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# THEORETICAL RESEARCH ON GEOMETRIC AND KINEMATIC ANALYSIS DEVELOPED ON AN INNOVATIVE TECHNOLOGICAL PRODUCT, THE 8x8 LAND VEHICLE

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***Abstract:*** *This paper studies the kinematics of an 8x8 skid-steering robotic vehicle with all-wheel drive. Each wheel is a driving wheel and without suspension, the power distribution is done by changing the supply voltage of the two electric motors, related to each wheel line. The robot has an energy system with a nominal voltage of 96V. The main objective is to create a collaborative robot system for logistics missions. For the first stage of development, we aim to determine the behavior when making a turn in the skid-steering situation, the wheels are not steered. The turn is performed by changing the speed of each wheel separately by changing the supply voltage of the motors. For this study, the robotic platform was created by converting an 8x8 land vehicle with mechanical transmission into one with electric transmission. This allowed the simulation of operating conditions based on a real operating situation. At this stage of the robot's development, we described the analytical operating system in order to be able to move on to the finalization of the technological demonstrator.*

***Keywords:*** *UGV – Unmanned Ground Vehicle; 8x8 robotic platform; skid-steering; analytical kinematic model; electric transmission; logistic missions.*

## 1. INTRODUCTION

The realities of the recent period of time regarding the international situation have created the premises for a different approach to the development of logistics systems. Thus, not only supply chains at the macro level but also at the micro level are beginning to be equipped with robotic systems. Their advantage derives from several points of view: increased temporal autonomy (robots being able to perform missions 24/7); organization into logistical fleets that maintain a continuous flow of supplies; they can perform multirole missions (such as using these robots for personnel evacuation), etc. Another aspect pursued was the transformation of an 8x8 land vehicle with a propulsion system powered by a thermal engine (fig. 1) into one with an electric propulsion system. The robotic system of collaborative land robots currently in the development phase aims to satisfy these requirements [1].

The 8x8 land vehicle is designed to be able to provide logistical transport of an average load of 900 kg and which can be transformed in due time into a robot for the evacuation of the wounded [2], [3].

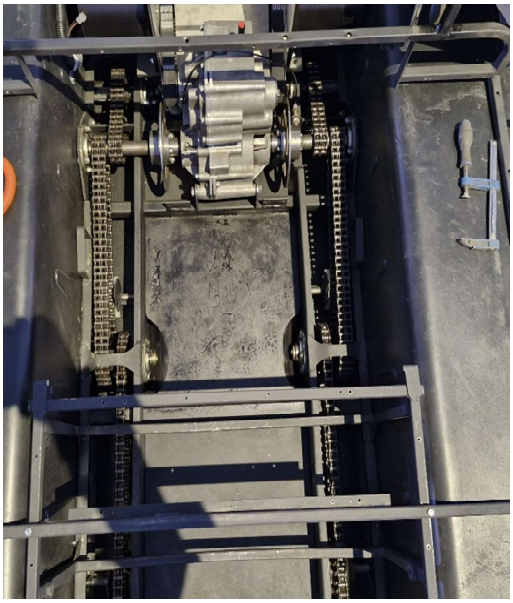


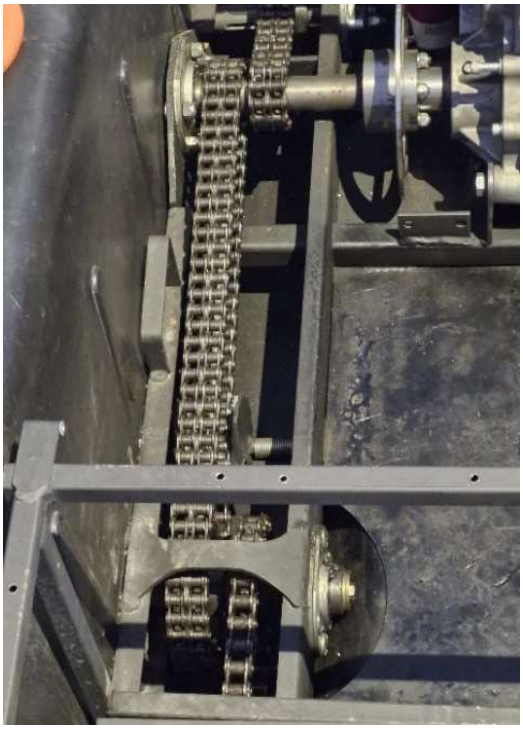
**Fig. 1.** Representation of the vehicle with thermal propulsion system.

