MOBILE ROBOTS ON 4, 6 OR 8 WHEELS ADAPTED FOR UNEVEN TERRAIN

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Abstract: The paper presents several types of mobile robots (MR) with 4, 6 and 8 wheels adapted for moving on uneven terrain. In the case of MR on 4 wheels, their diameter is limited and the chassis is raised, the ground clearance being higher than the height of a bump. MRs on 4 or 6 wheels have the chassis linked to the motor wheels by articulated bars as a dyad or tetrad variable geometry suspension. MR on 8 wheels use 4 planetary motor gear sets in tristar shape.
Keywords: mobile robot, motor wheel, planetary motor gear set.

1. General Aspects

Mobile robots (MR) have a very diversified constructive structure [1], especially regarding the movement system on uneven terrain [2, 3] and on stairs [4, 5, 10].

Mostly wheeled MRs use four motorized wheels for rolling on flat or uneven terrain, including going up / down stairs. The wheels used in MR are mostly circular wheels, offering low cost and simple solutions in differential drive systems [6, 7].

4-, 6- and 8-wheel MRs use electrically driven wheels, the movement being accomplished by means of a control software [8, 9].

Scientific research in the field of MR in our country has been also boosted by the establishment at the technical universities of Craiova and Iasi of Mobile Robots laboratories equipped with several functional models of educational MRs [11].

2. MRs on Four Motor Wheels

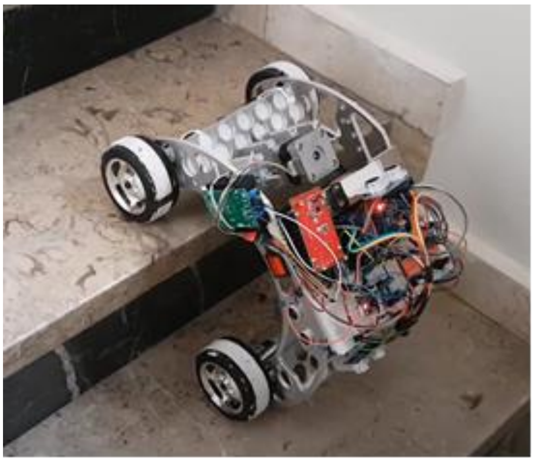
In the first model of MR on four motor wheels, the rigid metal frame rests on the two drive axles (front and rear), having enough ground clearance not to touch the steps of the stair (fig. 1). The front motor wheels move first on the vertical surface of the step and then on the horizontal surface of the step (fig. 1a). The same, when the rear motor wheels touch the vertical surface of the step, they begin to climb this surface (fig. 1b).

It should be noted that this type of MR has four mobilities, all four front and rear wheels (fig. 1) being driven by an electric motor each.

There is also the technical solution in which the motor wheels are mounted on separate bars (fig. 2a) that form kinematic chains linked by means of spur gears at the top [13].

When it overcomes the bumps, the two support arms 1 and 2 (fig. 2b) oscillate symmetrically due to the outer spur gear consisting of the gears 4 and 5, having their centers in joints B and C.

Each support arm (represented by bars 1 and 2) is connected to the robot body by specific suspension chains.



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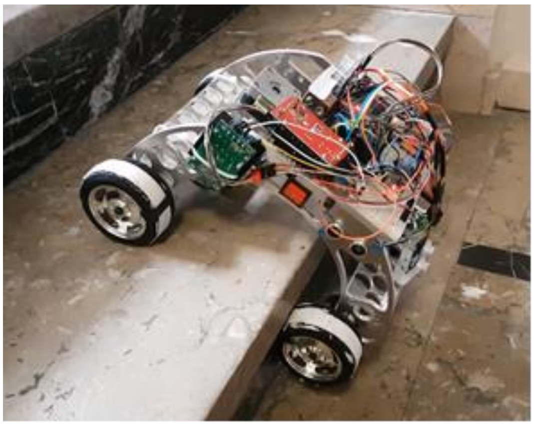

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Fig. 1. MR on 4 motor wheels [12, 14]

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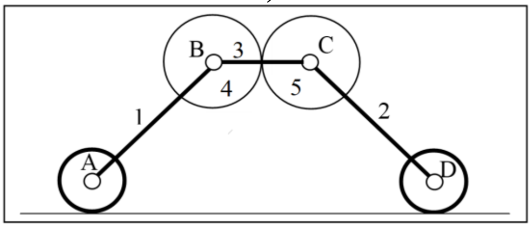

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Fig. 2. MR with 4 motor wheels on articulated arms

The motor wheels are articulated to the bars 1 and 2 respectively, at points A and D which can be moved closer or further away by means of the outer spur gear (fig. 2b).

