Design of the mobile robot Agri.q

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Abstract. In this paper, an innovative UGV (Unmanned Ground Vehicle), named Agri.q, is presented. The rover is specifically designed for precision agriculture applications and is able to work in unstructured environments on irregular soil, cooperating with drones, if necessary. It is equipped with specific tools and sensors to perform specific tasks, i.e. mapping the field, monitoring the crops and collecting soil and leaf samples. In addition, it is provided with a two degrees of freedom landing platform able to self-orient to ensure a safe drone docking or even to maximize the sunrays collection during the auto-charging phase. In this way, the rover autonomy and sustainability are increased. The functional design of the rover and the design of its actuation system are reported herein; furthermore, the first prototype is described and some preliminary results obtained during experimental tests are discussed.

Keywords: Agri.q, Mobile robot, Precision agriculture, Service robotics, Sustainability.

1 Introduction

"Precision Agriculture is a management strategy that gathers, processes and analyses temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production." [1]. Monitoring and analysing crops and soil is necessary to identify what to do, where and when to intervene. Several solutions aim to equip agricultural machines or commercial UGVs (Unmanned Ground Vehicles) with tools and devices to monitor, analyse both crops and soil [2, 3]. In other solutions, the UAVs (Unmanned Aerial Vehicles) are equipped with cameras in order to monitor the crops [4]. In addition, agricultural machines and commercial UGVs are equipped with specific tools or end-effector to do different actions [5, 6]. The authors have been studying and presented in the past the concept of an innovative UGV, named Agri.q, for precision agriculture [7-9]. Agri.q is a small sized electric rover designed to operate in unstructured environments and to move through the rows of vines. It is able to cooperate with drones and it is equipped with a robotic arm. Moreover, it is equipped with a solar panel in order to increase its autonomy and sustainability.

2 Functional design

A modular approach has been employed for the system of locomotion. Agri.q is composed of four driving units: two front and two rear. Each driving unit is composed of two wheels housed on a rocker arm structure connected to the body machine using a passive joint, whose respective DOF (Degree of Freedom) is hereby called Ω. The rocker arm can rotate about the joint to ensure a correct distribution of the normal forces on the ground. The two front driving units are connected with the front box. The front box is connected to the frame with a passive DOF θ joint that allows the front and the rear modules to exhibit a mutual yaw angle, necessary to approach curved trajectories. The two rear driving units are connected with the rear axle, constrained to the positioning mechanism with one passive DOF α_F joint that ensures the compensation of transversal inclination between the front and the rear driving units. The positioning mechanism connects the rear axle and the frame with a one DOF α_E active joint. The DOF α_E defines the pitch angle of the frame. A landing platform covered with two solar panels is connected with the frame with a one DOF α_R active roll joint. The two actuated DOFs α_R and α_E allow to orient the landing platform/solar panels in order to optimise the sun capture or to keep horizontal the landing platform for the drones.

2.1 Rocker arm mechanism

The design of the Agri.q rover was driven by its agriculture application, and due to that, eight wheels architecture, each couple supported by a rocker, has been adopted. This solution permits to distribute the static and dynamic forces acting on the ground over a wide contact surface, as occurs using a track system, see Fig. 2a). As a result, the vehicle itself is prevented from sinking, or getting stuck, into soft terrain and, at the same time, soil compaction is avoided. Nonetheless, the whole traction efficiency remains similar to that of a four-wheeled rover. A further advantage comes from the capability of the rocker to act like a filter with respect to the oscillations imposed by the ground. Figure 2b) shows that the vertical displacement imposed to the wheel by a remarkable soil irregularity is converted into a smaller displacement of the rocker passive joint and therefore of the whole vehicle. The oscillations transmissibility turns consequently reduced.

a) b)

Fig. 1. a) Agri.q in a simulated rough terrain condition: the wheels system adopted allows a force distribution similar so that of a tracked vehicle; b) filter with respect to the oscillations.