From the point of view of the level of technological development, the aim is to reach TRL 6 (Technology readiness level), so that

real technological development leads to an operational system.

The new concept of a robot with an electric propulsion system has two motors of 10KW each (fig. 2), a 96 V battery with a power of 22 KWA and a 4 KWA generator set to ensure battery charging during periods of downtime.





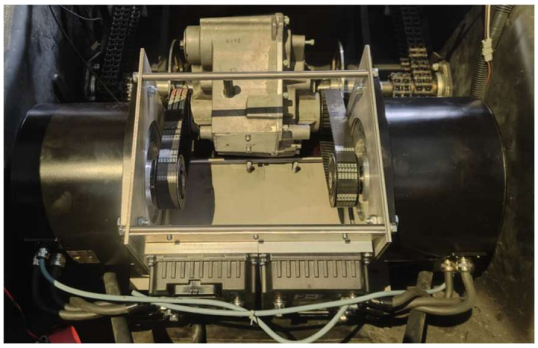


**Fig. 2.** Representation of the vehicle with electric propulsion system.

The transition from thermal to electric propulsion brings multiple operational and strategic advantages, including reduced acoustic and thermal signatures, improved energy efficiency, and simplified maintenance. These characteristics are particularly important in tactical logistics missions, where stealth, reliability, and reduced operational costs are essential. Moreover, the electric architecture allows for finer torque control at low speeds, which is critical for maneuvering in confined or uneven terrain.

The integration of two 10 kW traction motors enables differential control of the vehicle sides, facilitating enhanced mobility and improved traction management. The 96 V, 22 kWh battery pack is dimensioned to ensure sufficient operational autonomy for extended missions, while the 4 kW auxiliary generator provides range extension capability and energy resilience in remote deployment scenarios. This hybrid-support configuration ensures mission continuity even in situations where external charging infrastructure is unavailable.

To achieve TRL 6, the system will undergo testing in a relevant operational environment, including mobility trials, endurance assessments, and validation of the electric powertrain under realistic load conditions. These experimental stages will demonstrate the functional maturity of the prototype and confirm that the technological solutions adopted are suitable for integration into a fully operational logistics support platform.

The functional diagram of the chain transmission is shown in Fig. 3.

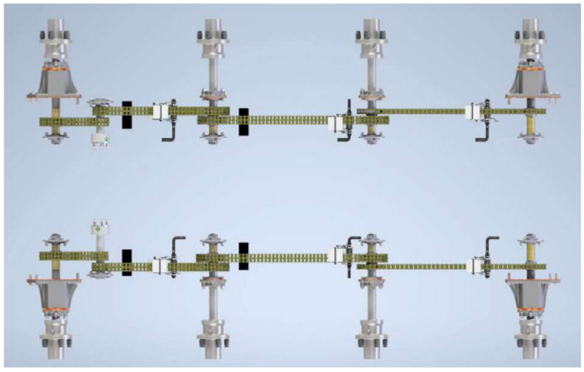


**Fig. 3.** Representation of the chain transmission scheme.

The prototype design to be finalized is an easily configurable platform for different types of missions (fig. 4).



**Fig. 4.** Design representation of the 8x8 electric-powered terrestrial robotic platform.

## 2. VEHICLE GEOMETRY CONSIDERATIONS AND ASSUMPTIONS USED

The vehicle has 8 fixed wheels, all driven by chain transmission. There are two motors, each motor driving the wheels on one side [4], [5]. In the assumptions of canceling the backlash in chain transmissions, of the stretched chains, neglecting the dimensional deviations of the components, all the wheels on one side of the vehicle have the same angular velocity.

The way to turn is to drive the wheels on each side of the vehicle at different angular velocities [6], [7]. The vehicle will turn towards the side where the angular velocity of the wheels is lower.

Since the wheel axles are fixed, during the turn the wheels have a rolling motion with sliding. To estimate the forces of interaction between the wheels and the ground it is necessary to determine the speed of the wheels at the points of contact with the ground. The speed of the center of mass and the angular velocity of the chassis and the angular velocities of the wheels are assumed to be known. The displacement of the vehicle chassis depends on the angular velocities of the wheels and the interaction of the wheels with the ground.

