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STUDIES REGARDING TETRAHEDRAL ROBOTS WITH OMNIDIRECTIONAL LOCOMOTION UNITS

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Abstract: *In this paper authors highlight modeling, simulation, and implementation of a mobile robot with spherical locomotion units. The design of the spherical locomotion units, characteristics of the proposed robot, kinematic analysis, and aspects related to control and testing of the experimental prototype are discussed.*

Key words: *robot, mobile, tetrahedral, locomotion unit, omnidirectional.*

1. INTRODUCTION

Over time, a large number of mobile robots of various sizes, shapes, and with different purposes have been introduced into human life, to facilitate it. Mobile robots have been designed based on applications, maneuverability, and various types of locomotion systems.

Following studies and research conducted on specialized literature, the foundations of a new structure of mobile robots with a tetrahedral structure have been established.

This structure is a great advantage when moving in areas at risk of rolling because, thanks to its pyramidal shape, it allows the robot to move regardless of its tetrahedral faces, always positioning itself parallel to the surface of locomotion.

Another important aspect in making mobile robots is the locomotion unit, which can have multiple structures, from conventional, simple, or pivoting wheels to more complex ones, such as omnidirectional wheels that are found in a wide variety of models.

Compared to classical mobile robots, as mentioned above, tetrahedral mobile robots can achieve movement regardless of the posture of the robot body on the locomotion surface.

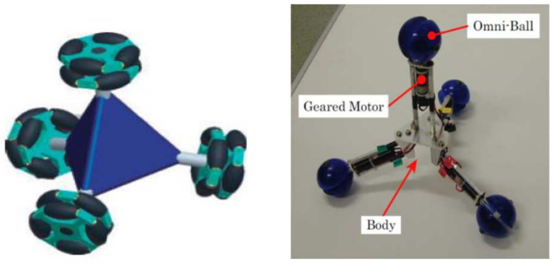
These robots maintain a constant operating position, and omnidirectional locomotion provides a significant advantage for movement, as the robot can move in any desired direction without the need for additional maneuvering. This allows the robot to reach hard-to-reach areas without difficulty.

The specialized literature [1], [2], [3], [4], [5] presents several models of mobile robots with a tetrahedral structure.

Figure 1(a) illustrates one of the commonly encountered models, a classic pyramid-like model with locomotion units at each corner. Figure 1(b) highlights an improved variant of the first model in terms of appearance and weight (stabilopod model).

Another model of a robot with a tetrahedral structure is the modular robot Odin, which can be seen in Figure 1(c).

The tetrahedral structure (resembling a stabilopod) is also found in Figure 1(d), depicting a mobile robot with flexible legs.



a) b)

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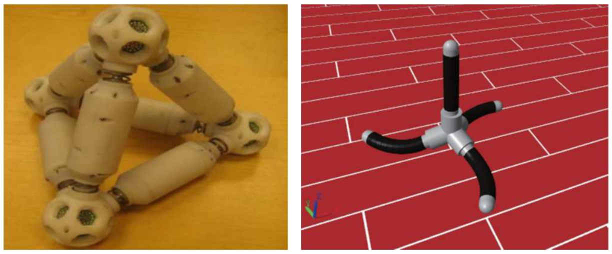


c) d)

Fig. 1. Tetrahedral Mobile Robot Structures
a) pyramid-like [1] b) stabilopod [2] c) tetrahedral modular [4] d) tetrahedral with flexible legs [5]

As locomotion units, a variety of wheel types can be used in the specialized literature, offering complex movement on the ground. However, not all types are compatible with tetrahedral robots.

Omnidirectional wheels compatible with the symmetry of tetrahedral robots can be classified into two categories: universal locomotion units and spherical locomotion units.

Some of the most common models of universal omnidirectional wheels are simple universal wheels [6] and double universal wheels [7]. However, there are also other more complex and less commonly encountered models, such as continuous alternative universal wheels [8] (Laquos models [7] and WESN models [9]).

a) b)

Fig. 2. Omnidirectional locomotion units [6]

The other category refers to spherical locomotion units, also known as Omni-Ball [6].

The proposed robot, in comparison to other robots in the specialized literature, exhibits differences in terms of the design of locomotion units and the internal electronic structure used.

