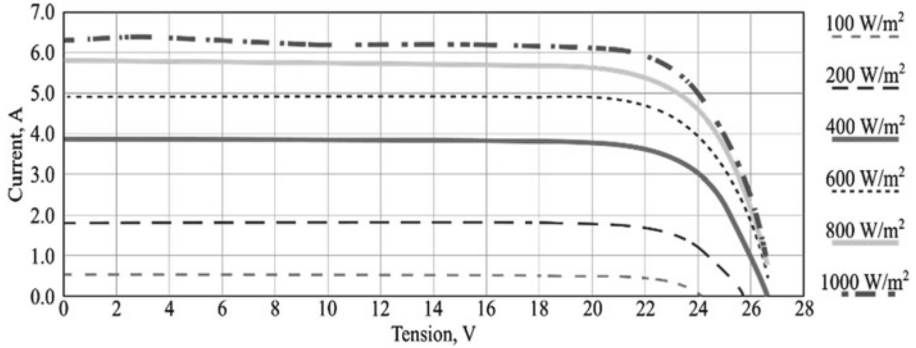

Fig. 6.3 Current/voltage characteristic of the photovoltaic panels at different levels of solar incident power

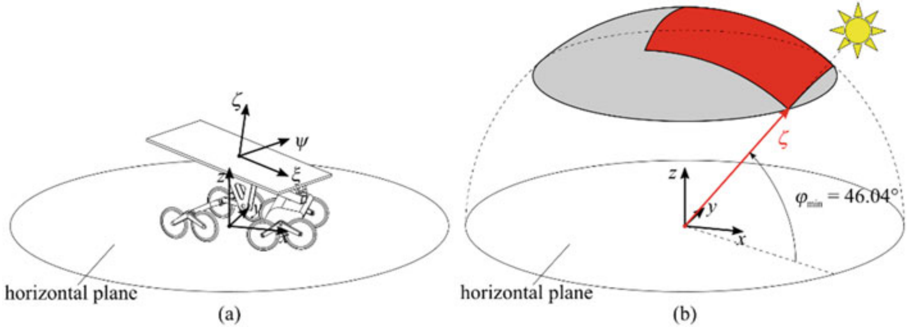

Fig. 6.4 **a** Reorientation of the Agri.q upper platform and **b** minimum inclination of the panels perpendicular with respect to the horizontal plane

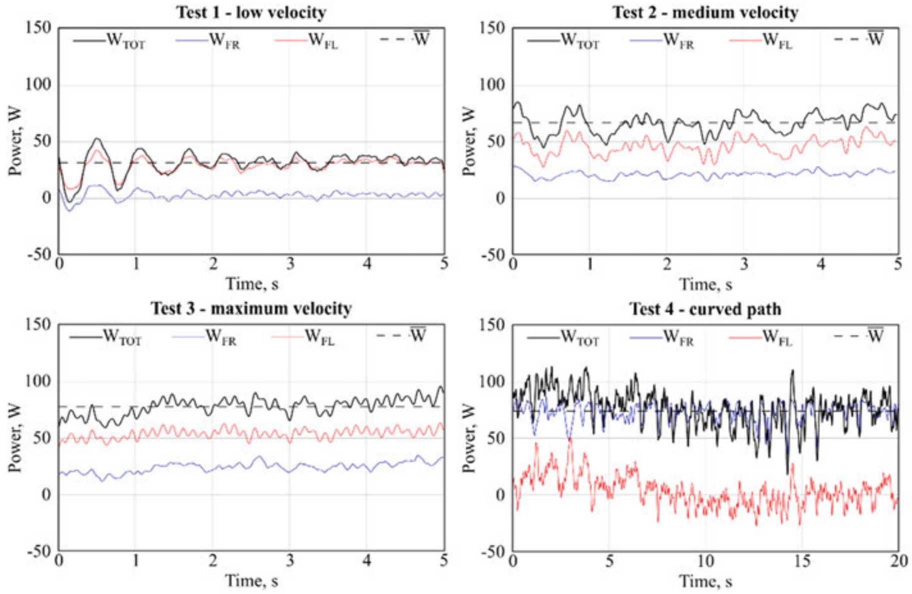

Fig. 6.5 Mechanical power measured in different use conditions

Table 6.4 Velocity, torque and power measurement for tests of Fig. 6.5

	Test 1	Test 2	Test 3	Test 4
Velocity	2.15 km/h	3.2 km/h	4.7 km/h	2.00 km/h
Mean motors torque	0.91 Nm	0.93 Nm	0.94 Nm	0.25 Nm
Mean motors power	30.94 W	66.28 W	78.19 W	74.14 W