In the next variant (fig. 3a), the arms of the two motor wheels are articulated bars with planar roto-translational movement [13], as it can be seen on the kinematic scheme (fig. 3b).

a)

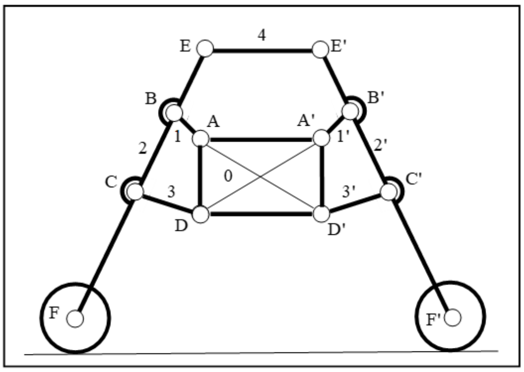

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Fig. 3. MR with 4 motor wheels on 4-bar linkages

The two bars 2 and 2' are coupler-type kinematic elements, which are articulated at points B and C, and B' and C' respectively, to the rockers 1 and 3, and 1' and 3' respectively.

It should be noted that the two couplers 2 (of length EF) and 2' (of length E'F') are connected to each other by bar 4, whose length EE' can be adjusted by means of a screw.

The mobility of this articulated planar kinematic chain (fig. 3b) is obtained by means of the structural formula [1, 12]:

$$M = \sum_1^5 mC_m - \sum_2^6 rN_r \qquad (1)$$

In formula (1) the parameters have the following meanings:

M - is the mobility of the mechanism representing the number of driving elements;

m - represents the number of degrees of freedom (independent movements) of a kinematic joint;

C_m - is the number of kinematic joints of class m;

r - is the rank of the space adjacent to an independent kinematic contour;

N_r - is the number of independent kinematic contours.

For the particulate planar mechanism (fig. 3b) the matrix with two rows is identified:

$$\begin{bmatrix} C_1 & C_2 & C_3 & C_4 & C_5 \\ N_2 & N_3 & N_4 & N_5 & N_6 \end{bmatrix} = \begin{bmatrix} 10 & 0 & 0 & 0 & 0 \\ 0 & 3 & 0 & 0 & 0 \end{bmatrix} \qquad (2)$$

The numerical values of the parameters m and r are: m = 1, r = 3. Substituting these numerical values in formula (1) the mobility of the analyzed mechanism is:

$$M = 1 \times 10 - 3 \times 3 = 1 \qquad (3)$$

3. MR with Four Planetary Motor Gear Sets

On horizontal or inclined terrain (fig. 4a) the MR with four planetary motor gear sets rolls on eight driving wheels, and on stairs (fig. 4b) it moves on four or eight independently operated driving wheels.

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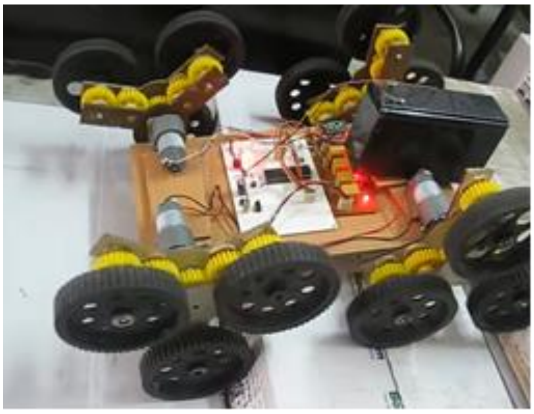