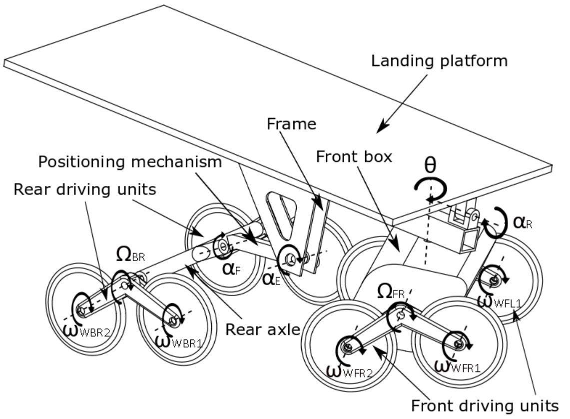


Fig. 2. Agri.q functional design

2.2 Landing platform and solar panels

Since the Agri.q is expected to interact with UAVs, it has been provided with an orientable platform, which allows drones landing over an always-horizontal surface even when the vehicle is moving on steep slopes. In fact, controlling the pitch angle α_E and the roll angle α_R both longitudinal and transverse ground slopes can be compensated, as shown in Fig. 3a). Since sustainability has been the leading concept in the development of the Agri.q, the landing platform is covered by solar panels, which ensure partial auto recharging of the batteries. Furthermore, the same positioning mechanism used for the platform orientation can be exploited to maximize the sunrays collection Fig. 3b).

a) b)

Fig. 3. a) Landing platform; b) solar panels.

2.3 Robotic arm

According to the principles of precision agriculture, the Agri.q is expected to collect ground or leaves samples for lab analysis, maybe laying them down on the docked drone, and has to apply chemical treatments or fertilizers when and where it is necessary. Therefore, a lightweight 7 DOF collaborative robotic arm has been integrated into the rover. The base of the robotic arm is assembled on the back chassis, in order to increase its workspace. As a result, the end-effector can reach the ground to collect samples, see Fig. 4a) but also the drone docked on the landing platform. Furthermore, exploiting the mobility of the landing platform, it can reach leaves at heights up to 2.5 m above ground, as shown in Fig. 4b).

a) b)

Fig. 4. a) The End effector of the robotic arm reaches the ground; b) end effector maximum height.

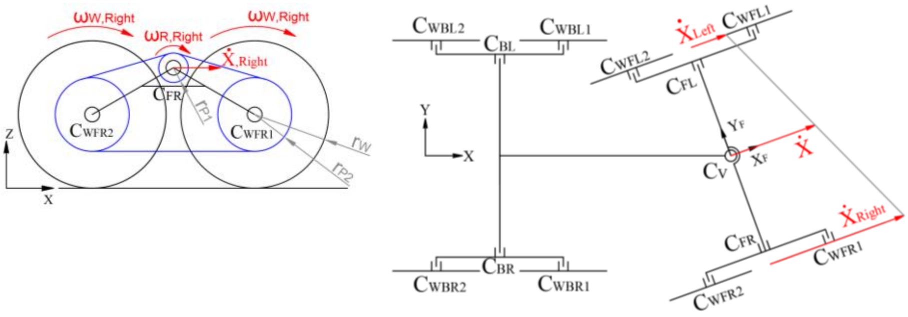
3 Design of the actuation system

The first application expected for the rover Agri.q is working in the vineyards. This kind of crops grows in a particular environment whose peculiarities lead the design requirements of the actuation system. A modular approach was adopted in order to simplify the design and to reduce the cost. A chain system transmission has been chosen for its robustness and transmission capabilities. Moreover, it can operate in the dirtiest condition with minimum maintenance. While going through the vineyards rows, the velocity of the rover must be limited to allow the accurate monitoring of the crops. The upper speed limit closely depends on the technology adopted for such task. In any case, the nominal speed of the vehicle has been set at 5 km/h. The rover must overcome rough terrains, in terms of both slope and unevenness. Only using the front driving units, the rover has been designed to overcome slopes with an inclination of $\alpha_{Soil} = 15°$.