mechanical power of the left and right driving units, also the global power absorption W_{TOT} and the mean value $\overline{W}$ are shown. A combination of such experimental tests can be used to estimate the average energy consumption of the rover during an actual monitoring mission. By simply mediating the registered powers, a mean value of 62.4 W is obtained. Such a value should be properly increased to take into consideration slopes, different possible levels of terrain roughness, and even the case in which all the four driving units (both front and rear) are needed. Moreover, the reorientation actuators and the electronic hardware are expected to increase the power absorption too. As also evicted in the following, an average consumption of about 90 W is an acceptable approximation.

As a further consumption estimation proof, some numerical data obtained during a two hours mission of the rover are reported. The tested duty cycle included almost all the working conditions reasonably foreseeable during a standard monitoring mission: paths on non-sloped uneven terrains, curves, slopes (of about 10° approached both with only the front locomotion units activated and with all the four units active), reorientations of the solar panels, etc. This wide use scenario resulted in the energy consumption reported in Table 6.5. A total consumption of 179.5 Wh, corresponding to 0.65 MJ, was recorded. Taken into account the tested mission duration, it corresponds to a power absorption of approximately 89.75 W; therefore, the 13.35% of the whole battery energy was used. A similar result can also be inferred from data on the used battery capacity: 6.54 Ah on a total capacity of 56 Ah, corresponding to the 11.71%. Even in terms of peak current, the powertrain turns to be well sized on the rover needs: the maximum value, recorded along a slope of 10° approached at the maximum rover velocity with all the four driving units active, is 24.19 A, which is well lower than the maximum battery current (128 A).

Table 6.5 Energy and electric parameters recorded during a two hours mission

Time	Voltage	Actual current	Actual power	Used charge	Used energy
0 h 00′	28.95 V	0 A	0 W	0 Ah	0 Wh
0 h 30′	28.50 V	0.97 A	27.9 W	3.86 Ah	106.8 Wh
1 h 00′	28.36 V	3.15 A	89.3 W	5.33 Ah	145.3 Wh
1 h 30′	28.47 V	0.94 A	26.7 W	5.44 Ah	148.8 Wh
2 h 00′	28.34 V	0.86 A	24.3 W	6.56 Ah	179.5 Wh
Peak current: 24.19 A		Peak power: 674.1 W		Average tension: 27.76 V	

6.5 Concluding Remarks

The exploitation of robotics technologies for precision agriculture applications is increasingly catching the attention of both research and industrial community, for it representing a smart and sustainable way to enhance profitability and productivity. Moreover the sustainable design approach adopted in this research represents a method to address the technological evolution to the achievement of some Sustainable Development Goals, fixed by United Nations in 2015 [20]. The most relevant SDGs, in this case are 7, affordable and clean energy, 13, Climate action, 15, life on land. The researchers of the Politecnico di Torino developed a novel wheeled UGV, named Agri.q, designed for unmanned monitoring and sampling tasks of crops and soil. This paper focuses on the sustainability features which characterize the robot, and in particular on its capability to exploit solar renewable energy. The installed set of photovoltaic panels, in fact, makes available an effective source of energy that increases the autonomy of Agri.q during operating missions. The panels can recharge the rover battery in the idle time between the missions, avoiding it to come back to base for such a reason. The tests showed the behavior of the robot in the most common use conditions, such as straight and curved paths, and allowed verifying the effectiveness of the chosen powertrain. Aside that, some details are also provided about the energy consumption during a reasonable mission-like usage.

Acknowledgements Authors' acknowledgement goes to the PIC4SeR (PoliTO Interdepartmental Centre for Service Robotics) which gave support and assistance to this research.

