The Agri.q mobile robot: preliminary experimental tests

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Abstract. Precision agriculture is a management strategy aimed at enhancing the productivity, profitability, and sustainability of agricultural production from incorporation of technological advances primarily developed for other industries. Among them, robotics is playing a leading role for it allows monitoring with unprecedented punctuality the number of factors affecting the production processes. In this scenario the researchers at Politecnico di Torino developed an innovative unmanned ground vehicle expressly featured for accomplishment of monitoring tasks, with particular focus on the vine cultivation industry which is peculiarly strong in the region. The rover, named Agri.q, is an eight-wheeled mobile robot whose conceptual design has been already presented to the scientific community. This paper presents the first experimental results gathered on the prototype under different conditions of use, in order to illustrate the actual performance of Agri.q in its work environment.

Keywords: service robotics, precision agriculture, wheeled mobile robot, autonomous rover.

1 Introduction

Precision agriculture relies on specialized technological equipments to improve the sustainability of agricultural production and, as a side yet concrete effect, to enhance its profitability and efficiency [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]. The actual environmental and economic benefits coming from the use of such precision tools are a matter of fact [3,4], so that the interest of private and government investments in the field significantly increased in the last decade.

As well understandable, the worlds of robotics and automation are nowadays playing a role of uttermost importance exporting the achievements proper of those fields and adapting them to the technological needs of precision agriculture applications. Many examples in literature are available of re-adaptation of agricultural machines: 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. In substance, a lot has been done under the point of view of control with the main aim of re-assessing existent tools to the need of the crops monitoring. In addition to that, few examples are available of machines designed to encounter some specific requirements. In these cases, the robots are usually expected to play an active role on the agricultural process. Among others [9] and [10] present two innovative solutions for automated harvesting, while in [11] the cutting of a specific tree is considered. In this scenario, the researchers of the Politecnico di Torino developed a novel wheeled UGV tailored on precision agriculture tasks and specifically design for monitoring and sampling of crops and soil [12-14]. The rover, named Agri.q, is a small sized electric vehicle designed to operate in unstructured environment, to move through the rows of vines and to cooperate with aerial drones. Moreover, it is provided with a robotic arm for accomplishment of sampling tasks. As shown in Fig.1, the robot is also equipped with solar panels aimed at sustainably enhancing its battery duration.

Fig. 1. Prototype of the Agri.q mobile robot.

2 Functional and mechanical design

The main guideline which drove the functional design of the Agri.q robot is locomotion efficiency on uneven terrains. As known, one of the most effective approaches to such issue is the adoption of tracks which own the great advantage of distributing the vehicle weight on a large surface. This allows tackling the soil asperities even in unfavorable ground conditions, i.e. wet or slippery terrains. The main disadvantage with respect to wheeled vehicles is an extremely reduced efficiency. The Agri.q traction system is conceived to meet a convenient point between the efficiency of wheels and the effectiveness of tracks on uneven surfaces, under both energetic and mobility points of view. To this aim, the rover was provided with four driving units, each one composed of two wheels housed on a rocker arm. A scheme of the robot is shown in Fig. 2a. The connections of each rocker with the robot main body takes place by means of a passive revolute joint, whose free rotation allows the wheels to follow the ground slops independently from the configurations of the other rockers (see Fig. 2b). The high number of contact points with the ground ensures a weight distribution similar to that of a tracked robot, while maintaining an efficiency closer to that of a wheeled machine.

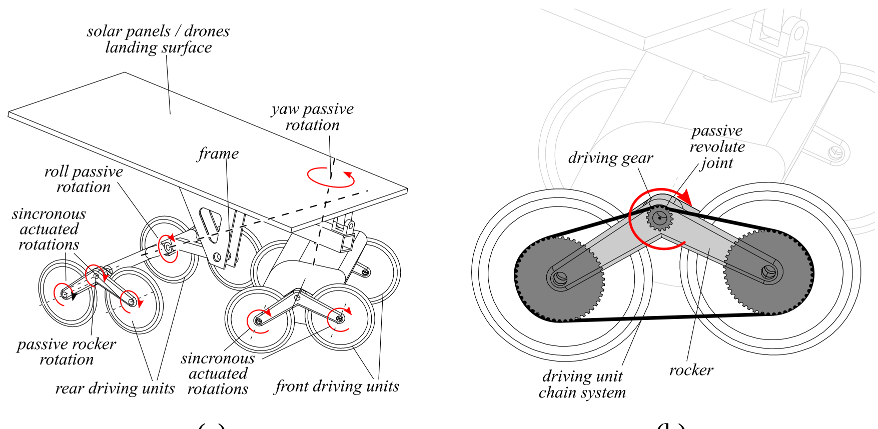

Fig. 2. Functional scheme of the Agri.q rover (a); connection of one of the rockers with the robot main body (b).

A further efficiency enhancement was achieved by providing the robot with a passive yaw rotation between the front and the rear rockers, which guarantees a significant reduction of the lateral velocities (i.e. of the lateral slipping) of the wheels with respect to ground when a curved trajectory is approached. Moreover, a passive roll degree of freedom was added to enhance the rover ability to assess the soil unevenness. This revolute joint in fact allows the mutual rotations of the front and rear rockers, ensuring their capacity to maintain a steady contact of the wheels with the ground in a large range of soil conditions.