Subsequently, the paper presents: the modeling of the locomotion unit, 3D modeling of the two proposed tetrahedral robot variants, kinematic analysis, robot control, implementation, and testing of the experimental prototype.

2. MODELLING THE LOCOMOTION UNIT

The proposed locomotion unit has a complex design that combines two types of omnidirectional locomotion units, namely the double universal wheel (Figure 2 a) and the Omni-Ball (Figure 2 b).

Figure 3 shows the author's proposed locomotion unit, consisting of two symmetrical halves with two pairs of rollers each on the entire circumference of the hemisphere. Elastic rubber bands are attached over the pairs of rollers belonging to the hemispheres (Fig. 3).

The proposed locomotion unit is in the form of an Omni-Ball unit and operates according to the double universal wheel model.

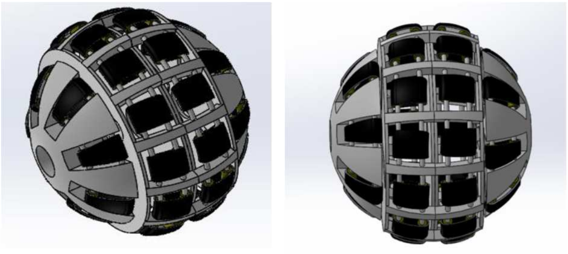


Fig 3. 3D modelling of the proposed locomotion unit [10]

3. MODELLING THE ROBOT

The robot is composed of two main components, the tetrahedral body, and the omnidirectional locomotion unit. The robot has been modelled in two constructive variants, shown below, in the shape of a pyramid and a stabilopod.

3.1. First design of the robot

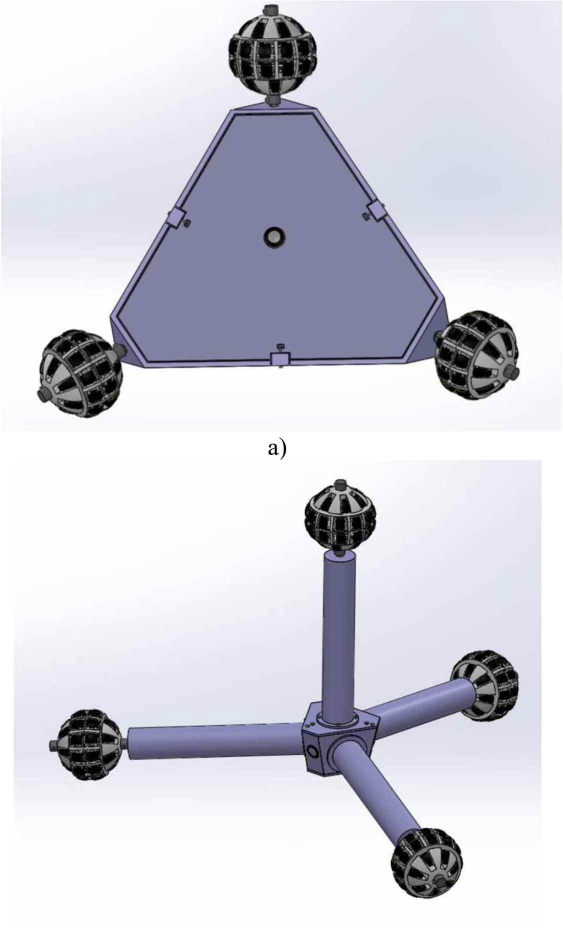
This design (figure 4 a) has the shape of a pyramid, its body is 463 cm high and has an advantage in terms of interior space compared to the second variant (figure 4 b) which is 398 cm high and has significantly less interior space.

This first design (figure 4 a) is a simple one, made of 4 triangular PMMA plates connected together, and 4 locomotion units arranged at each of the corners of the structure.

3.2. Second design of the robot

The second design is in the form of a stabilopod (Figure 4b), consisting of a small body, to which are attached 4 hollow aluminum pipes inside, and 4 locomotion units positioned at the free end of the pipes.