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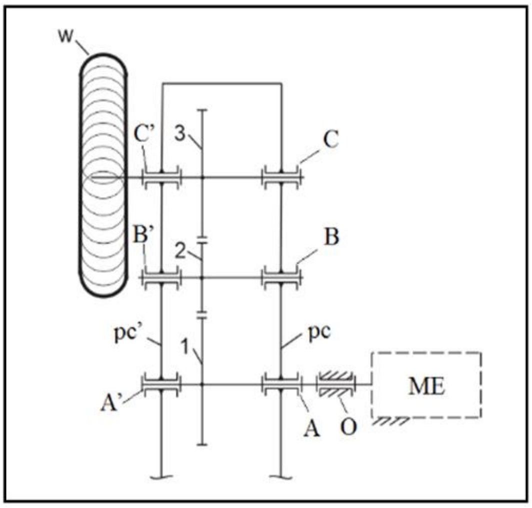
Fig. 4. MR with four planetary motor gear sets [12]



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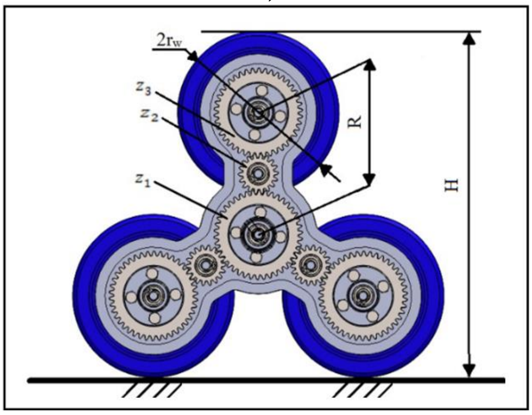

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Fig. 5. Details on a planetary motor gear set [12, 15, 16]

It should be noted that a motor wheel is driven by the planet gear 3 which is driven, through an intermediary planet gear 2, by the sun gear 1 which is driven by the electric motor ME (fig. 5a) [12, 15].

According to the structure of the tristar-shape spur planetary mechanism (fig. 5b) [12, 16], each ME drives three motor wheels with the same speed [1, 7].

Although the spur planetary mechanism has two degrees of mobility, only one electric motor is required to operate the gear set. Of course, a sufficiently high motor torque is required for the entire planetary gear set to rotate the motor wheels that are in contact with the step or obstacle to be climbed (fig. 4b, 5b).

During rolling on a flat surface, the speed (rpm) of the motor wheels n_w is:

$$n_w = n_{ME} \cdot \frac{z_1}{z_3} \tag{4}$$

where: $z_{1,3}$ - number of teeth of the gears; n_{ME} - speed of the drive motor.

During climbing on steps, according to the condition of the movement of the planetary carrier [1], the following equation results:

$$\frac{n_1 - n_{pc}}{n_w - n_{pc}} = \frac{z_3}{z_1} \tag{5}$$

where: n_1 – speed of the gear 1; n_{pc} – speed of the planetary carrier.

In equation (5) it is required that the wheel 3 is stationary during the climbing of the mobile robot over that obstacle. Therefore, the speed of the carrier is:

$$n_{pc} = n_1 \frac{z_1}{z_1 - z_3} \text{ where } z_1 > z_3 \tag{6}$$

4. MRs on Six Motor Wheels

These MRs have six motor wheels driven independently by an electric motor (fig. 6a). When the MR encounters a step, each motor wheel rolls on the vertical surface (fig. 6a) and then on the horizontal surface (fig. 6b).

The kinematic scheme of an improved MR on 6 wheels comprises of an open kinematic chain that is articulated, in the vertical plane, to the body directly through joint A, and indirectly through two damping cylinders (fig. 7). Therefore, the body 7 is articulated at point A to the rocker 1 which has two arms: one with the wheel r_3 that is articulated in C, and the other with the rocker 2 articulated in B. The wheels r_1 and r_2 are articulated in E and D to the rocker 2 having two arms BE and BD.

Besides the direct connection of the body 7 with the rocker 1, there are two indirect links through the dyad chains LD(3,4) and LD(5,6) articulated at points *a* and *b*, and *c* and *d* respectively. The RTR-type LD(3,4) and LD(5,6) kinematic chains are made as shock absorbers.