The energetic efficiency of the rover has been a design guideline of fundamental importance. As aforementioned, the rover has been provided with a set of solar cells, capable of recharging the rover batteries. Such panels own the double purpose of providing an efficient source of energy for the rover, and of being used as a landing platform by UAV’s (Unmanned Aerial Vehicles). In both cases, the upper plane of the rover should be oriented on need. The rover has then been provided with two active degrees of freedom, in order to modify the orientation of the solar panels in space (see Fig. 3). This allows to maximize the sunrays collection during the charging phase, as well as to provide a horizontal plane for drones landing.

3 Prototype description

The guidelines pointed out by the functional design of the mobile robot yielded the realization of a prototype which is briefly described in this section.

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 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 DC motor, connected to a planetary gearbox. A further motion reduction is then provided by a chain system which is demanded at synchronously moving the two wheels. Some details on the adopted mechanical components are provided in Table 1. Each gearmotor unit is also provided with an electric parking brake.

(a) (b)

Fig. 3. Usage of the orientable upper panel during solar recharge (a) and for safe drone landing (b).

Table 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	$I_{M,Max}$	$20\ A$	$20\ A$
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	$0{,}200\ m$	$0{,}200\ m$

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 such aspects are reported in Table 2.

Table 2. Battery technical specifications

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

The Agri.q was designed to perform monitoring tasks in any agricultural environment, even in presence of humans. Due to that, a particular care was adopted to make as safe as possible the coexistence of the robot with operators sharing the same workspace. To this aim, a hardware methodology for safe collision assessment was implemented on board. A mechanical switch has been connected to a front bumper, whose primary task is that of stopping any activity of the rover and setting it up in a parking condition, safe for both humans and the rover itself. The events flow is schematically shown in Fig. 4. An accidental impact with the front bumper puts the setpoint velocities of each motor drivers at zero. Such event allows the Agri.q to run a deceleration phase fast enough to avoid the effects of the collision, preventing at the same time any damage on the transmission system which could derive from an instantaneous activation of the motors parking brakes. When the deceleration phase is completed, the parking brakes are activated, and the motors supply is cut off.

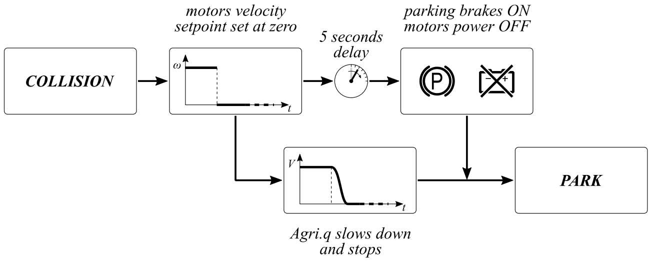

Fig. 4. Hardware safety management strategy on-board of the Agri.q rover.

4 Preliminary experimentations

In this section some experimental results are discussed to show the behavior of Agri.q in operative conditions. Figure 5 collects the results, in terms of velocities and torques of the front driving units, during four different experimentations. All the tests were conducted without significant slopes and with only the front locomotion units activated. The curved trajectory was performed on an uneven soft terrain.

The first two tests (Fig. 5a and 5b) show the motors velocities and the respective current absorption while performing straight trajectories. The experiments were conducted by providing a step-type velocity setpoint to appreciate the acceleration response of the rover. After few seconds at cruise velocity, the motors supply was interrupted so that it was possible to evaluate the space which was necessary to the rover to stop different velocities. In terms of motors burden, it is possible to see that the acceleration phase requires a peak current which do not overpass the maximum value of $20\,A$ allowed by the two motors. In particular, it is $I_{FR,Max} = 15.76\,A$ and $I_{FL,Max} = 17.36\,A$ for Test 1 (corresponding to values of torques of $C_{FR,Min} = 0.87\,Nm$ and $C_{FL,Min} = 0.95\,Nm$) and $I_{FR,Max} = 16.71\,A$ and $I_{FL,Max} = 17.19\,A$ for Test 2 (corresponding to values of torques of $C_{FR,Min} = 0.92\,Nm$ and $C_{FL,Min} = 0.95\,Nm$). During the cruise velocity phase, the current of the two motors is way lower than the nominal value of $10\,A$ (average values shown in Fig. 5a and 5b). The deceleration phase is performed without the action of the two driving units, to estimate the space needed by the rover to slow down and stop. In the first case, i.e. when the cruise velocity is $2.15\,km/h$, the rover needs $0.68\,m$ to stop, while $1.68\,m$ are needed when the cruise velocity is $4.7\,km/h$ (which represents the maximum velocity performable by Agri.q). As later shown, such distance is drastically reduced when a deceleration phase is actuated by the driving units.