Although there is the advantage of lighter weight and easier movement, there is also a major disadvantage, namely the difficulty of positioning the robot's electronic components inside.


a)

b)

Fig. 4. 3D modelling of the mobile robot [10]

3.3. Choice and testing of the experimental prototype

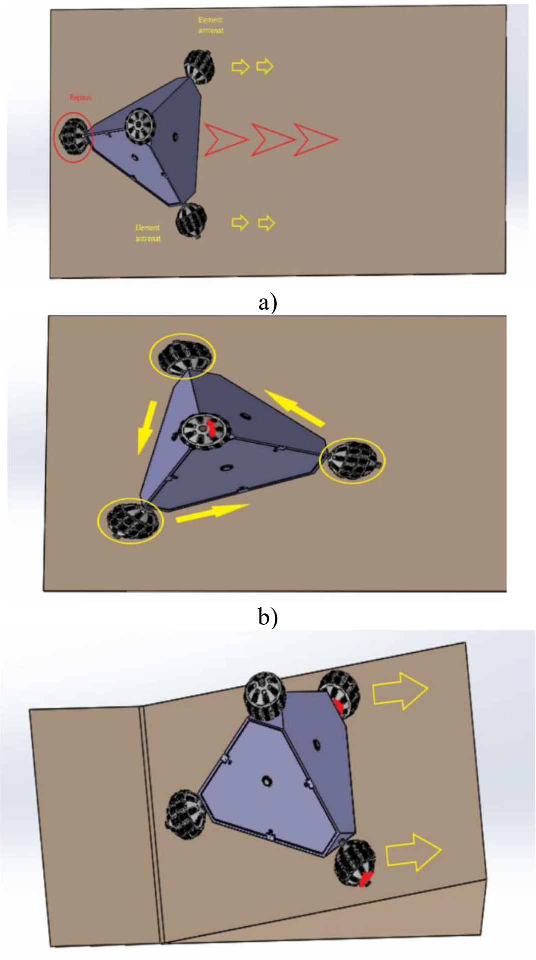
For the practical realization of the robot, the first version of the 3D model was chosen not before simulating the locomotion for 3 situations: forward motion, rotation around the central axis and forward motion on an inclined surface.

In the first simulation the robot can be observed moving on a flat surface where two of the locomotion units at the base of the robot are simultaneously driven in opposite directions while the third is at rest (Fig. 5 a).

In the second simulation, the robot can be seen as it rotates around the central axis. The locomotion units at the base of the robot are driven simultaneously in the same direction with the same speed (Fig. 5 b).

In the third simulation the robot can be seen moving on a horizontal surface and then tilted by 20 degrees. The robot moves with two locomotion units driven simultaneously in opposite directions at the same speed, while the other two locomotion units are at rest.

Figure 5 c) shows the combined linear motion of the robot on a horizontal surface and on an inclined surface [10].



a)

b)

c)

Fig. 5. Simulating robot movement in different modes [10]

4. KINEMATIC ANALYSIS

For the practical realization of the robot, the first version of the 3D model was chosen not before simulating the locomotion for 3 situations: forward motion, rotation around the central axis and forward motion on an inclined surface.

A great advantage of our mobile robot with omnidirectional locomotion units is the movement in any direction on the flat surface. For the kinematic modelling the kinematic scheme shown in Figure 6 will be considered.

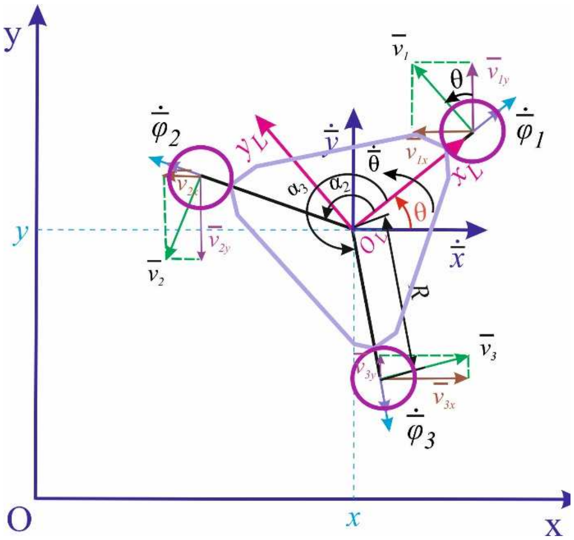


Fig. 6. Structural diagram of the tetrahedral robot [10]

In kinematic modelling a relationship will be obtained between the speeds of locomotion units $\dot{\varphi}_1, \dot{\varphi}_2, \dot{\varphi}_3$ and robot speed $\dot{x}, \dot{y}, \dot{\theta}$. For this purpose, we define the basic coordinate system Oxy from the robot's environment as in figure 6.