References

1. A.M. Adrian, S.H. Norwood, P.L. Mask, Producers' perceptions and attitudes toward precision agriculture technologies. Comput. Electron. Agric. **48**(3), 256–271 (2005)
2. R. Gebbers, V. Adamchuk, Precision agriculture and food security. Science **327**(5967), 828–831 (2010)
3. J. Lowenberg-DeBoer, I.Y. Huang, V. Grigoriadis, S. Blackmore, Economics of robots and automation in field crop production. Precis. Agric. 1–22 (2019)
4. A.P. Barnes, I. Soto, V. Eory, B. Beck, A. Balafoutis, B. Sánchez, M. Gómez-Barbero, Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers. Land Policy **80**, 163–174 (2019)
5. Y. Wang, Y. Lan, Y. Zheng, K. Lee, S. Cui, J.-A. Lian, A UGV-based laser scanner system for measuring tree geometric characteristics, in *5th International Symposium on Photoelectronic Detection and Imaging*, (Beijing, China, 2013).
6. S. Zaman, L. Comba, A. Biglia, D.R. Aimonino, P. Barge, P. Gay, Cost-effective visual odometry system for vehicle motion control in agricultural environments. Comput. Electron. Agric. **162**, 82–94 (2019)
7. P. Tokekar, J.V. Hook, D. Mulla, V. Isler, Sensor planning for a symbiotic UAV and UGV system for precision agriculture. IEEE Trans. Rob. **32**(6), 1498–1511 (2016)
8. A. Khaliq, L. Comba, A. Biglia, D.R. Aimonino, M. Chiaberge, P. Gay, Comparison of satellite and UAV-based multispectral imagery for vineyard variability assessment. Remote Sens.**11**(4) (2019)

9. A.P. Chatzimichali, I.P. Georgilas, V.D. Tourassis, Design of an advanced prototype robot for white asparagus harvesting, in *International Conference on Advanced Intelligent Mechatronics* (2009), pp. 887–892
10. A.A. Aljanobi, S.A. Al-Hamed, S.A. Al-Sushaibani, A setup of mobile robotic unit for fruit harvesting, in *19th International Workshop on Robotics in Alpe-Adria-Danube Region RAAD* (Budapest, Hungary, 2010)
11. S. Konam, Agricultural aid for mango cutting (AAM), in *International Conference on Advances in Computing, Communications and Informatics (ICACCI)* (2014), pp. 1520–1524.
12. A. Barili, M. Ceresa, C. Parisi, Energy-saving motion control for an autonomous mobile robot. Proc. IEEE Int. Symp. Ind. Electron. **2**, 674–676 (1995)
13. Z. Sun, J Reif, On energy-minimizing paths on terrains for a mobile robot. In: *Proceedings of the 2003 IEEE International Conference on Robotics & Automation* (2003), pp. 3782–3788
14. T. Kaur, D. Kumar, Wireless multifunctional robot for military applications, In *2nd International Conference on Recent Advances in Engineering and Computational Sciences* (2016)
15. G.B. Parker, R.S. Zbeda, Learning navigation for recharging a self-sufficient colony robot, In *Proceedings of the 2007 IEEE International Conference on Systems* (2007)
16. G. Quaglia, C. Visconte, L.S. Scimmi, M. Melchiorre, P. Cavallone, S. Pastorelli, Design of the positioning mechanism of an unmanned ground vehicle for precision agriculture, in, *IFToMM World Congress on Mechanism and Machine Science* (2019), pp. 3531–3540
17. G. Quaglia, C. Visconte, L.S. Scimmi, M. Melchiorre, P. Cavallone, S. Pastorelli, Robot arm and control architecture integration on a UGV for precision agriculture, in *IFToMM World Congress on Mechanism and Machine Science* (2019), pp. 2339–2348.
18. G. Quaglia, P. Cavallone, C. Visconte, Agri_q: Agriculture UGV for monitoring and drone landing, In *IFToMM Symposium on Mechanism Design for Robotics* (2018), pp. 413–423
19. G. Quaglia, S.L. Maurino, Solar. q_1: A new solar-tracking mechanism based on four-bar linkages. *in Proceedings of the Institution of Mechanical Engineers* (2017), pp. 2855–2867
20. https://sustainabledevelopment.un.org/