The assumptions used in the kinematic analysis are:

- the ground is flat and horizontal, without obstacles;
- the chassis is rigid, having a plane-parallel movement, the centers of mass of the wheels being in a plane parallel to the ground at all times during movement;
- wheels and ground are considered non-deformable;
- the center of mass of the chassis is located on the longitudinal plane of symmetry of the vehicle.

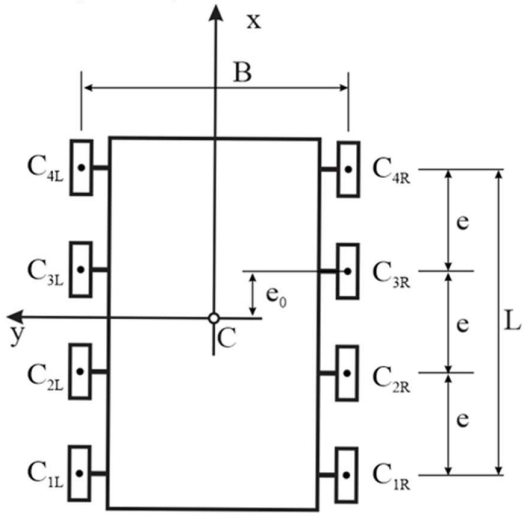



**Fig. 5.** Notations used for wheel and chassis center of mass positions.

In fig. 4 the vehicle with the local axle system and the notations of the position of the center of mass of the mobile part of the wheels are schematically presented. The coordinate system related to the chassis, with the origin in the center of mass, has the Ox axis in the longitudinal plane of the vehicle, with the positive direction in the forward direction. The Oz axis is perpendicular to the plane of the wheels, with the positive direction towards the upper part of the vehicle [8], [9]. If we denote by H the distance from the ground to the center of mass of the chassis and by r – the radius of the wheels, by e – the distance between the axles of the wheels, by L – the wheelbase and by B - . Table 1 presents the coordinates of the wheel centers with respect to the system related to the chassis.

*Table 1*

**Coordinates of the wheel centers relative to the chassis-related system**

| Wheel center | Coordinate x | Coordinate y | Coordinate z |
|---|---|---|---|
| $C_{1L}$ | $-2e+e_0=-\frac{2}{3}L+e_0$ | $B/2$ | $-H+r$ |
| $C_{2L}$ | $-e+e_0=-\frac{1}{3}L+e_0$ | $B/2$ | $-H+r$ |
| $C_{3L}$ | $e_0$ | $B/2$ | $-H+r$ |
| $C_{4L}$ | $e+e_0=\frac{1}{3}L+e_0$ | $B/2$ | $-H+r$ |
| $C_{1R}$ | $-2e+e_0=-\frac{2}{3}L+e_0$ | $-B/2$ | $-H+r$ |
| $C_{2R}$ | $-e+e_0=-\frac{1}{3}L+e_0$ | $-B/2$ | $-H+r$ |
| $C_{3R}$ | $e_0$ | $-B/2$ | $-H+r$ |
| $C_{4R}$ | $e+e_0=\frac{1}{3}L+e_0$ | $-B/2$ | $-H+r$ |

The following notations are used:

- the speed of the vehicle's center of mass $\omega$
- angular velocities of the wheels on the left side $\omega_{1L}=\omega_{2L}=\omega_{3L}=\omega_{4L}=\omega_L$;
- angular velocities of the wheels on the right side $\omega_{1R}=\omega_{2R}=\omega_{3R}=\omega_{4R}=\omega_R$.

## 3. KINEMATIC MODEL OF THE 8-WHEEL DRIVE ROBOT

If the speed of the center of mass and the angular velocity of the chassis are known, $v_{CM}$, $\omega$ with respect to the fixed reference system, the position of the instantaneous center of rotation of the chassis can be determined. This is perpendicular to the velocity of the center of mass, located at a distance IC from the center of mass of the chassis:

$$IC=\frac{v_C}{\omega} \qquad (1)$$

This can be used to determine the velocities of the wheel centers, as in Fig. 6. For example, the velocity of the center of wheel 4 on the left side of the vehicle is perpendicular to $IC_{4L}$, having the module:

$$v_{CM4L}=\omega\cdot IC_{4L} \qquad (2)$$

The speed of the center of each wheel can also be determined using the general calculation relation of a point of

a rigid solid in general motion relative to the fixed reference system:

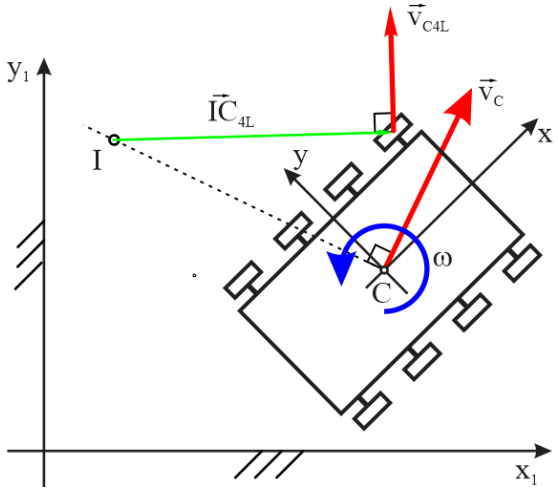


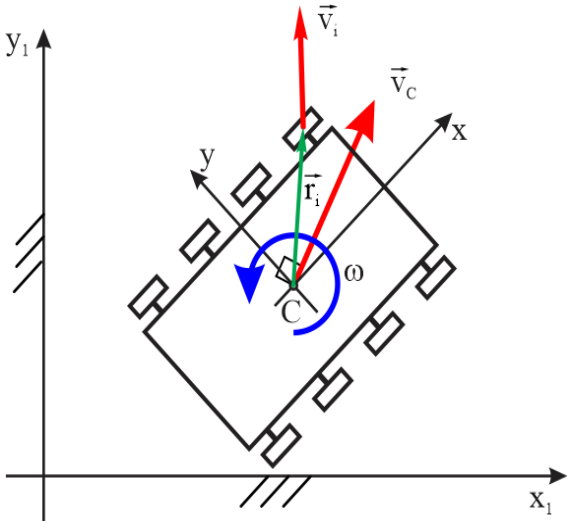

**Fig. 6.** Determining speeds using the instantaneous center of rotation.

$$\overrightarrow{v_1} = \overrightarrow{v_O} + \vec{\omega} \times \vec{r} \qquad (3)$$

where: $\overrightarrow{v_O}$ is the velocity of the origin of the system bound to the body relative to the fixed system, $\vec{\omega}$ is the angular velocity of the system connected to the body relative to the fixed reference system, and $\vec{r}$ is the position vector of the point relative to the body-bound system.

For any wheel $(\mathrm{i})$, relation (3) becomes (fig. 7):

$$\overrightarrow{v_i} = \overrightarrow{v_C} + \vec{\omega} \times \vec{r_i} \qquad (4)$$



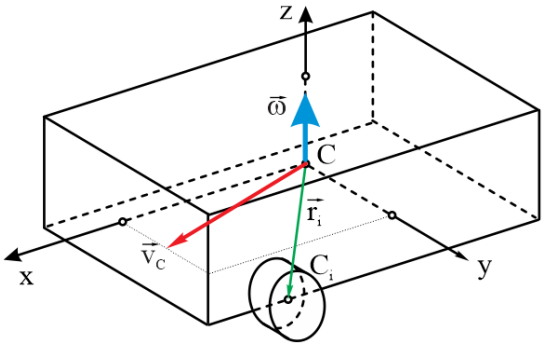




**Fig. 7.** Determining speeds using the general speed calculation relationship.

For the velocity of the center of mass of the chassis, the analytical form of the velocity of the center of mass can be expressed with respect to the system connected to the chassis, by the expression:

$$\overrightarrow{v_C} = v_{Cx}\vec{\imath} + v_{Cy}\vec{\jmath} + 0\vec{k} \qquad (5)$$

Angular velocity has the expression:

$$\vec{\omega} = 0\vec{\imath} + 0\vec{\jmath} + \omega\vec{k} \qquad (6)$$

where,

$$\vec{r_i} = x_i\vec{\imath} + y_i\vec{\jmath} + z_i\vec{k} \qquad (7)$$

the center of the wheel not being in the plane containing the center of mass of the vehicle.