In the base coordinate system, the position and orientation of the robot, is given by *(x, y, θ)* and the speed of the autonomous $\dot{x}, \dot{y}, \dot{\theta}$ .We define the local coordinate system O_L, x_L, y_L attached to the robot with origin O at the center of gravity G of the robot.

Locomotive units are arranged at 120º positioned by α_1, α_2, α_3. Measuring trigonometrically from x_L these angles are $\alpha_1 = 0^\circ, \alpha_1 = 120^\circ, \alpha_1 = 240^\circ$.

The angular velocities of the mobile robot locomotion units are determined with the relations [11], [12], [13]:

$$\begin{bmatrix} \dot{\varphi}_1 \\ \dot{\varphi}_2 \\ \dot{\varphi}_3 \end{bmatrix} = \frac{1}{r} \begin{bmatrix} -\sin\theta & \cos\theta & R \\ -\sin(\theta + \alpha_2) & \cos(\theta + \alpha_2) & R \\ -\sin(\theta + \alpha_3) & \cos(\theta + \alpha_3) & R \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} \tag{1}$$

R represents the distance between the center of the robot and the center of the locomotion elements, r represents radius of the locomotion units.

For the transformation from base coordinates to local coordinates, we use the next relation:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & 0 \\ 0 & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \dot{x}_L \\ \dot{y}_L \\ \dot{\theta} \end{bmatrix} \tag{2}$$

After replacing relation (2) in (1), the following relation is obtained:

$$\begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\theta}_3 \end{bmatrix} = \frac{1}{r} \cdot \begin{bmatrix} -\sin\theta & \cos\theta & R \\ -\sin(\theta + \alpha_2) & \cos(\theta + \alpha_2) & R \\ -\sin(\theta + \alpha_3) & \cos(\theta + \alpha_3) & R \end{bmatrix} \cdot \begin{bmatrix} \cos\theta & 0 & 0 \\ 0 & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \dot{x}_L \\ \dot{y}_L \\ \dot{\theta} \end{bmatrix} \tag{3}$$

5. ROBOT CONTROL

The control unit of the robot is made up of two parts, the first part contains the electronic components attached to the robot, consisting of an Arduino Uno development board powered by a 9V battery, to which are connected 2 dual drivers that will be used to control the speed and direction of the 4 DC motors used to drive the robot.

The second part is the robot controller, which is placed on an Arduino NANO development board, powered by a 5V battery, to which a joystick is attached to control the direction of movement.

The two parts communicate with each other by means of two wireless modules used for transmitting and receiving the signal from the controller to the robot (Fig. 6).

To realize the drive and control system, the Arduino language was used, based on electrical schematics formed with the software called Fritzing [10].

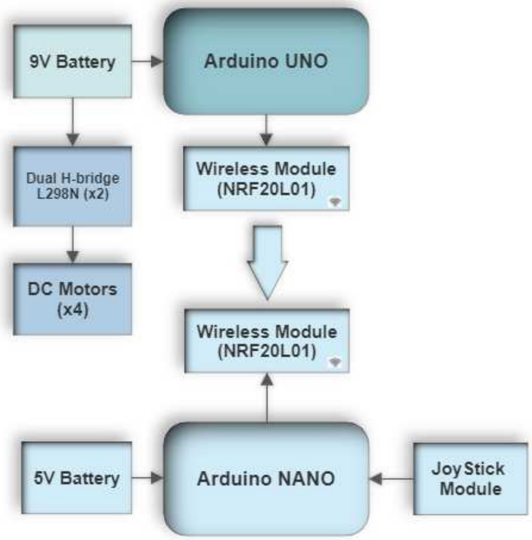


Fig. 6. Block diagram for robot control

6. EXPERIMENTAL PROTOTYPE

The locomotion units were made using 3D printers and the material used is plastic (PMMA).

After several modeling, the optimal solution for the practical realization of the locomotion units was chosen, which has a total diameter of 80 mm and 32 rollers. The first construction solution was 60 mm, 72 rollers.

Figure 7 shows the parts made for the initial (a) and final (b) model of the printed locomotion units.