3.1 Kinematic analysis

The transmission system of each driving unit is composed of an electric DC motor, a planetary gearbox and the aforementioned chain system. The angular speed required of the right motor $\omega_{M,R}$ is defined by

$$\omega_{M,R,Right} = \omega_{R,Right}\tau_1 = \frac{\dot{x}_{Right}}{r_W}\tau_1\tau_2 = \omega_{W,Right}\tau_1\tau_2 \quad (1)$$



a) b)

Fig. 5. Driving unit kinematics.

The longitudinal speed of the rover can be obtained from the following equation:

$$\dot{x} = \frac{\dot{x}_{Right} + \dot{x}_{Left}}{2} \tag{2}$$

Table 1. Parameters.

Symbol	*Description*	*Unite of measure*
ω_R	Output angular speed of the planetary gearbox	[rad/s]
τ_1	Transmission ratio of the planetary gearbox	[/]
$\dot{x}_{Right}, \dot{x}_{Left}$	Driving unit speed	[m/s]
τ_2	r_{P2}/r_{P1}	[/]
ω_W	Wheel angular speed	[rad/s]

3.2 Quasi-static analysis

By assuming a set of reasonable simplifications, a very simple dynamic model of the Agri.q can be drawn in order to address the motors choice. Figure 6 shows such a simplified approach. The rover is analysed in a quasi-static condition, while it is climbing a hill with a gradient of α_{soil} = 15° in order to define a maximum motor torque. Being the nominal speed of the rover limited at 5 km/h, it is possible to neglect both the inertial effect and the rolling frictions among wheels and ground.

With the hypothesis that the vehicle is symmetrical balanced left and the right side, the equilibrium along the x axis simply provides $T_{F1} + T_{F2} = 1/2\ F_p \sin\alpha_{Soil}$. The torque balance on the front wheel allows relating the driving torque C_F to the soil reaction as: $C_F = T_F r_W$ (see Fig. 7a) and so $C_{F1} + C_{F2} = F_P/2 \sin\alpha_{soil} r_W$. Considering the forces distribution of Fig. 7b, the driving torque can be estimated as $C_R = (C_{F1} + C_{F2}) r_{P1}/r_{P2}$. Therefore, the required torque of the motor is

$$C_{M,R} = \frac{C_R}{\tau_1} = \frac{F_P}{2\tau_1\tau_2} \sin\alpha_{Soil}\, r_W \tag{3}$$

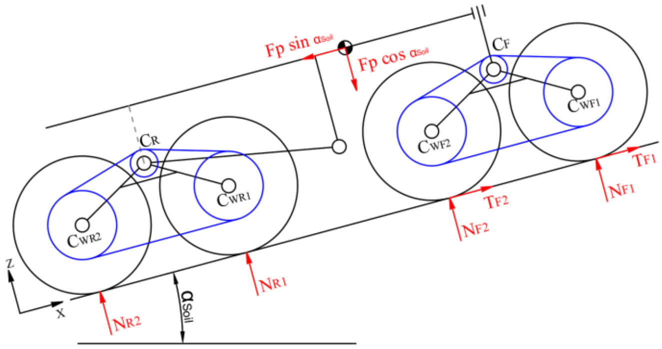
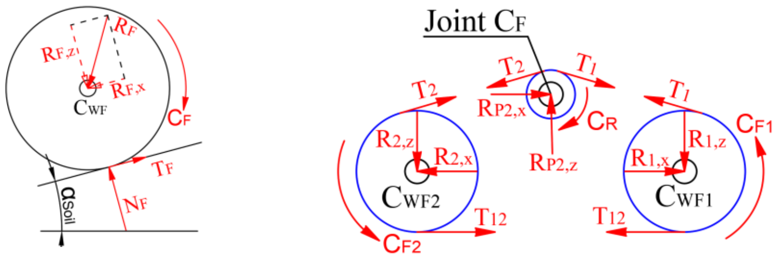


Fig. 6. Half-rover static model.



a) b)

Fig. 7. Free body diagram a) of the front wheel; b) force distribution among the three gears of a front driving unit.