The kinematic chain LC(1,2) allows an independent vertical movement of each wheel, which makes it possible to overcome more easily some obstacles on the track. If the analyzed kinematic scheme (fig. 7) corresponds to the right side of the mobile robot, the same kinematic scheme with the wheels r_4, r_5 and r_6 is in a symmetrical position on the left side.

a)

b)

Fig. 6. MR on 6 motor wheels [12]

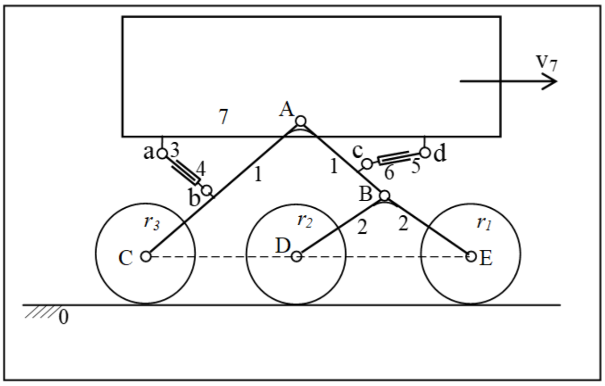

Fig. 7. Kinematic scheme of the 6-wheel MR [12]

5. MRs with Four Motor Wheels on Articulated Arms

In these cases the four motor wheels are connected to the body of the robot by means of a robot arm with articulated bars (fig. 8 and 9). The mobility is:

$$M_b = mC_m = 6$$

The 6 mobilities are specific to the bars 1, 2, 3, 4 and articulated motor wheels in C and F (fig. 9b).

The structural and kinematic study of the robot arm (fig. 8, 9a) used for each motor wheel [12, 13], requires a separate approach (fig. 9b), to which the calculation and control software can be added.

a)

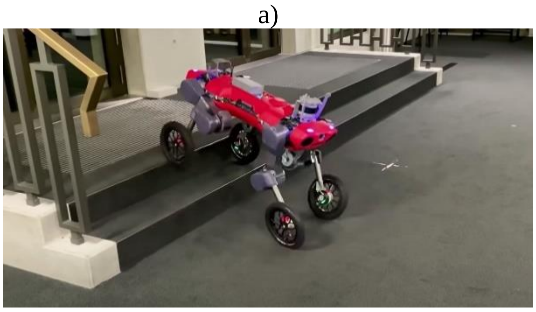

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Fig. 8. MR with 4 wheels on articulated arms – variant 1 [12]

a)

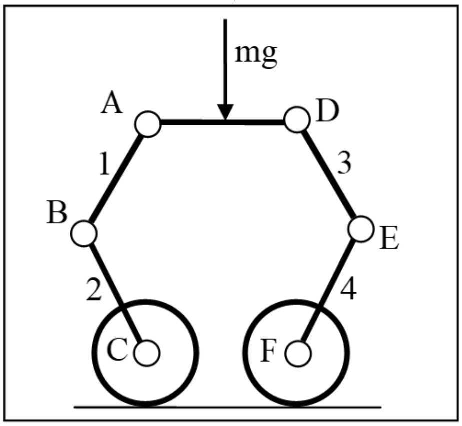

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Fig. 9. MR with 4 wheels on articulated arms – variant 2

6. Conclusions

The wheeled MRs are designed to roll and maneuver on uneven terrain or climb the stairs by means of the special adapted motor wheels.

The mobile wheeled robots, capable of climbing the stairs, present a great diversity of technical solutions regarding the structure and geometrical configuration of the motorized wheels.

First, the authors studied MRs with four motor wheels, the first variant having rigid axles, the second solution having simple flexible axles and the third variant having more complex flexible axles. In the last case, the mobility for a pair of front and rear axles has been calculated.

Further, a MR with four planetary motor gear sets rolling on 8 or 4 wheels have been analyzed. In this case, the speed of a planetary carrier has been obtained. There has to be outlined that there are only four electric motors (actuators) driving the MR, so that the power of them should be high enough to be able to climb the stairs.

Moreover, the authors analyzed two solutions of MRs on six motor wheels, the first one without damping system and the other with a damping system.

Finally, two solutions of MRs with four motor wheels on articulated arms have been analyzed. The obtained mobility is equal to six on a pair of two front and rear axles.

Another more complex solution would use arms which can have up to 4 mobilities each: one rotation with respect to a vertical axis for the first bar of the arm chain, two rotations with respect to two parallel horizontal axes for the other two bars, and one rotation of the motor wheel.

In conclusion, the more joints a MR has, the higher capacity to overcome obstacles it possesses.

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