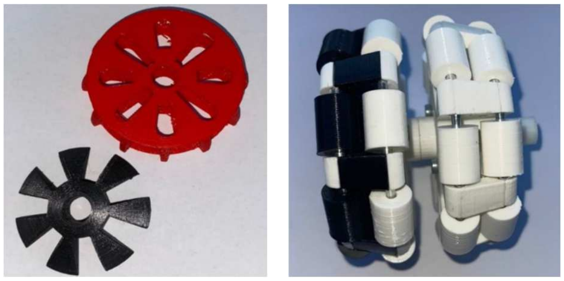
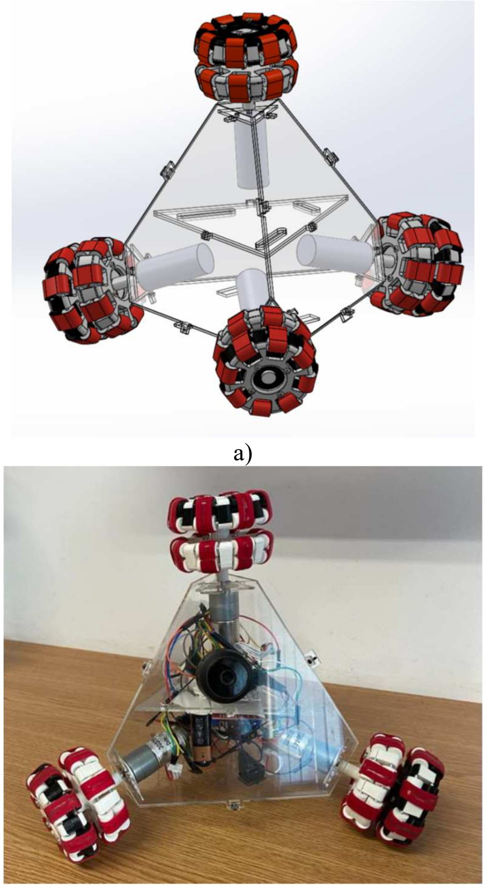

a) b)

Fig. 7. Component parts of the locomotion unit obtained through 3D [10]

The next stage involved making the robot body. This was made by laser cutting a 2 mm thick sheet of Plexiglas. The body consists of 4 triangular plates which, when joined together, form the tetrahedron, and 2 smaller triangular plates, attached inside it, used for clamping the electronic components on their surface.

The locomotion units are mounted on the robot body by a spindle that connects them to the motors inside the robot body. Figure 8 shows the CAD model (a) and the practical implementation of the whole robot (b).

As the robot is intended for inspection and exploration in hard-to-reach areas, a mini video camera with built-in microphone was attached to it.


a)

b)

Fig. 8. a) CAD model of the robot and b) practical realization [10]

6.1. Testing the robot

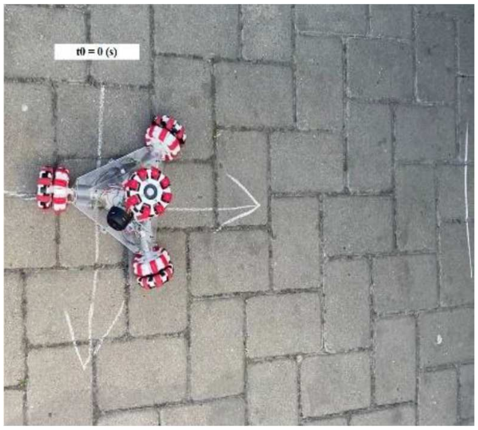
Pictures of the robot testing and the time the robot travels a certain distance in 3 cases, forward, sideways and up a ramp are shown in Figure 9.

The robot moves in the 3 cases, starting from the initial position, following an intermediate position and then the final position.