The speed of the wheel center results:

$$\overrightarrow{v_{Ci}} = \overrightarrow{v_C} + \vec{\omega} \times \vec{r_i} = (v_{Cx} - y_i \cdot \omega)\vec{\imath} + \\ +(v_{Cy} + x_i \cdot \omega)\vec{\jmath} + 0\vec{k} \qquad (8)$$

It is noted with $\mathrm{I_i}$ the point of contact between the wheel and the ground, located on the median plane of the wheel. This point is located below the center of mass of the wheel, at a distance from the center of mass equal to the radius of the wheel (fig. 8). Wheel (i) rotates around the vertical with the angular velocity of the chassis and around its own axis with the angular velocity $\omega_i$.

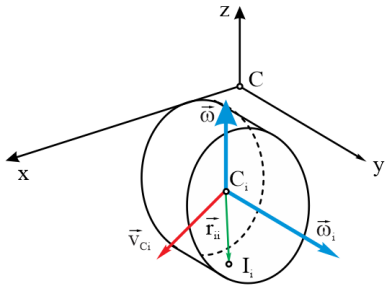



**Fig. 8.** Wheel angular velocities and wheel center velocity (i).

Speed at the point $\mathrm{I_i}$ of the wheel is:

$$\overrightarrow{v_{Ii}} = \overrightarrow{v_{Ci}} + (\vec{\omega} + \overrightarrow{\omega_i}) \times \overrightarrow{r_{ii}} \quad (9)$$

If the chassis-related system is used in the vector expression, it results in:

$$\vec{\omega} + \overrightarrow{\omega_i} = 0\vec{\imath} + \omega_i\vec{\jmath} + \omega\vec{k} \quad (10)$$

$$\overrightarrow{r_{ii}} = 0\vec{\imath} + 0\vec{\jmath} - r\vec{k} \quad (11)$$

It therefore follows:

$$\overrightarrow{v_{Ii}} = (v_{Cx} - y_i \cdot \omega - r \cdot \omega_i)\vec{\imath} + \\ +\left(v_{Cy} + x_i \cdot \omega\right)\vec{\jmath} + 0\vec{k} \quad (12)$$

Angular velocity $\omega_i$ is equal to $\omega_L$ if the wheel is on the left side and is equal to $\omega_R$ if it is located on the right side.

Table 2 presents the components of the ground contact point velocity of each wheel, calculated with respect to the chassis-linked system.

It is worth noting that rubber tires can absorb some of the shock from going over obstacles, or changing from hard to soft terrain. This topic requires a separate paper on how tires absorb the forces due to terrain.

*Table 2*

**Velocity components of the wheel ground contact points, relative to the chassis-linked system**

| Point of contact with the ground | Velocity component after x | Velocity component along y |
|---|---|---|
| $I_{1L}$ | $v_{Cx} - \frac{B}{2} \cdot \omega - r \cdot \omega_L$ | $v_{Cy} + \left(-2e + e_0\right) \cdot \omega$ |
| $I_{2L}$ | $v_{Cx} - \frac{B}{2} \cdot \omega - r \cdot \omega_L$ | $v_{Cy} + \left(-e + e_0\right) \cdot \omega$ |
| $I_{3L}$ | $v_{Cx} - \frac{B}{2} \cdot \omega - r \cdot \omega_L$ | $v_{Cy} + e_0 \cdot \omega$ |
| $I_{4L}$ | $v_{Cx} - \frac{B}{2} \cdot \omega - r \cdot \omega_L$ | $v_{Cy} + \left(e + e_0\right) \cdot \omega$ |
| $I_{1R}$ | $v_{Cx} + \frac{B}{2} \cdot \omega - r \cdot \omega_L$ | $v_{Cy} + \left(-2e + e_0\right) \cdot \omega$ |
| $I_{2R}$ | $v_{Cx} + \frac{B}{2} \cdot \omega - r \cdot \omega_L$ | $v_{Cy} + \left(-e + e_0\right) \cdot \omega$ |
| $I_{3R}$ | $v_{Cx} + \frac{B}{2} \cdot \omega - r \cdot \omega_L$ | $v_{Cy} + e_0 \cdot \omega$ |
| $I_{4R}$ | $v_{Cx} + \frac{B}{2} \cdot \omega - r \cdot \omega_L$ | $v_{Cy} + \left(e + e_0\right) \cdot \omega$ |

All of these will be able to be controlled with an integrated system of sensors, communication system, on-board controller according to Fig. 9 and Fig. 10. Necessary and sufficient elements to be able to trace or verify the route and kinematic elements.