3.3 Parametric analysis

The radius r_{P1} and r_{P2} depend on the number of teeth, respectively, Z_1 and Z_2. On the one hand, Z_1 should be as small as possible compatibly with the technological limits. $Z_1 = 16$ was chosen. On the other, Z_2 must be as high as possible, with the only upper limit of having a gear radius smaller than r_W, to avoid interference issues with the soil. It was chosen $Z_2 = 48$. The transmission ratio $\tau_2 = r_{P2}/r_{P1} = Z_2/Z_1 = 3$ is defined. The radius of the wheel $r_W = 0{,}2$ m has been defined employing a commercial mountain bike wheel. The size of the motor can be defined considering the power required P_R of when the rover overcomes at the speed of 5 km/h = 1,4 m/s a climb with $\alpha_{Soil} = 9°$ of inclination and a motor efficiency $\eta = 0{,}9$. Moreover, a more burdening yet brief using case was considered with a slope of $\alpha'_{Soil} = 15°$.

$$P_{M,R} = \frac{\omega_M C_M}{\eta} = 121\ [W]$$

A DC motor, with the following characteristics, has been selected:

$$P_{M,Nom,1} = 120\ [W];\ P_{M,Nom,2} = 160\ [W]$$

$$\omega_{M,Nom,1} = 315\ [rad/s];\ \omega_{M,Max} = 350\ [rad/s]$$

$$C_{M,Nom,1} = 0{,}38\ [Nm];\ C_{M,Nom,2} = 0{,}51\ [Nm]$$

where the subscripts 1 and 2 refer to the respective duty cycle ratings S1 (continuous duty) and S2 (short time duty, about 20 minutes). The motorgear choice has been then completed with a gearbox having a ratio τ_1 = 15,88 in order to satisfy the requirements.

4 Preliminary tests

Preliminary tests have been executed to determine the actual operating conditions of the rover. A couple of tests are shown herein: test 1 refers to reach maximum speed on an even and flat path; test 2 evaluates the torques of the motor when the rover climbs a road with an inclination of α_{Soil} = 9°. Both tests have been performed driving the rover manually. Therefore, the trajectories obtained are not perfect under the point of view of velocity or direction steadiness. Anyhow, some interesting results can be drawn as well.

4.1 Test 1

The fig 8 shows the angular speed of the right and left motor $\omega_{M,Right}$, $\omega_{M,Left}$, the current absorbed by the right and left motor $I_{M,Right}$, $I_{M,Left}$ during test 1.

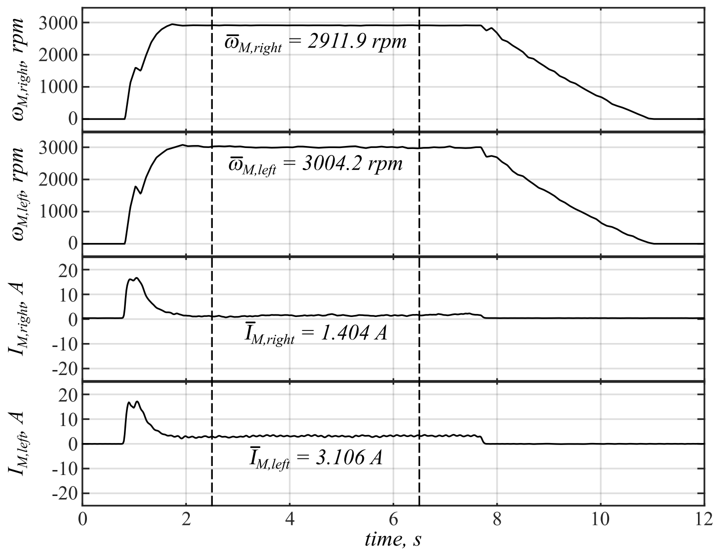


Fig. 8. Angular speeds and absorbed currents of the front motors during test 1, flat path.