The third experiment (Fig. 5c) shows a constant curvature trajectory performed on uneven soft terrain. The curve is imposed by controlling different velocities on the left and the right front modules (e.g. $\bar{\omega}_{FR} = 1412.2\ rpm$ and $\bar{\omega}_{FL} = 1058.1\ rpm$). Given the footprint width of the rover of $1\ m$, it is quite easy to come up with a radius of the resulting trajectory of about $3.5\ m$. In such condition, with a longitudinal velocity of $2.0\ km/h$, the currents on the two motors is clearly unbalanced on the external driving module (namely, the right one with $\bar{I}_{FR} = 9.15\ A$, $\bar{C}_{FR} = 0.50\ Nm$) while the internal one results much less burdened ($\bar{I}_{FL} = 0.02\ A$, $\bar{C}_{FL} = 0.001\ Nm$).

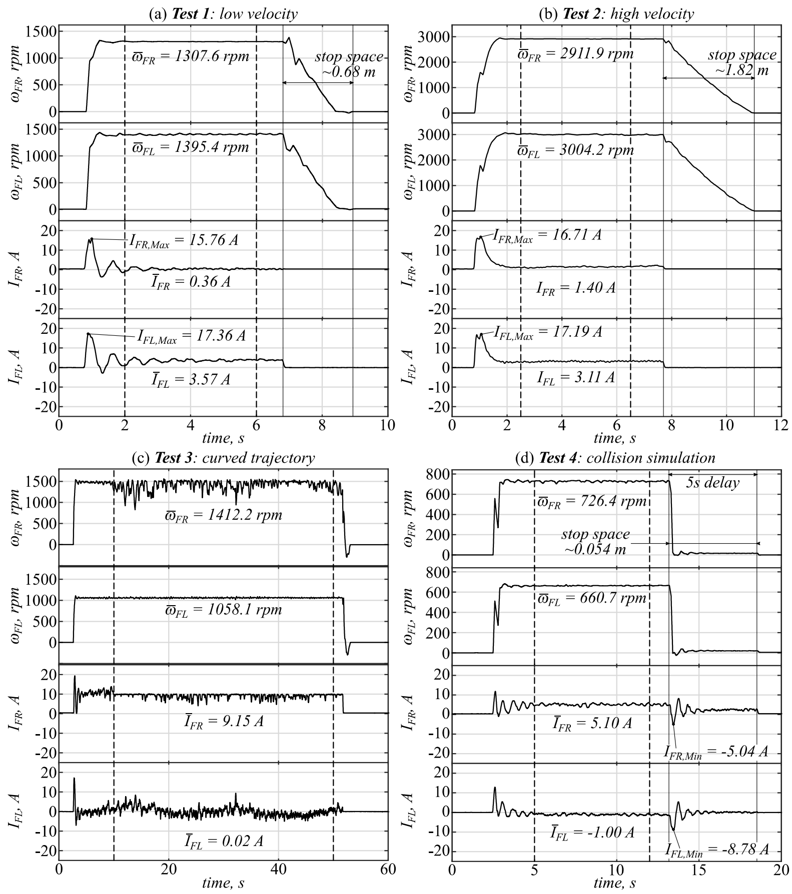

Fig. 5. Experimental results: (a) Test 1, straight path at 2.15 km/h; (b) straight path at 4.7 km/h; (c) curved path at 2.0 km/h with a curve radius of 3.5 m; (d) collision simulation test at 1.1 km/h.

At last, Fig. 5d shows the results collected while simulating a collision event. After few seconds at cruise velocity, the rover motion was stopped through the security device described in the previous section. In this case, the deceleration phase is handled by the two driving units which brake the rover through negative torques whose peak values are $I_{FR,Min} = -5.04\,A$ and $I_{FL,Min} = -8.78\,A$ (corresponding to $C_{FR,Min} = -0.28\,Nm$ and $C_{FL,Min} = -0.48\,Nm$). With such intervention, the stopping space reduces at $0.054\,m$. After few seconds in this static condition ensured by the two driving units, the safety strategy cuts off the motor feed current and activates the parking brakes.

Some numerical data is reported on the rover energy consumption during two hours of use. The time histories of motors velocities and current absorptions are not reported due to the experiment duration. The duty cycle which was experimented 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 with both only the front locomotion units activated, and with all the four units active), reorientations of the solar panels, etc. This wide use scenario yielded the energy consumption reported in Table 3. A total consumption of $179.5\,Wh$ corresponding to $0.65\,MJ$ was recorded, i.e. the 13.35% of the whole battery energy. A similar result is also given by the battery capacity used: 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 of the maximum battery current ($128\,A$).

Table 3. Energy and electric parameters recorded during a two hours mission.

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

5 Conclusions

The exploitation of robotics technologies for precision agriculture applications is increasingly catching the attention of both research and industrial community, for it represent a smart and sustainable way to enhance profitability and productivity. 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 follows up the advancements on the project, presenting the very first experimental results obtained on the prototype. The most relevant mechanical solution adopted for its realization are briefly described and a set of experimental tests are discussed. 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 collision assessment strategy adopted. Aside that, some details are also provided about the energy consumption during a reasonable mission-like usage.

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