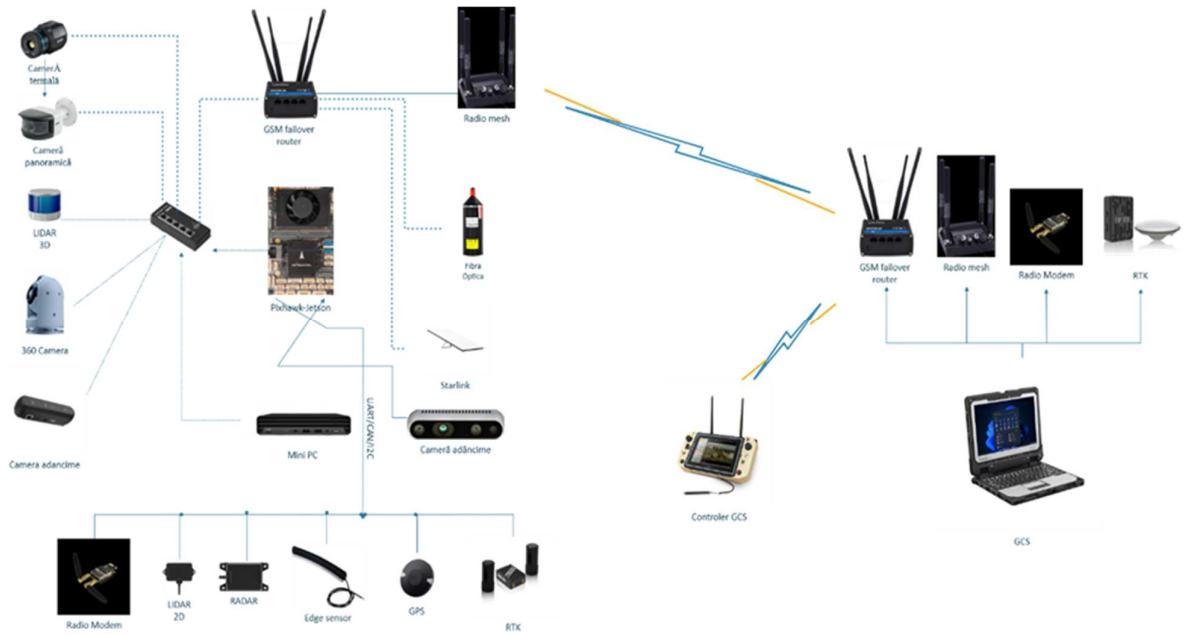



**Fig. 9.** Functional diagram of the command and control system, sensors, communication system.




**Fig. 10.** Detail on how to manage robot control.

## 4. CONCLUSIONS

In conclusion, it can be stated that the analytical model of the 8x8 robot satisfies the requirement of mobility and stability in operation.

The transition from a vehicle with a power unit based on a thermal engine to a power unit consisting of two electric motors involved changing the position of the gearbox so that the two brushless motors could be introduced. The transmission of the power flow from the gearbox to the wheels remained the same (chain transmission fig. 2). This aspect allowed obtaining sufficient space in the area of the power unit and the gearbox, space that is used to introduce the command and control elements of the propulsion but also of other elements such as communication. Thus, it can be appreciated that this modification also allowed lowering the body, which is essential for increasing the useful angle of the ballistic elements.

An aspect that we will take into account further when developing the dynamic model of the 8x8 robot with a propulsion system that has a gearbox and power is transmitted to the wheels through a cascade chain system, is the dimensioning of the CG center of gravity, so as to avoid that by increasing it, we lose stability when moving on a slope and braking, especially when braking while descending a slope and increasing the value of the forces necessary to execute the turn. We say this because the increase in forces when making a turn leads to an increase in the length of adhesion, respectively an increase in the contact patch with the ground by changing its width [10]. A positive effect of increasing the contact patch area is the reduction of the specific pressure on the ground, which is advantageous for situations in which the robot will move in deformable soils (most frequently possible).

It is also possible that the lateral excavation effect will be reduced, as will the cornering resistance moment.