4.2 Test 2

Figure 9 shows the angular speed of the right and left motor $\omega_{M,Right}$, $\omega_{M,Left}$, the current absorbed by the right and left motor $I_{M,Right}$, $I_{M,Leftt}$ during the test 2.

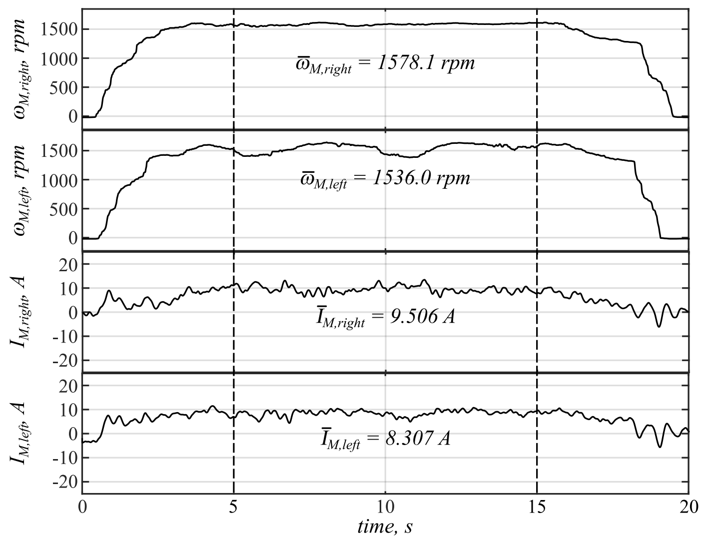


Fig. 9. Angular speeds and absorbed currents of the front motors during test 2, uphill path.

4.3 Analysis of results

The speed of the rover can be determined from (1), (2) and from figure 5 as it follows:

$$\dot{x} = \frac{\dot{x}_{Right} + \dot{x}_{Left}}{2} = (\frac{\overline{\omega}_{M,Right} + \overline{\omega}_{M,Left}}{2})\frac{r_W}{\tau_1\tau_2}\frac{\pi}{30} \tag{4}$$

The torque of the motor is related to the current I by the following equation:

$$C_M = k_M \bar{I}_M \tag{5}$$

Where k_m = 0,055 Nm/A.
During test 1 (T1), the speed of the rover can be determined using (4)

$$\dot{x}_{T1} = 4{,}7\ [km/h]$$

The test has been performed manually by a remote controller which is still in prototyping, and the reference signal has been limited by a remote controller. During test 2 (T2), the torque of the front motors can be calculated using equation (5)

$$C_{M,Right,T2} = 0{,}52\ [Nm];\ C_{M,Left,T2} = 0{,}45\ [Nm]$$

The torque of the motor can be compared with that coming from the simplified equation 2) with α_{Soil} = 9°.

$$C_M = 0{,}33\ [Nm]$$

Considering the efficiency of the motor and the chain of $\eta = 0{,}9$ and increasing of 2° the inclination due to the rolling friction $\alpha'_{Soil} = \alpha_{Soil} + 2°$, (3) can be modified as it follows:

$$C_M = \frac{F_P}{\eta 2\tau_1\tau_1} sin\alpha'_{Soil}\, r_W = 0{,}44\ [Nm]$$

Figures 8 and 9 show the difference between the angular speed of the right and the left motors. This fact causes a difference of torque and a difference of output power as

$$\bar{P}_{M,Right,T2} = 86{,}4\ [W]; \bar{P}_{M,Left,T2} = 73{,}5\ [W]$$

5 Conclusions

Applications of precision agriculture are arousing the increasing interest of the robotics scientific community. The rover Agri.q has been expressly designed and prototyped to approach such tasks. In this paper, an overview of the robot mechanical design is provided. The design guidelines adopted lead to the realization of a prototype which is nowadays in a mechanical test phase. Currently, different tests are still in program in order to validate the prototype in several ways. After such verification phase, the automatic drive and the control logics have to be defined and implemented. The paper also shows a couple of experimental tests performed to validate the adopted design simplifications. The results show that the rover is able to fulfil the initial requirements (slope and velocity).

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