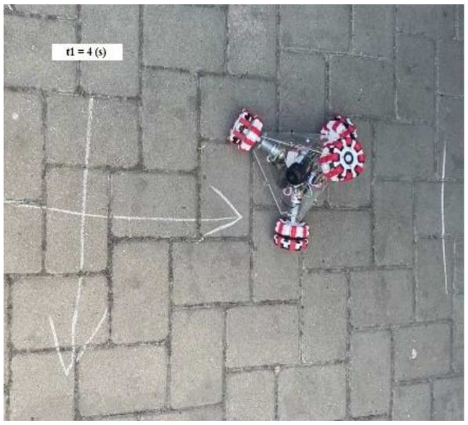
a1)

a2)

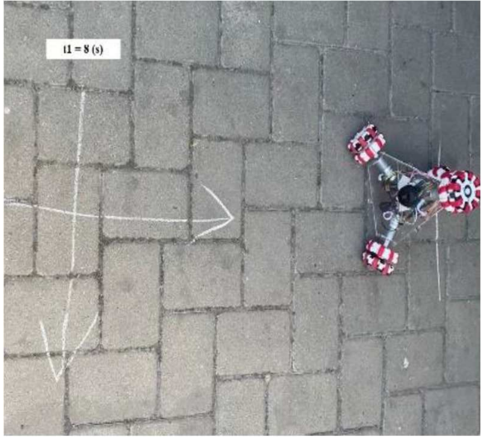
a3)



b1)



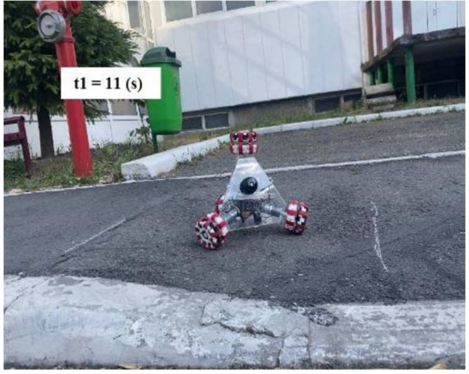
b2)



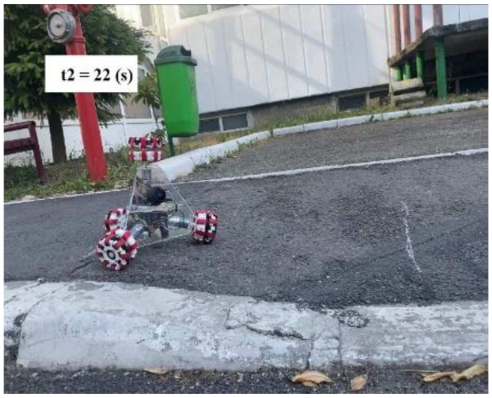
b3)

Fig. 9. Robot testing on paved surface [10]

c1)



c2)



c3)

Fig. 10. Testing the robot on asphalt surface [10]

Table 1 summarizes the robot travel time in the three cases.

The robot was tested on two types of surfaces (pavement/asphalt). The robot's locomotion units were driven at the same speed in all three cases.

In the first two cases (forward and sideways), the robot moved on the paved surface, while in the third case when moving on a ramp it moved on the asphalt surface.

The robot will travel the required trajectory in the shortest time when moving on the lateral direction, while when moving up the ramp it will travel the required distance in a longer time this is due to the friction between the locomotion units and the test surface.

In the test in Figure 9 a and Figure 10 c, two locomotion units were driven by driving two motors, and in the test in Figure 9 b, all three locomotion units at the base of the robot were driven simultaneously by three motors.

Table 1

Robot travel time [10]

Position	Initial	Intermediate	Final
Front (Fig. 9a)	t_0=0s	t_1=5s	t_2=10s
Right (Fig. 9b)	t_0=0s	t_1=4s	t_2=8s
Ramp up (Fig. 9c)	t_0=0s	t_1=11s	t_2=22s

7. CONCLUSIONS AND RESEARCH DIRECTIONS

Modeling, simulation, and realization of a tetrahedral mobile robot with omnidirectional locomotion units are detailed by the authors in this paper. The robot was tested on different surfaces proving a good performance.

This robot is intended for inspection in hazardous areas and can be operated remotely with a controller to avoid possible human accidents.

In the future it is proposed to use a more rigid material for the robot body, to attach a lighting system for a clearer view of the video camera, to attach an orientation sensor to detect the robot position. All this is needed to optimize its functionality.

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Studii privind robotii tetraedrici cu unități de locomoție omnidirecționale

Rezumat: Lucrarea propusă prezintă modelarea simularea și realizarea unui robot mobil cu unitățiі de locomoției sferice. Se prezintă proiectarea uitaților de locomoție, caracteristicile robotului propus, analiza cinematica a acestuia și aspecte privind comanda și testarea prototipului experimental.

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