From a dynamic perspective, the correct positioning and dimensioning of the center of gravity directly influence the load transfer between axles and between the left and right sides of the vehicle during acceleration, braking, and cornering. A lower and centrally positioned CG contributes to improved rollover stability, especially in off-road conditions where lateral inclinations and uneven terrain profiles are frequently encountered. Therefore, the redistribution of masses following the electrification process must be carefully analyzed to ensure that the stability margins remain within acceptable limits.

Furthermore, the interaction between the increased contact patch and the soil must be evaluated not only from the standpoint of pressure distribution, but also considering traction efficiency and energy consumption. A larger contact area can improve grip on soft or deformable terrain; however, it may also lead to higher rolling resistance. Consequently, a balance must be achieved between mobility performance and energy efficiency, particularly given the constraints imposed by onboard battery capacity.

## 5. FUTURE DEVELOPMENTS

One of the future goals is to develop a collaborative robot system for logistics missions. We will also perform validation tests of the kinematic and dynamic models through tests with and without load. The unladen variant will consist of tests with the robot suspended, and those with load within a polygon.

Another topic to be developed is the damping capacity of the tires when in contact with the ground. This will be carried out during the tests that will take place in the polygon. Then we will introduce the real operating conditions, leaving the paradigm of operating in ideal conditions.

In order to control the torque as precisely as possible, we will perform the two control methods in the subsequent development stage: Direct Torque Control (DTC) and Field Oriented Control (FOC), so that we can obtain vector control over the traction motors. Since we are talking about brushless motors (BLDC), we will adopt for FOC an architecture specific

to permanent magnet synchronous machines (PMSM).

In addition to these control strategies, we will implement a comparative performance analysis between DTC and FOC in terms of torque ripple, dynamic response, efficiency, and robustness to parameter variations. This comparison will allow us to determine the most suitable method for logistics applications, where smooth motion, precise positioning, and energy efficiency are critical. Furthermore, we will integrate advanced sensing systems, including encoders and current sensors, to ensure accurate feedback for real-time control.

Another important development stage will focus on the integration of the control algorithms into an embedded hardware platform capable of real-time execution. This will involve optimizing computational efficiency and ensuring reliable communication between the motor drivers, sensors, and the central control unit. Special attention will be given to fault detection and protection mechanisms to guarantee safe operation under varying load conditions and unexpected disturbances.

Finally, the complete robotic system will undergo full-system validation in realistic logistics scenarios, including trajectory tracking, obstacle avoidance, and cooperative operation with other robotic units or human operators. These tests will allow us to evaluate the scalability and adaptability of the system, ensuring that the proposed solution can be successfully deployed in industrial environments.

## 6. ACKNOWLEDGMENTS

We thank the research team at the Research Center of UM 01616. The current development stage refers to the creation of the prototype and the sizing of the systems: electric propulsion, communications, sensors and energy autonomy, according to the requirements of the sectoral research and development plan of the Ministry of National Defense. MULTIMISSION LAND DRONE, Sectoral Research and Development Plan no. 11/2025.

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## Aspecte legate de cinematica unui robot terestru 8x8 în viraj

**Rezumat:** Prezenta lucrare studiază cinematica unui vehicul robotizat 8x8 de tip skid-steering cu tracțiune integrală. Fiecare roată este roată motrică și fără suspensie, distribuția de putere se face prin modificarea tensiunii de alimentare a celor două motoare electrice, aferente fiecărei linii de roți. Robotul are un sistem energetic cu o tensiune nominală de 96V. Obiectivul principal constă în realizarea unui sistem de roboți colaborativi pentru misiuni logistice. Pentru prima etapă de dezvoltare urmărim determinarea comportamentului la efectuarea virajului în situația skid-steering, roțile nu sunt directoare. Virajul se efectuează prin modificarea turației fiecărei roți în parte prin modificarea tensiunii de alimentare a motoarelor.

Pentru realizarea acestui studiu, s-a realizat platforma robotizată prin transformarea unui vehicul terestru 8x8 cu transmisie mecanică într-unul cu transmisie electrică. Acest lucru a permis simularea condițiilor de operare plecând de la o situație reală de funcționare. În acest stadiu de dezvoltare al robotului am descris sistemul analitic de funcționare pentru a putea trece la definitivarea demonstratorului tehnologic.

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